INSECT PEST CONTROL RESEARCH: THE ANALYSIS OF HISTORICAL TRENDS WITH SPECIAL REFERENCE TO SCIENTOMETRIC ANALYSIS

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THESIS SUMMARY

The thesis investigates the value of quantitative analyses for historical studies of science through an examination of research trends in insect pest control, or economic entomology. Reviews are made of quantitative studies of science, and historical studies of pest control. The methodological strengths and weaknesses of bibliometric techniques are examined in a special chapter; techniques examined include productivity studies such as paper counts, and relational techniques such as co-citation and co-word analysis.

Insect pest control is described, this includes a discussion of the socio-economic basis of the concept of "pest"; a series of classifications of pest control techniques are provided and analysed with respect to their utility for scientometric studies. The chemical and biological approaches to control are discussed as scientific and technological paradigms.

Three case studies of research trends in economic entomology are provided. First a scientometric analysis of samples of chemical control and biological control papers; providing quantitative data on institutional, financial, national, and journal structures associated with pest control research fields. Second, a content analysis of a core journal, the Journal of Economic Entomology, over a period 1910-1985; this identifies the main research innovations and trends, in particular the changing balance between chemical and biological control. Third, an analysis of historical research trends in insecticide research; this shows the rise, maturity and decline of research of many groups of compounds.

These are supplemented by a collection of seven papers on scientometric studies of pest control and quantitative techniques for analysing science.

Keywords

Insect pest control
Economic entomology
History of science and technology
Scientometrics
Insecticides

DEDICATION

To my parents,

Lilian Rothman nee Crabtree and Bernard Rothman

on their Golden Wedding Anniversary 1937 - 1987;

and to my uncle Gershon Rothman.

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PREFACE

This thesis takes the form of unpublished work plus a small collection of published papers. To understand why this is so I need to say a little bit about its historical origins. Five events that I experienced during the period 1962-1967 have determined my interest in scientometric studies of research into insect pest control, an interest which, despite many distractions by other research programmes has continued to this day.

a. In 1962 I decided not to continue with research into insect ecology; having become more interested in the politics and social function of science than scientific research itself. Amongst the factors creating this change was CND and my concern at what I then regarded as the misuse of science, or as Bernal neatly put it "the frustration of science".[1]

b. In 1964 I was employed for two and a half years as an information scientist at Unilever Research. There I worked on the development of what was then a pioneering system to computerise the research report databases of Unilever's many research laboratories.[2] I was introduced to information science at a critical point in its history when it was becoming computerised and breaking away from its rather stuffy traditional librarian image. Many of the now familiar bibliographic tools such as KWIC indexes, citation indexes etc. emerged in that period. Fortunately for me Unilever Research was at the forefront of using, or trying to understand how to use, these techniques.

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1. Bernal (1939) p.386.

2. Shaw and Rothman (1967).

c. Reading, in the mid 1960s, Derek de Solla Price's books "Science Since Babylon" and "Little Science Big Science".

d. Reading round about the same time Rachel Carson's "Silent Spring"; and also being quite astounded by the political and media controversy which it precipitated.

e. Joining in 1967 Freddie Jevons' pioneering Department of Liberal Studies in Science at Manchester University, where I was allowed and encouraged to study the "pesticides controversy".

Event a. inclined me to concentrate my attention on social and historical studies of biological sciences; all my books have been concerned with biologically based phenomena, pollution[3], the food industry[4], and biotechnology[5].

Events b. and c. trained me in bibliographic methods and "infected" me with scientometrics. I accepted wholeheartedly, Price's conviction that science and scientific activity "... is peculiarly measurable and peculiarly regular in its behaviour".[6]

Event d. turned my attention to insect pest control. Here was something where I could combine my scientific training with my interests in science and society. This combined with event e. enabled me to conduct, often with my post graduate students[7], a series of studies of the social and environmental impacts of pest control, and

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[3]. Rothman (1972).

[4]. Kaufman and Rothman (1974).

[5]. Rothman et al. (1980) "Biotechnology: A Review", Rothman et al. (1984) "The Alcohol Economy: Fuel Ethanol and the Brazilian Experience", Jamieson, Jacobson and Rothman (1987) "The Biotechnological Challenge: Implications for the Third World".

[6]. Price (1978) p.8.

[7]. Most of these are listed at the end of Rothman and Lester (1985).

also more general aspects of the impact of technology through my work on technology assessment.[a]

That briefly is how my interests in scientometrics and insect pest control developed.

Subject of the Thesis

In this thesis I have attempted to bring some of this work together, concentrating on those aspects concerned with scientometric studies of historical research trends in insect pest control, and the applied science of economic entomology. I have also been concerned to investigate a number of quantitative methodologies, some of which, as we shall see, proved valuable in illuminating the advance of economic entomology, some less so, whilst some proved to be beyond my resources.

The issues that we are dealing with in the thesis revolve around questions concerned with what is measurable about scientific research. How can it be done, and when we have done it, does it tell us anything new? I have hypothesised that quantitative historical studies of science do not simply put numbers to that which is already known; that is, I thought that they might throw new light on old problems, and generate new problems. Thus I arrived at a subsidiary hypothesis that by applying scientometric approaches to historical problems one creates a hypothesis generator, which can open previously neglected, but potentially important, areas for research.

It is necessary to establish at this point that this is not a methodology study per se, but a historical study of research trends within a particular scientific discipline. If I had been only

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[a]. With Ira Kaufman, Fred Steward and others I formed the Technology Assessment and Consumerism Centre (TACC) at Manchester University, which produced the TACC Report on the UK Bread Industry. My ideas on Technology Assessment are further developed in Rothman (1977).

concerned with questions of methodology then my case studies might have been chosen using criteria determined by particular methodological goals. But, because I was also interested in aspects of the development of a specific scientific discipline, I have been constrained to choose, in a pragmatic way, methodologies able to utilise available databases and materials on a particular discipline, that of economic entomology. This has not, however, precluded me from making comparisons between methodologies.

My hypotheses about the general value of scientometrics in historical studies have, therefore, been examined in the context of a single discipline. This seems reasonable because, although the quantitative history of science is still relatively under-developed, there are other studies with which my findings might be compared. In any case, I was also hoping to illuminate problems which are discipline specific. Thus I have examined a hypothesis concerning the value of quantitative studies to the specific history of economic entomology. Economic entomology has, as I shall make clear later, for much of its history, possessed a schizophrenic character. It is split by two apparently contradictory "approaches", one basing itself more in chemistry and the other in biology. The overall balance between them was said by some observers to change over time, and at the time Carson wrote her condemnation of insect control practice the chemical approach dominated. In this study I wanted to see if, by using scientometric methods, it is possible to periodise changing research emphasis on these approaches. Further, if this is possible, whether scientometric analysis of research trends could provide insights into how or why the relative concentrations on the two approaches changed when they did?

Finally, I would like to stress that I have not sought to produce a complete scientometric history of economic entomology, rather I have attempted to explore the possibilities offered by a variety of scientometric methods to throw some light on important developments associated with changing research trends.

Quantitative Historical Studies

History is still not generally regarded as a quantitative field, however, it is becoming increasingly respectable to bolster qualitative insight with statistical data and measure "the dimensions of the past"[9]. Much of the pioneering work was done by economic historians, who developed the field of clinometrics[10]. An indication that quantitative methods are now beginning to permeate historical studies is the arrival of elementary quantitative methods textbooks for historians[11].

The use of quantitative methods in the history of science goes back to Babbage's "Reflections on the Decline of Science in England", published in 1830. However, as Arnold Thackray pointed out in an excellent review[12] of quantitative studies by science historians, the record since then has been patchy, and he noted with envy the achievements in other branches of history. I shall review, briefly, in a later chapter, the main quantitative studies in the history of science. Suffice to say at this point that Thackray perceived five "genres" of quantitative studies in the history of science; "civilisation history, genius studies, statistical bibliography,

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[9]. Lorwin and Price (1972).

[10]. See for example Andreano (1970), and the clinometric analysis of the American slave economy by Fogel and Engermann (1974) and the introductory readings in clinometrics edited by Temin (1973).

[11]. For example Floud (1973).

[12]. Thackray (1978).

sociology of progress, and policy oriented work"[13]. This thesis might be considered to be a representative of his third genre, "statistical bibliography: bibliometrics of science", however, I say this reservedly, because I tend towards a scientometric rather than a purely bibliometric philosophy.

Bibliometrics and Scientometrics

The dividing line between bibliometrics and scientometrics is not completely clear. To some extent I think it reflects an attitude of mind. Scientometrics has more of a programmatic ring about it; for example, if one reads the first number of the journal "Scientometrics"[14] some of the editorial comments are like phrases in a manifesto. Dobrov[15] writes

> "... the orientation of scientometrics towards systems analysis and practical management of science should encompass all aspects of the functioning of science susceptible to quantitative evaluation, namely the amount of scientific results, numbers of scientists, number and structure of scientific institutions, financial support, intensity and direction of scientific relations, efficiency of research etc."

In the same issue of "Scientometrics" Garfield attributes to Pritchard[16] the term "bibliometrics"; "... the application of mathematics and statistical methods to books and other media of communication". Clearly bibliometric studies could be made of any field of scholarship, and indeed in the context of this thesis one might, as Thackray did, speak of bibliometrics of science. Bibliometrics is really a subfield of scientometrics, and much of the emphasis, and nearly all of the early work, in scientometrics is

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[13]. Thackray (1978) p.21 and pp. 14-21.

[14]. Scientometrics, September 1978.

[15]. Dobrov (1978) p.4.

[16]. Garfield (1978) p.6, and Pritchard (1969).

bibliometric, concerned as Dobrov[17] has stated, with the "... informational parameters of scientific endeavour, such as numbers of papers, patents, journals, laws of 'aging' and 'dissipation' of scientific information, structure of the flow of scientific documents, citation processes etc.". Finally, it is necessary to stress scientometrics' relationship to science policy, indeed scientometrics might be seen as a response to the intractable managerial problems associated with the contemporary R & D scene, whilst bibliometrics originally flourished mostly in library and documentation science circles. Without wishing to become further entangled in definitional hair-splitting, I would argue that although much of my methodology has been bibliometric it has been done within a scientometric context, and for that reason I often use the term scientometrics where others might speak of bibliometrics.

Economic Entomology

Economic entomology is an applied branch of entomology concerned with controlling the damage done by insects, chiefly to agricultural crop and stored products. As I have already said, the choice of scientific discipline to be analysed in a purely methodological study would have been determined by different criteria. However, my studies have not been solely methodologically driven for I have chosen to apply a wide range of techniques to a single discipline, or group of related fields. Nevertheless, one needs to say why one chooses one discipline rather than another. My reasons for picking economic entomology are an amalgam of personal and, I trust, rational factors. Let us get the personal out of the way first. I have already mentioned a series of five "events" which determined me to carry out these studies. Two of

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[17]. Dobrov (1978) p.4.

these five occurred in the form of an historical conjuncture. "Little Science Big Science" by Price and "Silent Spring" by Carson were both published within a year of each other and I read them in the mid sixties. At first sight one might be tempted to dismiss this conjuncture as pure coincidence, and as far as I am aware neither author knowingly influenced the other. I believe, however, it is arguable that both were responding to aspects of the same social phenomenon, a mutation in the nature of science. Price showed scientometrically the increase in scale, scope, and expense of science as it grew from relatively small scale activity to "big science" associated with grand laboratories, and massive resources, whereas Carson picked up the contradictory nature of this process in a specific area, pest control. Carson noted that the chemical approaches to control were big science, though she did not use that term, involving massive corporate, and state finance. The biological or ecological approaches on the other hand were still little science activities in comparison. This contradiction, manifested at the scientific level as an uneven development of research, appeared at the political level as "the pesticide controversy". When I began to study the controversy one of the ways in which I looked at it was scientometrically, and my first paper on the subject was called "The changing pattern of economic entomology"[18].

There are reasons other than my personal predilections why economic entomology is worthy of examination. I deal with these at length throughout the thesis, and also in a special chapter devoted to an overview of the discipline. They can be summarised: as an applied science economic entomology brings into the research realm a wider

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[18]. Rothman (1969), this is appended to the thesis.

group of social forces than one would find in a study of a basic science, this complexity creates analytical difficulties but it enables one to touch on important issues such as the relations between industry and university research, and the relation between science and technology; the discipline was subjected to major changes, due to the development of new control techniques; the impact of some of these techniques became a matter of great public concern and controversy, bringing to the fore issues of technology assessment, indeed the insecticidal use of DDT, which brought a Nobel Prize to Müller, became almost as potent a symbol of science "gone wrong" as the Atomic bomb; the discipline was characterised by competing technological paradigms, whose proponents often, because of the public furore over pesticide pollution, fought their struggle in the mass media as well as in research papers; the field is in many respects exceptionally well documented which made certain aspects readily amenable to quantitative analysis.

The Thesis Structure

The thesis combines previously unpublished material with published articles. The latter have been placed in Appendix A, but wherever appropriate their contents are integrated into the main body of the thesis. There are 7 published articles, which are of two kinds: scientometric studies of pest control; and articles on scientometrics in general, or wider disciplinary coverage than economic entomology.

The chapter structure is:

Chapter 1. Review of Scientometric Techniques and Their Use in Historical Studies of the Development of Science.

Chapter 2. Insects and Economic Entomology. Reviews the social and scientific basis of the discipline.

Chapter 3. Scientometric Analysis of Key Papers on Pesticides and

Papers on Biological Control.

Chapter 4. Case Study: Research Trends Based upon a Content Analysis of a Core Journal: The Journal of Economic Entomology, 1910-1985.

Chapter 5. Historical Trends in Insecticide Research: A Case Study.

Chapter 6. Conclusions.

Appendix of Seven Published Articles

Bibliography.

A Health Warning

For some reason which I have never understood, quantitative studies, unlike qualitative studies, must always warn their reader against being taken in by their apparent "objectivity". It is possible to make quantification a fetish but it seems likely that the close relationship which scientometrics seeks to make with policy studies, forces most of its practitioners to keep their feet on the ground. My own feeling about historical quantitative studies of science have been adequately expressed by TePaske[19], a historian, who wrote

> "... quantification is not an end in itself. It complements traditional research but can never replace it. In fact, quantitative analysis poses as many historical problems as it resolves ... (it) alone gives no complete answers to vital historical questions; it provides only another dimension to investigate".

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[19]. TePaske (1972) p.446.

CHAPTER 1

HISTORICAL STUDIES AND PUBLICATION ANALYSIS: AN OVERVIEW

This chapter addresses two main tasks. First it reviews historical studies of insect pest control and quantitative studies in the history of science. Second it provides an overview of bibliometrics, the branch of scientometrics deriving measures from publication analysis. The bibliometrics part provides a "users" guide to available techniques and some examples of how they have been used, with the aim of illuminating the potential that these techniques offer the historian of science.

Historical Studies of Entomology and Insect Pest Control

This does not pretend to be the definitive review of the subject and indeed historical treatment of entomology and insect pest control is patchy to say the least. Professional historians have not been attracted to the field until recently, when the pesticide crisis provided the subject for several perceptive "historical sociological" studies. Most of the history of entomology and pest control has been written by scientists, often from an internalist, or even subjective, point of view. So far very little has been written about corporate and institutional histories despite the fact that the activities of chemical companies and state research and agricultural advisory organisations have determined the major lines of development.

There are few modern histories of entomology, Essig's[1] massive study was written in the early 1930s. It is written by a scientist

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[1]. Essig (1931).

rather than a professional historian and is, by modern historigraphic standards, dated. The most recent and complete history is the multi-authored work issued by the Annual Review of Entomology[2]. This deals with many aspects of entomology's development from a conservative internalist point of view.

Howard's "History of Applied Entomology"[3] chronicles the history of applied entomology from the mid 19th century to 1930. Despite its self-confessed "anecdotal" style, it is still a valuable introduction, written by one of America's leading economic entomologists of his day.

In 1940 the Journal of Economic Entomology[4] (J.E.E.) published a valuable series of five historical articles to mark "fifty years of entomological progress. This provides a valuable summing up of the pre-DDT era of economic entomology.

Large's[5] classic study of pest control deals primarily with fungi, but is useful for its discussion of the early development of spraying and pesticides such as bordeaux mixture. It is arguably still the finest social history of pest control.

George Ordish[6], an agricultural economist specialising in pest control, is the most prolific contemporary historian of insect pest control. He has produced a valuable series of popular studies over the last twenty years.

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[2]. Smith, R.F. et al. (1973).

[3]. Howard (1930).

[4]. The Journal of Economic Entomology, Vol. 13, No.1, 1940. See Marlatt (1940), Caesar (1940), Metcalf (1940), Rohwer (1940), Essig (1940).

[5]. Large (1940).

[6]. Ordish (1967, 1968, 1972, 1974, 1976).

Jones[7] wrote the chapter on "agricultural entomology" in the Annual Review of Entomology History. In it he briefly presents a quantitative analysis of the chemical-biological bifurcation of economic entomology. I discuss his analysis in chapter 4.

Commercial entomology, the control of domestic pests has been the subject of only a few historical studies; by practitioners rather than professional historians[8]. Geigy have produced a company history[9] which describes their pest control innovations up to 1950.

A number of historical studies have been made of insecticides[10], the more important are discussed in Chapter 5.

Biological control histories have been written by practising scientists[11].

It is clear that economic entomology has not attracted a great deal of attention from the professional historians of science. To some extent this may be because the field is mostly a 20th century development. However, the field has begun to attract some attention from sociologists of science and there now exists what Beaver[12] might

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7. Jones (1973).

8. Osborne (1952).

9. Buxtorf and Spindler (1954).

10. Brennan (1976), Läuger et al. (1944), Lefroy (1915), Metcalf (1959), Rothman and Lester (1985), Smith and Secoy (1975, 1976a, 1976b, 1977, 1981), Schrader (1952), Brook V.1 (1974).

11. Doutt (1964), Hagan and Franz (1973), Huffaker and Messenger (1964), Ordish (1967), Steinhaus (1956).

12. Beaver (1978) argues that "Certain interests in the history of science appear virtually indistinguishable from those in the sociology of science". p.143. Over a decade earlier Bernard Barber made a similar observation when reviewing Kuhn's 'The Structure of Scientific Revolutions'. "The newer generation of historians of science has become more and more quasi-sociological" Barber (1963) p.298.

recognise as social histories or historical sociologies. Cushing[13] has provided an account of American military use of pest control in World War II. Mike Worboys[14] produced a study of British anti-locust research as an aspect of imperial development. There are two recent studies on the insecticides crisis in America[15], and in Britain Sheail[16] has analysed the conflict between pesticide use and nature conservation.

Simon and Rothman[17] have applied bibliometric techniques to historical aspects of entomology and pest control, but little else of a quantitative nature appears to have been done.

Quantitative Studies in History of Science

The fact that Arnold Thackray's review[18] "Measurement in the historiography of science", written in 1978, is still the most important survey[19] is perhaps a sad reflection on the unwillingness of

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[13]. Cushing (1957). Pest control is of vital importance in war, when armies and civilian populations can be decimated by insect spread diseases. Zinsser (1935) has written a classic social history "Rats, Lice and History" which fully documents this.

[14]. Worboys (1972), this was an MSc. dissertation written under my supervision.

[15]. Dunlap (1981) deals with the historical, political and legal background to the DDT debate. Perkins (1982) deals with the impact of the crisis on entomologists and the pressures generated towards the innovation of new pest management strategies. Graham (1970) has reviewed the response to Rachel Carson's "Silent Spring", her role in the public campaign against the misapplication of pesticides.

[16]. Sheail (1985) analyses the controversy in Britain 1950-1975, especially the role of Nature Conservancy scientists.

[17]. Simon (1977, 1982), Rothman and Woodhead (1968, 1971), Rothman and Lester (1985).

[18]. Thackray (1978).

[19]. Hahn (1980) provides "A Bibliography of Quantitative Studies on Science and its History". This has approximately 1,400 articles and books, but less than 10% are truly history of science.

mainstream historians of science to quantify. The major quantitative history of science since then comes from Thackray's school in Philadelphia[20]. Yet as I noted in the Introduction, quantification in the history of science is not new, its origins being associated with Alphonse de Candolle and Francis Galton in the 19th century.

De Candolle's scientometric work[21] has recently been disinterred after many years in oblivion. Shelishch's quantitative study of biologists in the 18th and 19th centuries recognised de Candolle's contribution to the study of " ... historical change in the character of scientific specialisation ... (who analysed it) quantitatively for the first time .... Since then, however, no essential advances are known in, and de Candolle's work itself remained forgotten for many decades"[22] Szabo thinks that de Candolle "was actually an early

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[20]. Thackray _et al._ (1985). "Chemistry in America" 1876-1976. This is quite an amazing book, the production of which and its structure illuminate some of the problems of quantitative historiography. It took four researchers, Arnold Thackray, Jeff. Sturchio, P.T. Carroll and Robert Bud, many years to complete at a reported cost of over $150,000. Almost 60% of the book consists of tables of data (more than 300 pages of them), which made it extremely difficult and very expensive to publish. The authors had sought to produce sets of historical indicators on American chemistry, taking as their model the NSF Science indicators.

[21]. Szabo (1985). De Candolle was a fine botanist and is considered a "forerunner of modern ideas on the evolution of crop plants ... Vavilov dedicated his epoch making book (he does not give its title. H.R.) to the remembrance of de Candolle. He persuaded the International Botanical Congress of 1867 "to recognise subspecies, varieties and other sub-divisions of species". Mayr (1982) p.263. Along with Edward Forbes, Mayr (1982) considers that de Candolle helped "to convert static biogeography into a dynamic developmental science". p.444. It has even been argued that his ideas on "the struggle for existence" may have indirectly influenced Charles Darwin", Mayr (1982) p.483.

[22]. Shelishch (1982) p.318. He argues that his own findings "illustrate de Candolle's opinion that the professionalism of science was accompanied, and at the same time accelerated, by a narrowing of specialisation of scientists and by their concentration on some definite field of research". p.326. Some idea of the extent of de Candolle's oblivion can be gathered from the fact that he is not mentioned by Sorokin, Bernal, or Barber in their major works, which pay

scientometrician;[23] Merton[24] sees him as a pioneer of prospography, collective biography. Szabo[25] has discussed de Candolle's contribution to scientometrics, and he notes that whilst de Candolle called his book "Histoire des Sciences" compared

> "... with traditional studies in history of sciences, his approach was characterised by some important differences:
> 1. Numerical criteria were established and mathematical methods applied.
> 2. The same methodology was used for similar phenomena for fixed time intervals in order to guarantee reproducibility of evolutionary trends.
> 3. A standard list of 'factors of development' was used for comparisons."

De Candolle made pioneering innovative statistical analyses of scientists using the following:[26]

> "1. Bibliographical study of academic bulletins, the analysis of the activity and sociobiological characteristics of eminent scientists - elected members of the scientific academies of Paris, London, Berlin, Rome, Edinburgh, Turin, Brussels.
> 2. Calculation of science indicators (numbers of member scientists per country, per cent participation per country, number of elected members - scientists per million inhabitants etc.)

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attention to quantification in the history of science. Merton (1977) and Szabo (1985) have discovered possible reasons for de Candolle's neglect. Merton made "extensive references" to de Candolle's and Galton's work in his Ph.D. thesis "Science, Technology and Society in Seventeenth Century England" [1938] 1970: 131-36. Merton sees the prosopographic contributions of Galton and de Candolle as premature, doomed to be "institutionally and cognitively rootless (which is far from saying that they were without foundation), not having been rooted in any other discipline before being adopted by the sociology of science". p.47. Szabo believes the main reason why de Candolle's "Histoire des Sciences et des Savants..." "sank into oblivion was perhaps that the author paid no attention to the future possibilities of the specialisation of a science of science ... (and perhaps) by the interest of de Candolle in the role and heritability of intelligence in science..." p.27.

23. Szabo (1985) p.27. But he continues "If scientometrics is regarded in a more bibliometric sense ... then perhaps the papers of Cole and Eales (1917) and that of Lotka (1926) may be regarded as founders of scientometrics". p.27

24. Merton (1977) pp.27-34.

25. Szabo (1985) p.16.

26. Szabo (1985) pp.16-17.

3. The characterisation of the scientific development of different countries according to a set of codified factors or factor groups."[27]

Amongst the problems Candolle studied by these techniques, according to Szabo[28] were: Ethnography of knowledge; Language use[29]; Mobility in Science[30]; Geography of Science; Ranking of countries[31]; Public attitude. Science Policy[32].

I have outlined de Candolle's contribution since it demonstrates the extent to which he had recognised techniques and problems appropriate to scientometrics. I suspect that his belated recognition reflects not only the internal development of sub-disciplines such as

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[27]. de Candolle lists twenty such factors "Causes favourables" which can be either positive or negative in their influence on the development of science in specific countries. The distribution pattern of these factors differed from one country to another. These factors include, for example: the proportion of the population rich enough not to have to constantly work for their livelihood i.e. have leisure; proportion of rich, leisured classes able/willing to occupy themselves with intellectual matters; immigration of foreign intellectuals; public opinion favourable to science and scientists; public curious about true and real rather than fictitious or imaginary matters. Clearly de Candolle's factors are not unproblematic and contemporary sociologists would regard the task of preparing them for use as indicators as considerable.

[28]. Szabo (1985).

[29]. De Candolle concluded his language use trends showed that by the end of the 20th century English would be the leading language of science.

[30]. He strongly emphasised the importance of mobility in scientific development and saw the relative success in science of small countries such as Netherlands, Belgium and Switzerland as a result of their tolerance, which allowed the immigration of intellectuals from less tolerant societies. This is now a well established area of research, see Hoch (1987) for a recent example.

[31]. He ranked countries according to indicators, e.g. the proportion of the population who were members of national academies; proportion who were members of foreign academies, and so forth.

[32]. Some idea of the changes in science since his day may be gauged from the fact that de Candolle's data on the distribution of the most important scientists showed that "the form of government had little influence on scientists in western Europe", Szarbo (1985) pp.26-27.

the sociology of science and prosopography, but also the external demands of policy makers - now that government and commercial organisations financially underpin and control scientific activities. The latter requirements have led to a growing demand for science and technology indicators and strategic and comparative analyses of scientific developments, hence the use of disciplines such as scientometrics. The fact that scientometricians rather than science historians are developing research lines initiated by de Candolle may reflect the social distance of most science historians from science policy circles.

Bibliometrics is a major strand of scientometrics. The earliest reference that I am aware of to "paper counting" is an indirect one by Merz[33] who refers to the debate c. 1830 initiated by Charles Babbage's pamphlet "Decline of the State of Science in England"[34]

> "The answers to the challenges of Babbage and the Edinburgh Reviewer given by English writers themselves cannot on the whole be said to be very reassuring. One[35] of them counts the scientific periodicals in England and in France, but omits to weigh the merit of their respective contributions."

The generally accepted pioneers of bibliometrics are: Cole and Eales (1917)[36] on the history of anatomy literature, Hulme (1923)[37],

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[33]. Merz (1896) p.238 Vol.1.

[34]. Babbage argued "That science has long been neglected and declining in England is not an opinion originating with me, but is shared by many ...".

[35]. Merz gives no reference for this.

[36]. "The history of comparative anatomy: a statistical analysis of the literature."

[37]. "Statistical Bibliography in Relation to the Growth of Modern Civilisation", Merton (1976) says of this "a work that did not fulfill the great promise of its title". p.26.

and Lotka (1926) on scientific productivity[38]. Other pioneering works were White (1915) on fluctuations in mathematics research and Rainhoff (1929) on wave like fluctuations in the productivity of West European physics in the late 18th and 19th centuries.

The work of Pitirim Sorokin[39] and Robert K. Merton[40] forms the next major milestone in the development and use of quantitative historical analysis of science. In 1935 they wrote[41] a quantitative history of the development of Arabian civilisation which was published in Isis. Social and Cultural Dynamics, Sorokin's magnum opus, has been generally ignored by historians and sociologists of science. The empirical indicators of scientific and technical development which it contains have been overshadowed by the meta-theory of Sorokin's macro sociological, idealist theory of socio-cultural system dynamics. History is determined by three types of "culture mentalities":

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[38]. In this, Lotka enunciated his famous law of scholarly publication - the number A (n) of authors who publish exactly n papers is fixed so that the relation A (n) is proportional to $1/n^2$ obtains; for a large n (greater than 20) $1/n^3$ gives a better approximation. Vlachy (1978) lists 437 papers on "Lotka's law and related phenomena" up to 1978. Very few papers were written before 1950. Then there were never more than 10 papers per year until after 1965 when output rose steadily to 30-40 a year.

[39]. Sorokin (1937) especially Vol. 2. Chapter Three "Movement of scientific discoveries and technological inventories". R.K. Merton was his research assistant for this chapter.

[40]. Merton (1977) writes "I was set to work to compile quantitative indicators through content analysis ... in the fields of science, technology and medicine... Along with qualitatively examining historical fluctuation in theories of atomism, evolution, abiongenesis, and so forth, I compiled numerical indicators of scientific development based upon such standard sources as Darmstadter's Handbuch zur Geschichte der Naturwissenschaften und der Technik and Garrison's Introduction to the History of Medicine. At the same time, I was working on my own study of science in seventeenth century England and it soon become self-evident that the technique could be utilised for the quantitative analysis of shifts in the foci of scientific interest as registered in Philosophical Transactions. pp.25-26.

[41]. Sorokin and Merton (1935).

"ideational", which conceives of reality as "non-material everlasting Being"; "sensate" which limits reality to what is sensually perceived; between these extremes there is a "mixed type", the "idealistic". Culture says Sorokin continually shifts from one dominant culture mentality to another[42]

Merton and Barber, pioneers of the sociology of science and both former students of Sorokin, have subjected Sorokin's sociology of science to detailed criticism[43]. They believe that Sorokin is highly ambivalent in his attitude to the use of social and cultural statistics. They note that whilst exceedingly critical of what he elsewhere calls "quantophrenia"[44] in his "Dynamics..." "Sorokin drenches us in quantitative facts ... and thus provides both himself and his readers with the occasion for matching theoretical expectations and empirical data"[45]. Sorokin's "Dynamics ..." has, I believe, great value to the student of quantitative studies of the history of science, but like de Candolle in an earlier period Sorokin's study is generally ignored, though for different reasons. Therefore, I have summarised Sorokin's views on quantification in general, and in the study of science and technology in particular[46].

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42. "The continual shift of human culture from one of the dominant types to the others is not a sign of regression. On the contrary it represents a striking manifestation of the indefatigable human creativity which having exhausted for the time being the creative potential of a given supersystem, shifts and continues its creative elan in the form of other supersystems, each opening ever new aspects of the inexhaustible total reality undiscovered by the other two super systems". Sorokin (1963) pp.490-491.

43. see Merton and Barber (1963).

44. Sorokin (1956).

45. Merton and Barber (1963) p.357.

46. This is based upon Sorokin (1937) V.II, pp.125-180, Sorokin (1956) and Sorokin (1963) pp.440-449.

The data on science and technology which Sorokin used came from four major sources[47]: Darmstadter's Handbuch, Garrison's Introduction to the History of Medicine, Encyclopedia Britannica (9th ed.), and patent statistics.

Sorokin knew that "a perfect device for measuring the comparative progress of science at various periods is ... unavailable"[48]. It was, therefore, necessary to be content ('temporarily') with the best available barometer - indices of numbers of discoveries and technological innovations made in the time periods being compared. Thus if in two equal periods the number of discoveries was markedly different it is reasonable[49] to "maintain that scientific progress was, at least quantitatively, greater" in the one with the larger numbers.

Sorokin provides an exemplary discussion of the shortcomings of his quantitative indicators. They do not necessarily indicate qualitative difference. However, he had earlier shown[50] that the addition of quality weightings[51] to his data made no major difference to the trends obtained from unweighted and weighted data - the separate curves showed 'synchronous movement'. Sorokin concluded that "... an index based exclusively upon the number of discoveries and inventories

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[47]. See footnote 40 for Merton's description.

[48]. Sorokin (1937) V.II, p.126.

[49]. Sorokin (1937) V.II. p.126.

[50]. Sorokin and Merton (1935).

[51]. Sorokin is not happy with weighting since it presented "insurmountable" difficulties and he argued that the indices he derived provided "... at least a reliable approximation to the quantitative aspect... However, imperfect, it is certainly better than mere speculative generalities or fragmentary, unsystematic selected facts. Furthermore, it can be improved. Once the 'quantitative' basis is obtained, it is possible to correct and supplement it by data (not necessarily numerical) which give a qualitative idea of the most fruitful discoveries in each period". Sorokin (1937) V.II. p.126.

is not misleading and that it reflects natural movements in so far as they are accurately described by the historian of science"[52].

The final caveat in this statement raises the issue of bias in the data. There were three main sources. First biased selection by authors for nationalist and subjective reasons. He notes that the Encyclopedia Britannica seemed more chauvinistic than Darmstadter. Second, loss of data due to ignorance. The further back in time one goes the more likely 'events' are to be missed[53]. Also western sources tend to be ignorant of, and therefore underestimate, Oriental contributions. Third, bias introduced by the coder. All these can to some degree be compensated for, but clearly comparisons between periods closer in time and culture are more likely to be accurate than those involving large historical periods and different cultures. Sorokin often cross checks his indices with those created by other workers.

Sorokin provides an excellent critical discussion of the value of patent data.

> "It is understood that invention and patent are of course not identical units; that statistics of patents issued represent an imperfect reflection of the actual movement of inventions ... Yet despite these shortcomings, there is no more adequate index of the movement of inventions than these patent statistics. As an approximate measuring device it may serve more effectively than any other now at hand".[54]

Sorokin makes use of the data created by his student J.W. Boldyeff, who without calling it such, carried out a pioneering content analysis on the Encyclopedia Britannica. Boldyeff classified all the names of persons mentioned and measured the number of lines devoted to

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[52]. Sorokin (1937) V.II p.128.

[53]. "...it is highly probable that the discoveries and inventions of relatively recent times are registered in the annals of history of science much more completely than, for instance, the discoveries made several hundred or thousands of years ago". Sorokin (1937) V.II p.129.

[54]. Sorokin (1937) V.II. p.163.

them[55] The data was used to create what Sorokin termed a "quantitative-qualitative" "barometer".

In the light of his analysis of the data and indices, Sorokin argues that ideational systems, dominated by the 'truth of faith', are associated with periods of low scientific activity whilst the rate of scientific discoveries and inventions is greatest in sensate systems, dominated by the 'truth of the senses'. Merton and Barber have developed a convincing critique of this view[56]. That being said Sorokin's quantitative approach allowed him to make a number of valuable observations. For example, that over the long term scientific development shows an "undulating" or "wavelike" character. That there are[57] "long-time waves comprised by high and low levels in the rate of scientific discovery. The time span of these waves has been roughly

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[55]. Sorokin comments "Realising that the number of prominent scientists is not a satisfactory barometer of the state of science, for each period, he computed the number of lines devoted to each of the scientists. His assumption that ... the more important the scientist the more space devoted to him in the Encyclopedia, is essentially sound though not, perhaps quite perfect". Sorokin (1937) V.II p.142.

[56]. Merton and Barber (1963). For example they show, from Sorokin's own data, that even in sensate periods empiricism is not overwhelmingly dominant. More fundamentally, they question the very concept of 'sensate', 'ideational' and 'idealistic' as gross over-simplifications.

[57]. Sorokin (1937) V.II. p.157. The observation of wavelike undulations in scientific and technological creativity has been made by other workers e.g. Rainhoff (1929) and more recently Price (1977). Although Price is commonly cited as the proponent of the exponential growth of science he was referring of course of a general trend (c. 16th century to now), within that trend he was able to demonstrate "ups and downs in the pulse of science and technology" (Price, 1978). His paper has been generally ignored, despite (or because of) the fact that it suggests the need to revise the conventional historical view of the scientific revolution that "chemistry and biology were not late; astronomy and mechanics were early ...". Shelishch (1982) has demonstrated similar fluctuations in 18th and 19th century biology, Sheldon (1980) has developed a "cybernetic" theory to explain fluctuations in physical science, whilst Simonton (1980) has applied time series analyses to examine the relationship between war and scientific and technical development. Simonton (1984) has presented "historiometric" studies of creativity in general.

about 700-1,000 years".

It would appear that Sorokin has had little impact on the history of science and not much more on contemporary sociology of science. However, through his former student Robert Merton, he can be said to have exerted a profound, though indirect, influence on quantitative studies of science.

Merton can be regarded as "a founding father of the sociology of science"[58] and through him content analysis became a more widely utilised tool in social studies of science. It was as Sorokin's research assistant that he began to use the technique. Merton[59] has described the "Jourdain-like" manner in which he came to utilise, in his doctoral studies, both content analysis and prosopography - before he knew that they were called that. His "The sociology of science, an episodic memoir"[60] brilliantly describes, through his own personal experience, the origins of contemporary sociology of science. Part of his "story" concerns quantitative studies of science. Whilst there is little purpose in providing here a further detailed description of his story the salient points are worth noting.

Merton says that the contemporary methodological finesse of content analysis is chiefly due to its development by communication scientists[61] and modern research procedures of historical prosopography

[58]. In his introduction to Merton's "The Sociology of Science: Theoretical and Empirical Investigations" (1973), Norman Storer writes "If Robert K. Merton has not yet been publicly described as the founding father of the sociology of science, there is at least substantial agreement among those who know the field that its present strength and vitality are largely the result of his labours over the past forty years. His work has given the discipline its major paradigm". p.xi.

[59]. Merton (1972).

[60]. Merton (1977).

[61]. See Berelson (1954).

have been most strongly developed by ancient historians. However, there are developments in research procedures, says Merton[62],

> "that are specific to the discipline of the sociology of science. They are speciality - specific procedures in a double sense: first, in their being connected to certain distinctive aspects of the cognitive and social structures of scientific knowledge and second, in having been invented as part of that discipline or have first been put to use in it".

These are "the tool of the citation index and the correlative method of citation analysis"[63]. The Science Citation Index (SCI) was developed by Garfield[64]. We shall describe citation analysis methodology later, however, it is worth noting here that one of the first non-documentary uses made of the SCI was a historical study.[65]

Garfield and his co-workers compared a network diagram of DNA history generated from an analysis of Isaac Asimov's book "The Genetic Code" with one generated by citation analysis. The two networks were compared for resemblances and discrepancies. Sixty five per cent of the relationships mentioned by Asimov were picked up by the citation analysis, rising to 72% of those thought by Asimov to be most important. The citation analysis also uncovered an important event

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[62]. Merton (1977) p.47. Meadows (1974) has argued in a similar vein about the peculiar advantages of scientific communications to social scientists and historians studying it. "... scientific communication possesses the incomparable advantage of being assessable in more objective, quantifiable terms than most areas of human endeavour. Moreover, to the extent that the assessment can be carried out directly from an analysis of published scientific literature, a vast mass of data is readily available; and these, unlike so many sociometric data, are not influenced by the process of acquisition". Preface.

[63]. Merton (1967) p.49.

[64]. see Garfield (1979).

[65]. E. Garfield, I.H. Sher and R.J. Torpie "The Use of Citation Data in Writing the History of Science". Institute for Scientific Information, Philadelphia, 1964. This is summarised in Garfield (1979) pp. 82-97.

overlooked by Asimov. The author concluded[66] "... that citation analysis, even at a level considerably less than exhaustive, provides a way of identifying key events, their chronology, relationships and relative importance, and that it is a very useful tool in working out the history of a given scientific effort".[67]

The standard critique of co-citational analysis as a sociological and historical tool is still that of David Edge[68]; it is the one everybody cites! Edge's argument is that citation data is only a portion, and not the most important portion, of the data required for historical analysis of scientific development. That there is no consensual theory of publication and citation behaviour; further, publications and citations are the formal visible part of scientific communication, and in his view, the informal communication or "soft underbelly" of science is where the real social and historical action should be sought.

Edge finds the claims of the Institute for Scientific Information school for what he terms their "strong programme of citation analysis" to be unacceptable, it has scientistic overtones in its claim for 'scientific status' and 'objectivity'. He is prepared to allow a "weak

66. Garfield (1979) p.93.

67. The use of citation analysis in historical studies is not frequent. I have experimented with it, though not in the economic entomology study; see Parkinson and Rothman (1984). David Parkinson, an MSc student of mine at Aston University, and I produced the study for the Commission of the E.E.C. DG XII, FAST Programme, Biosociety subprogramme, C1.4 Analysis of Scientific Disciplines Germane to Biotechnology. It was entitled "Monoclonal Antibodies: Historical Development and Citation Analysis". We were able to show that ".. the techniques used in the development of hybridoma secreting a predetermined monoclonal antibody were in fact not new ... the idea was familiar to several workers in the field by the early 1970s ... the hybridoma technique evolved from existing methods of biological investigation, and that this evolution occurred in small steps". Parkinson and Rothman (1984) p.C29.

68. Edge (1979).

programme of citation analysis" which lays no claims for a "preferred logical status" over other historical techniques, and where the technique is used carefully, alongside more conventional techniques and data.

Edge's views have to be treated with respect, he and Mulkay made use of quantitative techniques in their history of British radio astronomy[69]. Their quantitative studies produced a picture of the Cambridge and Jodrell Bank research groups that "was completely consistent with that obtained earlier from our 'soft' data"[70]. Edge goes on to argue that although the quantitative data made their case about the social nature of the two research groups "more convincing", it carried the status of "secondary validation only".

> "Essentially our picture is derived from our 'soft' data: if the 'hard' data had been seriously inconsistent at any point, then it would have to be re-interpreted. We would have had to devise explanations for the precise form the 'hard' data took in terms of what we could deduce from the 'soft'... I cannot conceive of circumstances in which the explanatory logic might 'flow in the other direction'."[71]

I find Edge's position quite illogical; it is quite easy to conceive of situations in which several distinct studies of a historical subject might put out quite different interpretations of their soft data, in which case quantitative data might throw some light

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[69]. Edge and Mulkay (1976).

[70]. Edge (1979). p.125.

[71]. Edge (1979) p.126. An example, which seems generally to have been ignored is Sorokin's historical data on national scientific and technical activity and religion which he claims "... will refute Max Weber's contention that Protestantism was the cause of the growth of nationalism, scientism and technology ... We see long before the emergence of Protestantism discoveries begin to increase in Catholic countries ... even after its emergence during the sixteenth and first half of the seventeenth centuries, the scientific contribution of the Catholic Italians was higher than that of any other country ... it is enough to call attention to the contradiction between these data and the theory of Max Weber" Sorokin (1937) V.II. pp.152-3.

on it. I suspect that Edge finds quantitative studies personally uncongenial since as he says "... to scholars of my ilk, ... individual variations constitute the field"; no-one would disagree with the view that citation analysis is not well suited to studies of individual papers or individual scientists. However, they cannot be said to constitute the field, they are elements of a far grander and complex system, within which there are often further fields for historians to plough.

There is surely no better example of a science historian who knew how to recognise fields suitable for quantitative ploughing than Derek de Solla Price. Many people working in science studies, including myself, readily admit to being encouraged to make quantitative studies of science by Price's "Little Science, Big Science"[72]. Within the history of science community itself Price was probably most recognised for his work on the history of scientific instruments.[73] His initial studies on the exponentiality of the growth of science "fell flat"[74] and he waited almost ten years before taking them further. "I did not take up the matter again until it forced itself into my work as a historian of science, being needed to explain why science progressed as it did in certain periods"[75]. By the early 1960s Price had seized upon citation analysis.

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[72]. See S. Cole in Cole and Meyer (1985) p.443.

[73]. For example, his book The Equatorie of the Planetis, Cambridge U.P. 1955.

[74]. Price's words according to Merton (1977) p.55. The paper "Quantitative Measures of the development of science" was published in two mainstream history of science publications; Archives Internationales d'Histoire des Sciences, 14, 85-93, 1951 and Actes du VI Congres International d'Histoire des Sciences, pp.413-21. Hermann and Cie, Paris, 1951. Merton (1977) refers to "the deafening silence of colleagues in the history of science ..." p.56.

[75]. Cited by Merton (1977) p.56.

"Means of pushing the usefulness of such models (theoretical models of science H.R.) further is provided, strangely enough, as a by-product of the citation index method of handling scientific literature ... the citations in papers from a network linking them all together in a complex fashion. The pattern of this network may be studied by graph theory and matrix methods, and seems to suggest that papers do conglomerate into continents and states that might almost be mapped and shown to have salients and impassible bogs".[76]

From this emerged his second seminal work "Networks of Scientific Papers"[77]. It could be arguably said that Price was, together with Garfield, responsible for putting scientometrics on the map in the USA.

After the mid 1960s we find a confluence of various streams of scholarly activity flowing into what we may now regard as mainstream scientometrics. That period of the 1960s is undoubtedly an important historical conjuncture in which many social and political changes come to a head. No doubt the developments which I have outlined here could be related to them, it would be a valuable and illuminating study. Already Merton in his "An episodic memoir"[78] has provided a valuable personal, and somewhat internalist, account of some of these developments with respect to the inflow from the sociology of science.

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[76]. Price (1964) p.206. I was excited by this sufficiently to encourage George Lester, an M.Sc. student at Manchester University, to make an empirical test of science networks. see G. Lester "On the structuring of a scientific field using citations". M.Sc. Thesis, Victoria University, Manchester, 1970.

[77]. Price (1965). Kochen (1984) says of this paper it "is still exemplary for the quality of science he brought to bear on ... citation indexing." His other seminal work is, of course, Little Science, Big Science. Garfield (1985) has made a citation analysis of Price's work. Little Science, Big Science was cited over 700 times in period 1963-1983. Significantly, no articles in History and Philosophy of Science journals cited the work until 1974 (Isis gave two citations). Garfield writes "... the increase to a total of 40 citations from 1979-1983 may be seen as ... probably indicating an increasing interest in quantitative methodology in the history of science". p.492. Little Science, Big Science is Price's most cited work, followed by "Networks of Scientific Papers" (see Garfield, 1985) providing quantitative support for my own subjective judgment.

[78]. Merton (1978).

An equally important inflow came from information science which consolidated the bibliometric computation and science communication aspects.[79] A further important stream was that springing from the growth of science and technology policy studies which led to the development of science indicators[80], and to a better climate for external support for research and appropriate institutionalisation[81]. These developments were not confined to USA and Western Europe but were paralleled in the Soviet Union and Eastern Europe[82], which adds some support to the conjecture that the development of scientometrics reflected in some fashion underlying socio-economic developments.

The two decades since Price's seminal work and the development of

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[79]. White and Griffith (1981) have quantitatively analysed information science's development using author co-citation. The cognitive structure that this produced shows 3 main groupings: "scientific communication", "bibliometrics" and documentation and retrieval analysis. This is shown in Fig 1.3 of this chapter. The scientific communication grouping includes Price, Garfield, Meadows, Small, Griffith, Mullins, Narin and Crane - all of whom are also to be regarded as quantitative sociologists of science, often studying "invisible colleges". The concept of invisible college was yet another of Price's contributions (for a critical discussion of this see Chubin, 1985). George Lester (1977) has produced a valuable survey of the information science literature relevant to the development of scientometrics.

[80]. The OECD science and technology indicators were started in the mid 1960s and codified by the Frascati Manual, and the National Science Foundation published its first Science Indicators in 1972.

[81]. Without wishing to write an "episodic memoir" of my own it is worth recalling that in the UK by the mid 1960s SPRU at Sussex University, Science Studies at Edinburgh University and Liberal Studies and Science at Manchester University had all been established (see Jevons's [1969] limpid argument for that educational development). The radical anti-establishment response was the formation in April 1969 of the Society for Social Responsibility in Science.

[82]. The theory of "scientific and technological revolution" might be associated with progressive or liberal groups there. One key collective work on the scientific and technological revolution was a product of the "Prague Spring" Richta (1968). A more technocratic, mathematical approach is presented by Dobrov's "Science of Science" school, whose work parallels Price's, see Dobrov (1966) Nauka o nauke, Kiev.

citation analysis have seen, if not a blooming, a consolidation of scientometrics in the form of further methodological developments and applications in social and historical studies of science. The next section of this chapter provides an over-view of these[83].

Publication Analysis Overview

Figure 1.1 "Overview" shows in general and broad fashion how publication analysis can provide information and intelligence suitable for evaluative and strategic studies of scientific research and also for social and historical studies. It identifies two main study areas: **productivity studies**; and **relational studies**. Both are applied to various elements of the scientific research process, some of which are on the figure under the heading **Possible elements of interest**. The first step in publication analysis is the selection and extraction from an appropriate database of a **Target literature**, what this is depends upon one's particular problem. Ideally the target literature should have associated it with a variety of useful bibliographic data such as: authors' names; reference details; keywords; institutional addresses and so forth. There are, in the figure, three principal routes to analysing this data: **Publication counts/analysis; citation counts/analysis; keyword counts/analysis.**

Productivity studies

These are concerned with measuring the outputs of scientific research which, in the context of this thesis, are publications; e.g.

[83]. This is based upon part of an unpublished report that I wrote for the ESRC, Rothman (1985). Other reviews include: Elkana (ed.) (1978); Moed et al. (1983); Narin (1976); King (1987); an extensive Soviet review of the subject has been published, Haitun (1983) this reviewed in Scientometrics, 6, 204-5, 1984; Knorr et al. (1979); the journal Scientometrics publishes a regular bibliography "Quantitative studies of science. Current Bibliography" compiled by A. Schubert; van Raan (ed.) (Forthcoming).

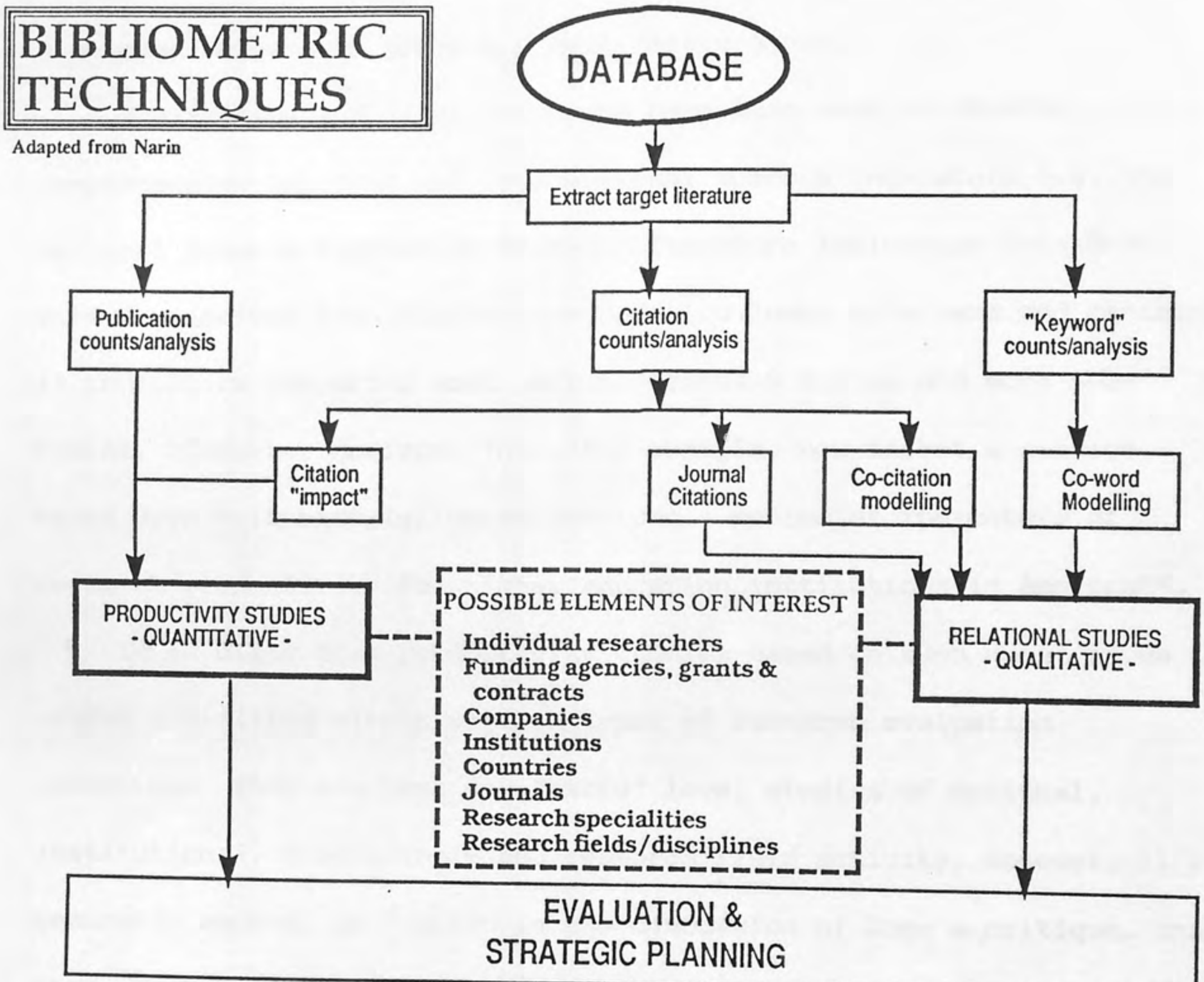

Fig. 1.1 Overview of Bibliometric Techniques

books, papers, patents etc. It is relatively easy to produce various kinds of publication counts which can be used to make quantitative indicators of the research activities of: individuals, institutions, research fields, disciplines, nations etc. Of course, quantity is not synonymous with quality of research and the more sophisticated publication analyses also draw upon some form of citation counting - discussed below - to provide a qualitative gloss.

Publication and citation counts have been used to develop comprehensive national and international science indicators e.g. the National Science Foundation Science Literature Indicators Data Base. This was derived from the Science Citation Index data base and contains 13 indicators comparing most nations across 9 fields and more sub-fields. Computer Horizons Inc., for example, now market a service based upon this material which provides a series of indicators of research productivity for higher education institutions in America[84].

It is clear that productivity studies based on such data can be usefully utilised within certain types of research evaluation exercises. They are best for "macro" level studies of national, institutional, disciplinary and research field activity, however, it is generally agreed, as I noted in the discussion of Edge's critique, that they are not suitable for evaluating individual workers or individual departments within universities.

Relational studies

These bring a new dimension to productivity studies for they are designed to seek and highlight linkages and relationships within scientific research. These relationships may be between research groups, institutions, nations, research specialties, disciplines etc.

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[84]. Narin (1985).

The relationships between social and cognitive aspects of research (in so far as they are distinguishable) are sought, thus bringing a qualitative complexion to the bibliometric analysis of scientific research. To use the jargon of the Information Age one is interested in identifying "networks". I believe that one's intelligence capacity and planning capabilities are directly related to how well one understands and can "map" the socio-cognitive networks of science. This is best done by co-citation and co-word analysis techniques.

Citation counts/analysis

The chief defect of publication counts is their inability to measure quality (except insofar as quality might have a quantitative aspect e.g. some studies show that there is a correlation between numbers of papers published and peer group ranking[85]). Citation analysis offers a greater qualitative dimension than publication counts, since one would expect good papers on the whole to be more cited than mediocre ones. It is, however, now usual to argue that citation rates measure impact rather than quality. There is evidence of a strong correlation between citation impact and quality as judged by peer group evaluation. A further advantage of citation studies over publication counts is that they allow one to study and measure relationships and linkages between authors, research fields, institutions, countries etc.

There are several types of citation analysis:

* citation counts
* journal citation analysis
* co-citation analysis

Most citation analyses draw upon the citation indexes produced by the

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[85]. See Chapter V. "Correlation with non-literature measures" in Narin (1976).

Institute of Scientific Information (ISI).

Problematic Aspects [86]- Before dealing with each of these approaches it is necessary to discuss the general problems associated with citation analysis. For one finds that scientists unfamiliar with citation analysis studies often 'find' many faults with the concept of citation analysis, unaware that practitioners of citation analysis have already identified these problems and attempted to control them in their analyses.

There are two major kinds of problems to be taken into account:

1. Those deriving from the technical limitations of the citation data bases produced by the ISI - the Science Citation Index (SCI), the Social Sciences Citation Index, and the Arts and Humanities Citation Index. These include: listing of first authors only; homonyms and inconsistencies in spelling; clerical errors; limited journal coverage, much biased towards English language journals (arguably it does cover the most important journals of big science). It is possible to deal with the first three problems by "cleaning up" the data, and the NSF Indicators data base used a cleaned up version of the SCI. Whether or not the limited/biased journal coverage turns out to be a disadvantage depends on what one wishes to do; a big science study will be covered adequately, whereas obscure research areas in small countries may not be adequately covered. If the degree of coverage by ISI is too restricted it may be better to resort to an alternative technique, such as co-word analysis, able to draw upon a broader based data source.
2. Those deriving from the sociological characteristics of citation

[86]. A clear exposition of these is provided by Cronin (1984).

practices. Things that may need to be taken into account include: negative/critical citation (it is rare for papers so cited to become highly cited); undue citation of powerful and eminent individuals; excessive citation of self and friends; differences in citation practices between disciplines and national cultures; variation in citation rates of papers over time.

The existence of these factors forces one to talk of the impact rather than quality or importance of highly cited work. Nevertheless, impact indicators taken together with other indicators/data provide a potentially useful aid to evaluative analyses. None of these objections raised against citation analysis as a tool of policy, or historical, analysis are sufficient reasons for avoiding their use-provided that appropriate controls are applied.

Citation counts

The number of citations to particular papers, authors, institutions, countries and so forth can be counted and applied to productivity studies. These, as I have noted already, can be linked to other indicators such as publication counts etc. It is now possible to obtain lists of most highly-cited papers by discipline and country. Institutions such as universities and research centres can be linked to such citation scores, and ranking lists based on them are available from specialist data bases (e.g. Computer Horizons Inc.).

If citation impact, based upon citation counts, is viewed as a valid indicator, then it is arguably equally valid to give authors more credit for publishing in prestigious journals, weighting sets of publications accordingly. If one assumes some relationship between a journal's prestige or influence and the number of times its papers are cited one is able to calculate an appropriate measure. This is the basis of the journal influence approach. Journal influence is defined by its originator as "... the weighted average number of times a paper in a journal is cited"[87], the higher the figure the higher the journal's influence is considered to be. In practice this means that publication counts can be adjusted by taking account of the journal influence measures so that papers published in journals with higher "influence" are given more credit than those published in journals with lower influence. Table 1.1 compares the advantages and disadvantages of journal influence measures with direct citation counts. Perhaps the greatest advantage of the journal influence approach is that it can be applied to the most recent sets of publications without the necessity of waiting 3 - 5 years for citations. Its main disadvantage is that it is gross and unspecific.

Table 1.1 COMPARISON OF DIRECT CITATION COUNTING AND JOURNAL INFLUENCE AS PRODUCTIVITY MEASURES

Direct Citation Counting	Journal Influence Measure
Advantages	
Higher precision: identifies specific papers and individuals.	Available quickly, as soon as bibliographies are completed. Not as labour intensive or computationally complex. Relatively easily normalised.
Disadvantages	
Must wait 3 - 5 years. after publication. Labour intensive and/or computationally complex. Must always be carefully normalised.	Only valid for relatively large sets of papers. Lose identification of specific highly cited individuals and papers. Journal influences may change over time.

(After Narin, 1985).

[87]. Narin (1985) p.3.

Citation counts should be used in conjunction with other softer information, such as interviews and peer review. This, of course, applies to all bibliometric indicators. For as an OECD report noted[88] they "... are only partial indicators and must be used in groups... (and) in conjunction with other available tools and judgement".

Irvine and Martin[89] use such an approach with their "converging partial indicators" method for evaluating and comparing the scientific quality of research groups. Matched or "like" groups can be compared in their approach by drawing upon publication and citation data, funding data, and peer group opinion. From such data they develop a range of indicators with which to compare the research groups under evaluation. For example:

* Numbers of publications per researcher
* Numbers of publications per unit of funding
* Numbers and proportion of a) theoretical papers; b) experimental papers
* Citation rate per paper
* Numbers of highly cited papers; indicative of work having a "substantial impact on the advance of scientific knowledge".
* Peer evaluation in the form of a "league table" ranking; the information for which is obtained by interviewing appropriate experts.

From an examination of such a range of indicators, each in itself only a partial view, they look for convergence of results. Convergent indicators being regarded as reliable indicators of research performance.

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[88]. OECD (1980) p.5.

[89]. Irvine and Martin (1985).

The convergent indicators approach has been applied by Irvine and Martin to several studies, e.g. in radio astronomy, particle physics[90]. In the ABRC Study[91] they built ad hoc data bases to investigate research performance in Ocean Currents and Protein Crystallography, mostly utilising publications and citation productivity data.

Their work has come under a great deal of scrutiny and criticism - much of it misplaced, more to do with fears of cuts in a period of financial stringency than intellectual analysis. However, serious critical points have been made that caution against over-optimistic claims for their method. The major lines of criticism are:[92]

* Those against bibliometric methods in general.
* Their method for matching research groups is too simplistic and stems from their inadequate input-output model of research. This, it is argued, appears to assume that the "black box" of scientific production, that lies between the inputs to science and the outputs of research (on both of which they have data and indicators), is the same for all research groups that they hold to be matched groups.
* Peer evaluation rankings have been based upon interviews without it being made clear how interviewees were chosen and sampled, or indeed questioned.
* Their idea of "convergence of partial indicators" has been held to be misleading in that since it is agreed that individual indicators are partial and need to be examined together for a more global picture it is beside the point whether they converge or

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[90]. Irvine and Martin (1985).

[91]. Healey, Rothman and Hoch (1986).

[92]. see Social Studies of Science, 15(3), 525-75 which contains a series of articles discussing Irvine and Martin's methodology.

not.

To return to the main subject of citation I would like to stress that when used in isolation citation counts contain the seeds of a dangerous quantitative fetishism, especially in our current cultural climate which seems obsessed with 'lists', 'records', and 'winners'. Unfortunately, that could divert attention from citation analysis' most potent value, which is identifying and evaluating relationships and linkages between researchers, specialities and disciplines, and institutions and nations, i.e. relational studies.

Journal-Journal Citation Analysis

ISI produce Journal Citation Reports (JCR) which contains citation data on all the SCI source journals, who cites each journal and to what extent. The relationships between journals can be studied by creating matrices into which citing or cited data between particular journals is entered. This data (after normalisation) can be analysed by clustering methods which allow the journal linkage to be mapped according to their strengths. These results can be displayed in various ways e.g. in the form of dendograms. The method provides a relatively simple and objective technique for classifying scientific fields and examining relationships within and between disciplines. Time series can be prepared to examine such relationships dynamically.

Figure 1.2 shows a map of biotechnology based on journal-journal citation. This is discussed in an appended paper (Rothman and Aston, 1985).

There can only be an approximate correspondence to research fields because journals may have a narrow or catholic conception of their field of coverage; journals' coverage are not always consistent, some are multidisciplinary (e.g. Nature, and Science), and sometimes highly cited and these distort the cluster maps (this can be controlled by

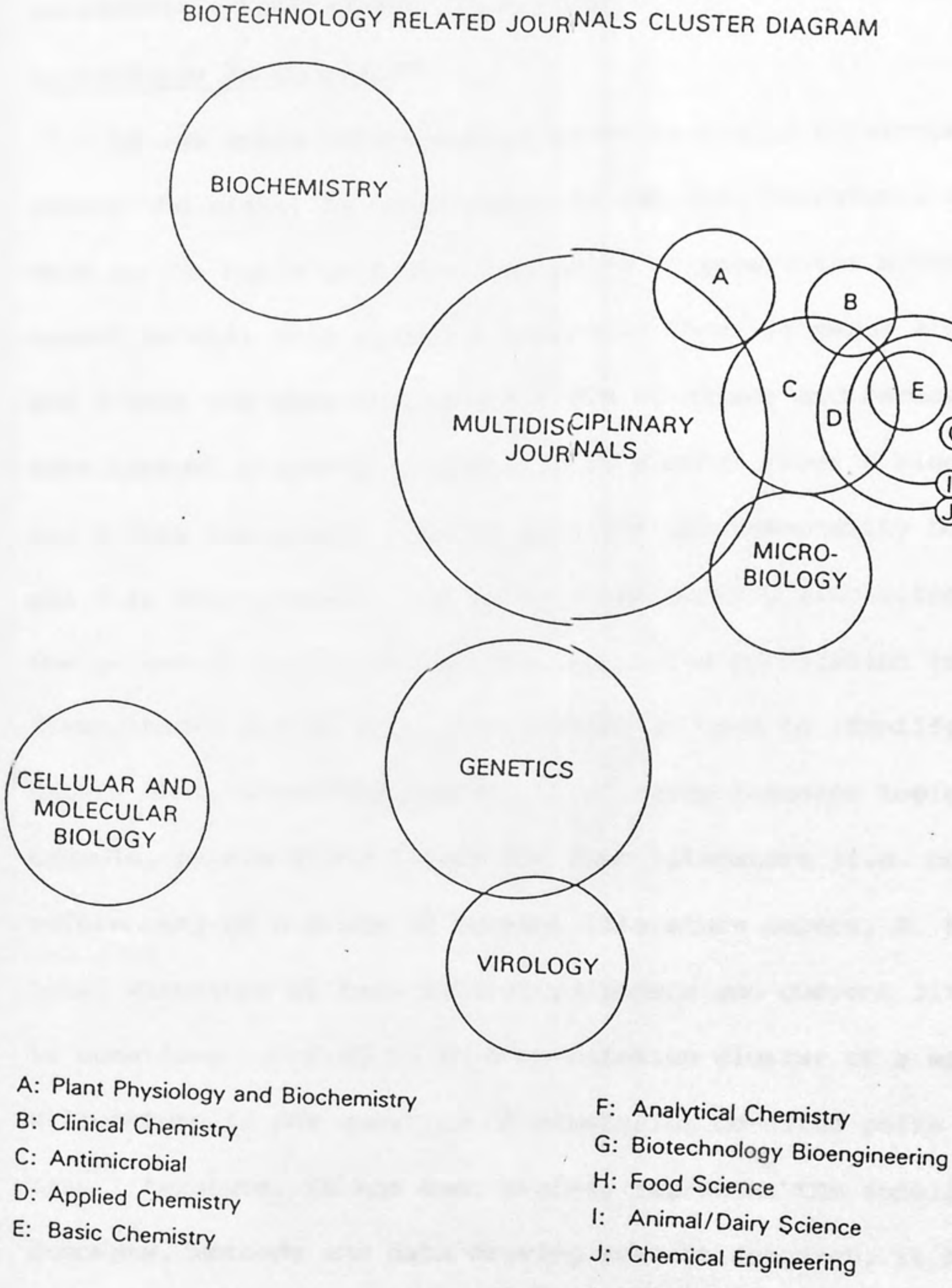
BIOTECHNOLOGY RELATED JOURNALS CLUSTER DIAGRAM
BIOCHEMISTRY
MULTIDISCIPLINARY JOURNALS
A
B
C
D
E
F
G
H
I
J
MICRO-BIOLOGY
GENETICS
CELLULAR AND MOLECULAR BIOLOGY
VIROLOGY
A: Plant Physiology and Biochemistry
B: Clinical Chemistry
C: Antimicrobial
D: Applied Chemistry
E: Basic Chemistry
F: Analytical Chemistry
G: Biotechnology Bioengineering
H: Food Science
I: Animal/Dairy Science
J: Chemical Engineering

Fig. 1.2

seeing how sensitive the clustering is to their absence or presence). A further disadvantage arises from the limited coverage of the JCR. Finally there are technical limits to the matrix size that can be conveniently handled for clustering.

Co-citation in General[93]

If one seeks relationships based on single references held in common the signal to noise ratio is too low, therefore, analysts have used as the basic unit co-cited pairs of papers (or authors, for the moment we will only speak of papers). Thus, if paper A cites papers X and Y then one says that X and Y are co-cited, and perhaps have some intellectual property in common. If another paper B also cites both X and Y then the possibility of intellectual commonality between papers X and Y is strengthened. If yet another paper C also cites X and Y then the potential intellectual strength of the co-citation is further strengthened and so on. Co-citation is used to identify groups of papers that, plausibly, relate to a common research topic. In this example, papers X and Y form the **base literature** (i.e. co-cited references) of a group of **current literature** papers, A, B and C. The total structure of base literature papers and current literature papers is sometimes referred to as a **co-citation cluster** or a **speciality**. We will return to the question of clustering co-cited pairs later. The base literature, it has been argued, represent the intellectual base, concepts, methods and data driving current research, it has even been likened to the paradigm of a particular speciality. The current literature, which cites into the base literature represents the latest published work within the speciality, and has been regarded as the **research front**. The validity of this approach has been explored by a

[93]. Garfield (1979), Small and Griffith (1974), Leydesdorff (1987), Rip (forthcoming), Weingart (forthcoming).

series of validation studies of co-citation clusters in fields such as: collagen research, rDNA, pain and neurotransmitter research, hypothalmic hormones, and monoclonal antibodies[94].

One can examine the changing nature of base and current literatures over time and the interrelationships between various specialities.

The current literature can be linked to SCI/SSCI corporate indexes to provide data for institutional and national analyses of speciality relationships. For example, one is able to see which institutions and/or countries are most active in particular specialities. I have been especially interested to identify specialities that show a high degree of industrial activity[95].

ISI have created a series of on-line information retrieval systems (for biomedical, mathematical and geological sciences) based on a co-citation clustering of the SCI data base. As far as I am aware only the current literature of each cluster is available through their on-line system, the base literature of specific clusters would have to be specially obtained. Another source of co-citation clusters is the ISI Atlas of Science. This is a collection of biochemical, bio-technological and molecular biology specialities. There have been three editions so far.[96]

There are two types of co-citation modelling; that based on co-cited papers; and that using co-cited authors. I shall describe the latter first.

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[94]. see for example, Small (1977), Small and Greenlee (1980), Cozzens (1981), Parkinson and Rothman (1984).

[95]. These are discussed in Rothman (1985).

[96]. ISI (1984). The third edition is a multi-part series, whose publication is still in progress.

Co-cited Author Modelling

Areas of research can be mapped using authors, rather than papers, as the basic unit of analysis. White and Griffith[97] used co-citations of pairs of authors to work out the distances between groups of authors, on the assumption that the more any two authors were cited together by others the stronger is their intellectual relationship and the closer they appear to each other in the map of their field research. The raw data for the necessary co-citation counts can be obtained on-line from ISI.

Figure 1.3 shows a map of information science, which I mentioned earlier, made by this technique. It appears to indicate three main groups/schools of authors; "scientific communication", "bibliometrics", and "information retrieval".

Like journal-journal citation modelling this approach offers a relatively cheap and simple means of modelling broad scientific fields to understand their structure, time series modelling can be done to study structural changes.

Co-citation Literature Based Modelling[98]

The first step in building a co-citation model involves the creation of an appropriate literature data base of the subject under investigation - which could be a research field, an organisation or nation. This is a key phase in the procedure, since misjudgments made at this stage significantly affect the overall model. A start is often made by identifying a core set of journals focussing on the target field. All the papers from this core set are removed from the SCI, together with their full bibliographic details, including references

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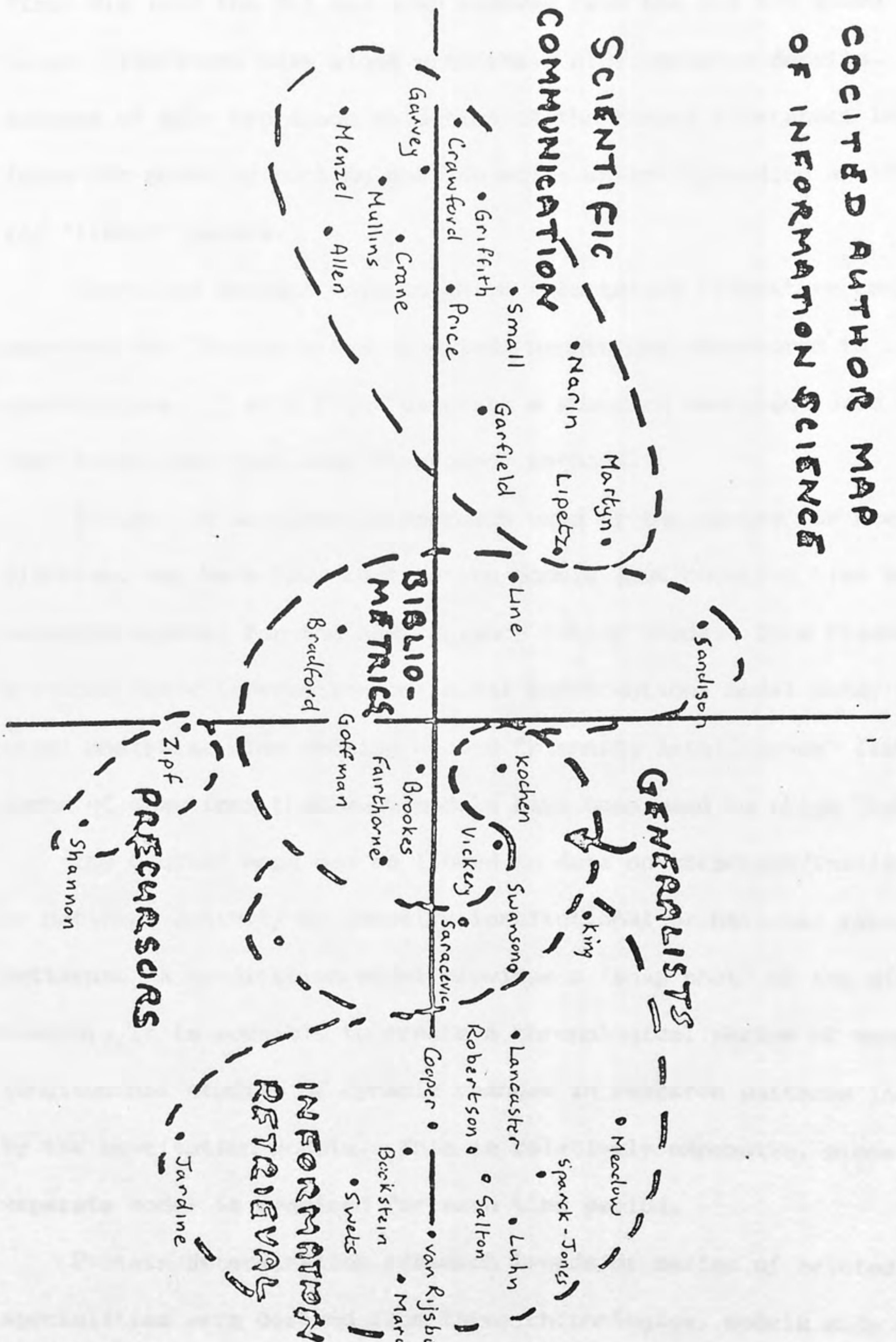
[97]. White and Griffith (1981).

[98]. Small and Sweeney (1984), Small et al. (1985), Healey, Rothman and Hoch (1986); Franklin (1987).


COCITED AUTHOR MAP OF INFORMATION SCIENCE
SCIENTIFIC COMMUNICATION
Garvey
Crawford
Griffith
Small
Narin
Martyn
Lipetz
Menzel
Mullins
Crane
Allen
Price
Garfield
Line
Sandison
BIBLIO-METRICS
Bradford
Goffman
Fairthorne
Brookes
GENERALISTS
Kochen
Vickery
Swanson
King
Saracevic
Lancaster
Robertson
Cooper
Meadow
Sparck-Jones
Salton
Luhn
Bookstein
Swets
Van Rijsbergen
Maron
INFORMATION RETRIEVAL
Jardine
PRECURSORS
Zipf
Shannon

and corporate addresses. The next step is a so-called second dip into the SCI in which papers citing any of the references obtained in the first dip into the SCI are also removed from the SCI and added to the target literature base along with their bibliographic details. The purpose of this two stage selection of the target literature is to focus the model by cutting down on noise whilst spreading a wide net for "likely" papers.

There are various ways in which this target literature can be searched for 'highly cited co-cited' papers and structured to identify specialities. I will first describe a standard technique used in the ABRC Study, and then some "improved" methods.

Figure 1.4 outlines an approach used by the Centre for Research Planning, who made five co-citation models (not counting time series as separate models) for the ABRC Science Policy Study. This figure provides basic information on: model construction; model data; and model analysis. The section headed "planning intelligence" lists the sorts of questions that such models have been used to throw light on.

The cluster maps can be linked to data on corporate/institutional or national activity to identify institutional or national research patterns. A co-citation model provides a 'snap shot' of the situation, however, it is possible to create a chronological series of models for longitudinal studies of dynamic changes in research patterns indicated by the co-citation models. This is relatively expensive, since a separate model is required for each time period.

Protein determination **research trends** or series of related specialities were derived from three chronological models made for the ABRC study. We were able to obtain the basic statistical data associated with the trend; especially noteworthy were the **national demographics** or national publication productivity within each

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speciality in the trend. This work showed the possibility of combining productivity and relational data. Bear in mind that such data is available for each speciality in the model, and a 1,000 specialities per model is not unusual.

The co-citation models that were evaluated for the ABRC proved more satisfactory than co-word models, which were at an earlier stage of development. However, the study did bring to light certain short-comings in the modelling technique. Most important were: problems associated with the creation of multidisciplinary models; and problems relating to model regionalisation, in which one seeks to aggregate specialities into higher level relationships. Fortunately, recent advances, outlined below, have gone some way to overcoming these weaknesses.

The chief disadvantages of this methodology are:

* data base coverage. The limitations of the ISI data base referred to already, naturally still apply. The coverage of technology is poor, and various approaches have been devised to find ways of linking science and technology in the models and testing their utility for industrial intelligence. Briefly these are identification of specialities with industrial corporate activity, linkage of science papers with patent citations, linkage of science author lists with patent author lists.
* expense. These models are expensive to make, particularly for longitudinal studies, however, it is expected that costs will fall as advances in techniques enable the creation of multi-use models built for multi-client consortia.
* model analysis is labour intensive. There is a need for developing interactive software for analysing the models; I am currently developing such software with Gill George of Bristol

Polytechnic Sci-Tec Centre. Skills for model analysis are still being developed and experience with modelling is limited.

* sociological and cognitive objections made to citation analysis in general are believed to be applicable to co-citation based modelling; there is a need to strengthen theoretical understanding of the model's correspondence with the actualities of the socio-cognitive structures of science. I believe the models will prove of great value to historians and sociologists of science prepared to develop the necessary skills to use them.

In 1982 the Institute for Scientific Information made an experimental citation index of major physics journals for the years 1920-1929. From this they created co-citation clusters. Figure 1.5 shows a multidimensional scaling map of these clusters.[99] The material

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[99]. Workshop on Historical Applications of Citation Data: The Physics Citation Index 1920-29. Institute for Scientific Information, Dec. 10-11, 1982, Philadelphia. The following short informal presentations were made:
Henry Small, "The Physics Citation Index: Compilation and Analyses".
Elizabeth Garber, "Do Citations Show a Quantum Revolution? Report of an Earlier Study".
Dan Sullivan, "Remarks on a Quantitative Research Program in the History of Elementary Particle Physics".
Stephen Brush, "Estimating the Importance of Subfields in Physics and Their Changes in a Decade".
Belver Griffith, "Three Approaches to Citation Data: Author Co-Citation, Document Obsolescence and Journal Inter-Citation".
Spencer Weart, "Use of 1920s Citation Data by the International Project in the History of Solid State Physics".
Karl Hufbauer, "Trends in Theoretical Astrophysics in the Physics Citation Index".
John Heilbron, "Some Indicators Concerning the Social History of Physics".
Lew Pyenson, "Physics in the 'Northern Minerva': Canada as Seen in Citation Analyses 1920-29".
Joseph Sneed, "Logical Structure as Literature Structure?"
Paul Forman, "Searching for the Crisis of the Old Quantum Theory in the Citation Index".
Mara Beller, "The Heisenberg-Schrodinger Controversy in the Physics Citation Index".
Katherine Sopka, "Light Shed on the Emergence of American Quantum Theorists by the Citation Index".
Stanley Goldberg, "Big Data Bases and Small Computers".

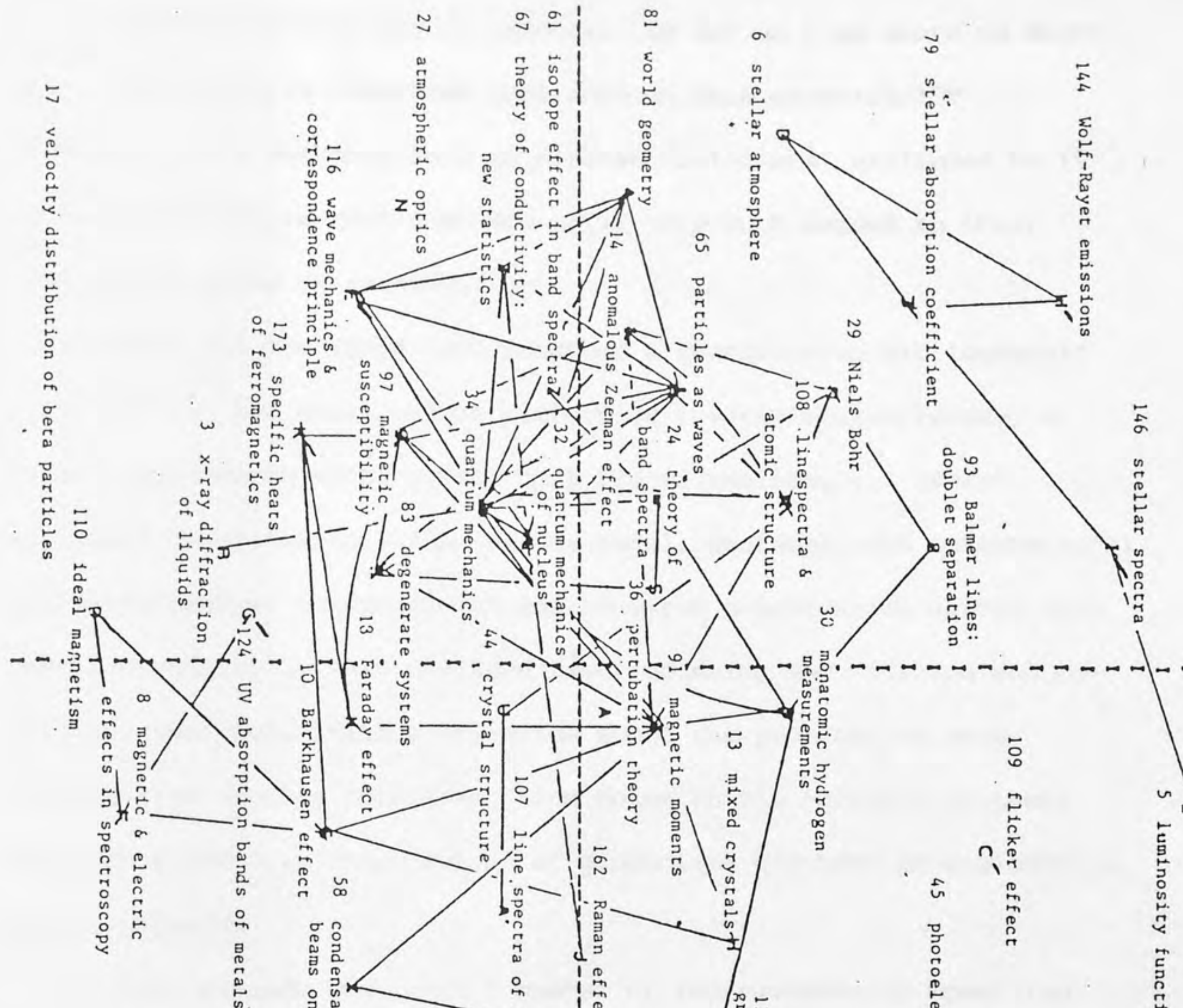
Multi-Dimensional Scaling Map of Physics clusters (1920-29):
Clusters at .3 normalized co-citation
Cluster size ≥ 5 cited documents
Linkages drawn if ≥ 5 co-citations
Cluster #1 (point A) omitted
144 Wolf-Rayet emissions
79 stellar absorption coefficient
6 stellar atmosphere
81 world geometry
61 isotope effect in band spectra
67 theory of conductivity: new statistics
27 atmospheric optics
17 velocity distribution of beta particles
146 stellar spectra
5 luminosity functions
29 Niels Bohr
93 Balmer lines: doublet separation
109 flicker effect
45 photoelectric effect
85 Brownian motion
65 particles as waves
108 linespectra & atomic structure
30 monatomic hydrogen measurements
14 anomalous Zeeman effect
24 theory of band spectra
36 pertubation theory
91 magnetic moments
13 mixed crystals
119 temperature gradient in gases
57 thermal diffusion
22 velocity of light
32 quantum mechanics of nucleus
44 crystal structure
107 line spectra of I2
162 Raman effect
34 quantum mechanics
83 degenerate systems
13 Faraday effect
97 magnetic susceptibility
116 wave mechanics & correspondence principle
173 specific heats of ferromagnetics
10 Barkhausen effect
58 condensation of molecular beams on surfaces
37 cooling bodies in gases
60 dielectrics
3 x-ray diffraction of liquids
124 UV absorption bands of metals
110 ideal magnetism
8 magnetic & electric effects in spectroscopy
7 electrical transmission in upper atmosphere

Fig. 1.5

was created for historians to examine. As far as I am aware no major historical articles have been published on this material;[100] experience of a workshop held to discuss historians' attitudes to it appeared to confirm that most are still very much wedded to their traditional modes of research.

Studer and Chubin[101] have produced a quantitative bibliographic study of "... the intellectual history of reverse transcriptase, a domain of research within viral cell transformation, ... [which analyses] quantitatively the various local, sectoral, and international configurations of collaboration and research organisation within this cancer community". They utilised paper counting and citation and co-citation analyses. With a wry aside about the problems of such quantitative studies Robert Morrison notes in his foreword to their book that the "... sheer labour of production has been prodigious".

Recent advances

I have already mentioned a number of improvements in modelling that are being attempted by CRP and ISI, amongst others. Briefly, and without going into technicalities, these will allow: better multi-disciplinary models, by using fractional rather than integer citation counting - hopefully reducing the problems created by differences in disciplinary citation practices; improved clustering techniques that reduce arbitrariness of speciality size, and allow good multilevel models to be created (Henry Small, pioneer of co-citation modelling, refers to these as "nesting maps"). Attempts are being made to utilise keyword/phrases in co-citation models and relate specialities derived

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[100]. This is no longer strictly truth in so far as Weart (forthcoming) makes some use of the model in his study of the early solid state physics community.

[101]. Studer and Chubin (1980) p.101.

from co-citation to maps produced by co-word techniques.

Such advances, when combined with appropriate model analysis software, open the possibility in the foreseeable future of interactive analysis of global models of research activity, held in a main-frame or mini-computer, via a micro by anyone seeking intelligence for strategic planning, policy analysis or even their next research project[102].

CRP have developed what they term a **stratified** model. It is so termed because research specialities are defined in a series of tiers by a novel procedure for determining the citation and co-citation thresholds used in model building. I have been informed that the method involves successively recalculating the co-citation threshold for the distribution of all co-cited pairs of documents meeting the citation threshold that failed to link up with other pairs at the initial or preceding co-citation threshold. Thus at each tier of the model a new and lower citation threshold is used, a novel algorithm has been developed to choose the threshold. An interesting claim about this method is that as one moves down the strata, from the higher to lower co-citation thresholds, one is also moving from higher to lower levels of peer consensus. The top stratum represents the highest level of peer consensus on the base literature, the documents thought to be "driving" the specialities. Lower strata represent decreasing consensus. The final stratum is reached when the remaining co-cited document pairs fail to link, this unstructured literature is referred to, by CRP, as the **research back**, as opposed to the **research fronts**

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[102]. Small et al. (1985). "While the Price metaphor of the war map of science may appear fanciful to some, with the 'generals' of science policy observing the progress of their operations and planning future battles with Nature, we are, it seems, close to the technical feasibility of such a system. The real scenario, however, is probably more personal and less centralized, involving the solitary scientist at his or her micro-computer with attached video-disk, consulting the Atlas of Science and thinking about the next experiment". p.339.

represented by the higher and more consensual strata. They speculate that the research back may represent those areas of low consensus from which new science, new research fronts, could emerge. The properties of the stratified models remain to be studied, it is noted that the model building algorithm is claimed to be more rigorous than the earlier methods, which involved either: trying four different ad hoc co-citation levels, then choosing the most productive; or the variable range method, where the threshold for each cluster is different (within a range) and determined by cluster size. CRP claim that "the rigour of the algorithm eliminates the problem of how one is to select comparable thresholds when building time series models. The relationship of the threshold to levels of peer consensus also seems to represent a more rigorous theoretical basis for building models of scientific activity".[103]

CRP have also experimented with a novel way of regionalising their models. In the ABRC co-citation models some problems associated with the regionalised models were noted, most important being the loss from the regions of some specialities which may cause regions to lose their coherency. It appears that this problem can be resolved by regionalising specialities using a similar approach adopted to that in the stratified modelling procedure. Normally, when regionalising one starts with the lowest co-citation threshold, progressively raising it to break up the dominant region, i.e. a bottom-up approach. CRP's new approach to building regions involves a top down procedure in which the co-citation thresholds used to qualify pairs of specialities for clustering begin with the highest one computed from the distribution, and not the lowest. The loss of specialities is avoided by returning

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[103]. Lenard Simon, Personal Communication, Centre for Research Planning, Philadelphia.

all speciality pairs that do not cluster at a particular threshold to the distribution from which the next threshold is to be computed. That threshold will be lower than its predecessor, because speciality pairs that regionalised will have been removed. The procedure is continued iteratively until all pairs of specialities are linked. CRP believe their approach holds certain advantages:

> "Conservation of all specialities should improve greatly the intellectual coherency of the regions. Stratification of the regions by the strength of peer consensus about the interaction should provide a way of distinguishing between emerging, decaying, and stable research directions. The interactions of any given speciality can be examined from a number of different viewpoints, each of which corresponds to a level of peer consensus."[104]

Co-word modelling

Co-word analysis provides an alternative approach for using bibliographic data bases to map out the cognitive and institutional structure of scientific and technological research fields. It possesses the merit of combining quantitative and qualitative analysis, and allows relationships between research fields and institutions etc. to be analysed over time. It avoids many of the objections raised against citation models, although at the expense of introducing problematic elements of its own.

The techniques of making and using co-word models have been pioneered by the Centre de Sociologie de l'Innovation (CSI) at the Ecole des Mines in Paris[105].

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104. Lenard Simon, Centre for Research Planning, Philadelphia, Personal Communication.

105. The standard reference book for co-word modelling is Callon, Law and Rip (1986). A detailed summary of the co-word contribution to the ABRC Science Policy Study, which was eventually confined to the single area of "Protein nutrition in ruminants" can be found in Rothman (1984). See also, Callon et al. (1983); Rip and Courtial (1984), Bouin and Michelet (1987). Latour (1987) provides a sociological underpinning to the Centre de Sociologie de l'Innovation's co-word

The basic approach is to build up a map index[106] of an area of scientific or technical research by co-word analysis. Documents may be analysed to identify keywords that describe their research content. Files of keywords and other bibliographic data are created and papers linked by the degree of co-occurrence of their keywords. Using this approach the relationships between research areas can be mapped and the passage of ideas and techniques from one area to another can be identified and followed.

The steps in producing a map index are:

1. Identify appropriate document data base. This would contain key bibliographic information such as: authors, keywords, journal reference, institutional and national affiliation etc.
2. Define a target literature with respect to the problem under investigation, and extract a sample of documents from the document data base (these may be any written document, reports, patents, etc. as well as journal papers).
3. Create a lexicon of the keywords found in the documents and rank them in descending order of frequency.
4. All words meeting a specific frequency threshold are placed in a co-occurrence matrix (fig. 1.6) which provides the starting point for a series of computations that generate a series of maps, or graphs, which display the inter-relationships of keywords. These can be computed in a variety of ways depending on what features and properties of a research field are of interest. For example:
   * To show dominant (high frequency) word association patterns

approach; Law and Lodge (1984) also deals with the sociology of networks in science. Law has recently produced a co-word analysis of acid rain research, personal communication.

[106]. This is referred to as the "Leximappe" technique.

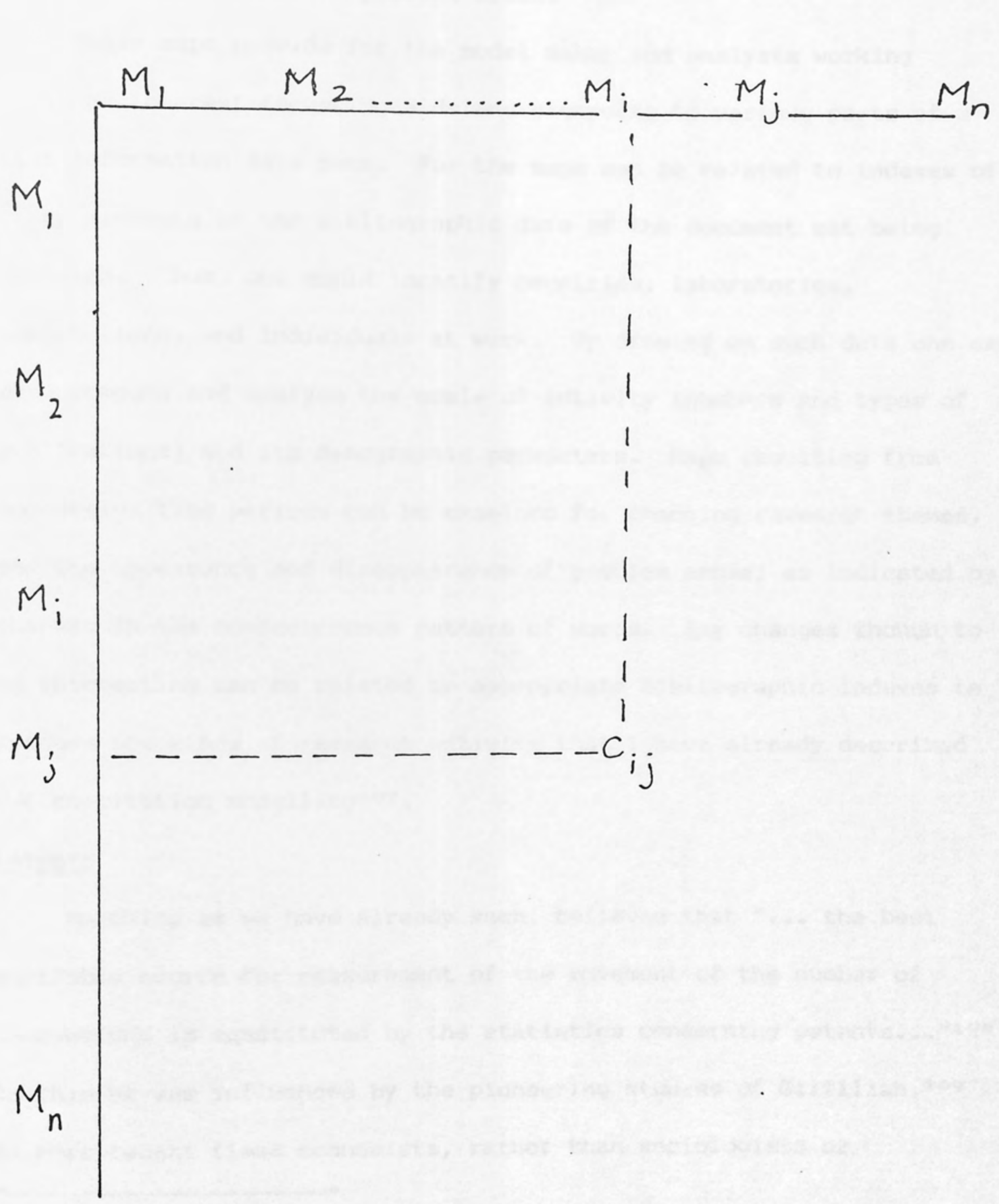

Fig. 1.6

which provide a guide to the hierarchial organisation of Research Themes (see fig. 1.7)

* To show the association of low frequency words, which pin-point Research problem areas.

These maps provide for the model maker and analysts working together interest focussing aids and signposts to various parts of a rich information data base. For the maps can be related to indexes of other elements of the bibliographic data of the document set being analysed. Thus, one could identify countries, laboratories, institutions, and individuals at work. By drawing on such data one can also compute and analyse the scale of activity (numbers and types of publications) and its demographic parameters. Maps resulting from successive time periods can be examined for changing research themes, and the appearance and disappearance of problem areas; as indicated by changes in the co-occurrence pattern of words. Any changes though to be interesting can be related to appropriate bibliographic indexes to produce the kinds of research activity that I have already described for co-citation modelling[107].

Patents

Sorokin, as we have already seen, believed that "... the best available source for measurement of the movement of the number of innovations is constituted by the statistics concerning patents..."[108] In this he was influenced by the pioneering studies of Gilfillan.[109] In more recent times economists, rather than sociologists or

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[107]. There is a possibility, which I am currently exploring with French colleagues, Jean-Pierre Courtial, Serge Bouin, and Bill Turner, of utilising Leximappe techniques on keywords and titlewords found in co-citation models to produce "hybrid" co-word/co-citation models.

[108]. Sorokin (1937) V.3, p.162.

[109]. Gilfillan (1935).

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historians, have been associated with the use of patent statistics as indicators of trends in technological developments.[110] Pavitt has reviewed the value of patent statistics for aiding the analysis of innovative activities.[111] Vivian Walsh has used patent statistics, alongside statistics of scientific and economic development, for analyses of the historical development of various fields of chemical technology.[112]

The major sources of patent data are, of course, national patent offices, however, these vary greatly in the extent to which their data are amenable to intelligent statistical analysis for the purposes I am discussing.[113] Patent statistics have a number of weaknesses as indicators of inventive activity which have been well described in the literature.[114]

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[110]. For example, Schmookler, J. (1966); Griliches, Z. (ed.) (1984).

[111]. Pavitt, K. (1985).

[112]. Walsh, V. (1985).

[113]. Pavitt (1985) draws attention to the following sources as particularly comprehensive: The US Office of Technology Assessment and Forecast; the Canadian Patent Data Base; the French Institut de Propriete Industrielle; the European Patent Office; the International Patent Documentation Centre; and commercial sources such as the Derwent Patent Information Services. The US National Science Foundation includes patent statistics in its Science Indicators, in a form that allows for international comparisons between fields and sectors.

[114]. See Pavitt (1985). There are various ways in which statistics can be distorted by variations in patent systems. National systems vary in the time taken to process applications, short term studies need to take this into account. Care has to be taken in long term studies to ensure that there are no artifacts created by administrative changes in the system. The usual quantity quality problem also applies to patents. Many patent studies now pay particular attention to interpreting statistics of "out-patenting", the extent to which patents are taken out in countries beyond the country of their origin. These have been used as a guide to patents' "quality" on the grounds that the higher a patent's perceived value the more likely is out-patenting; such an approach was used by Marstrand (1982). The multiplicity of national systems means that inventions can be registered in many countries, and crude international counts will

A recent and exciting advance has involved making use of citations to previous work, either scientific papers or patents, which are included as part of the prior art record in all US patents. This has opened up some interesting possibilities. It is possible, for example, to make international comparisons of technological strengths and weaknesses in more qualitative fashion[115]; in Chapter 5 I draw attention to such a study. Also the technique has been used to examine the extent to which the patent literature of a given field is related to scientific literature; the implications of such an approach for science and technology policy studies are extremely important, and offer novel ways of examining the science technology nexus.[116]

Techniques Used in the Thesis

It is clearly beyond the scope of a single thesis to adopt all the quantitative techniques listed in figure 1.1 and discussed in the chapter. In particular I was unable to make use of the more sophisticated and expensive[117] co-citation and co-word techniques in my historical studies of pest control, although I have used them in other

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include double counting and other errors; to avoid this, patent concordances or patent families have to be utilised, see Towalski (1982).

115. Carpenter, M.P. and Narin, F. (1983). Validation study: patent citations as indicators of science and foreign dependence. World Patent Information, 180-185.

116. For example, "If... it is true that science and technology are converging, or at least converging in key high-tech areas, then this is a very powerful demonstration of the utility of basic research to technology". Narin, F. and Noma, E. "Is technology becoming a science?" Scientometrics, 7, 369-381, 1985.

117. The co-citation models prepared for the ABRC Science Policy Study cost about £20,000 each.

contexts[118].

Chapter Three "Bibliometric Analysis of Key Papers on Pesticides and Biological Control" utilises: paper counts and publication analyses, journal-journal citations.

Chapter Four "Research Trends Based Upon a Content Analysis of a Core Journal - The Journal of Economic Entomology 1910-1985" utilises: paper counts and content analysis.

Chapter Five "Historical Trends in Insecticide Research: A Case Study", utilises: paper counts in abstract journal.

Published Papers in Appendix

Rothman and Woodhead (1968) utilises paper counts.

Rothman and Woodhead (1972) utilises paper counts.

Rothman and Lester (1985) utilises references in an abstract journal.

Rothman and Aston (1985) utilises journal-journal citations.

Healey, Rothman and Hoch (1986) utilises co-citation, co-word and productivity methods.

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[118]. In the ABRC Science Policy Study, see Healey, Rothman and Hoch (1986), Rothman (1985) and the FAST Biosociety Programme, Rothman (1984).

CHAPTER 2

INSECTS, INSECT PESTS AND INSECT PEST CONTROL

Entomology is the scientific discipline that studies insects. Its subject matter deals with all aspects of insects, their classification, morphology, physiology, genetics, ecology, behaviour and so forth. It is therefore one of those peculiar disciplines whose nature causes it to bring to bear on its subject the knowledge and skills of other disciplines. It is a basic science, however, because its object of study - insects - is often entangled with Humanity it has great practical implications. One can speak, therefore, of "applied entomology"; this application occurs in various areas of human activity and consequently is given different names. Thus one finds, for example, agricultural entomology and medical entomology. These applied entomologies are mostly concerned with identifying and controlling pests. There are exceptions, such as apiculture, the branch of agriculture concerned with bees. Most entomologists are applied entomologists.[1]

Another way of looking at the insect-society nexus is economic: what economic good and economic damage arises. It is this with which economic entomology is concerned, though because of a historical convention it is separated from medical entomology. Thus economic entomology can include applied entomologies that some might designate by other names, e.g. agricultural entomology. In practice, economic entomology seems to be the general term in the USA, but agricultural entomology is often used in Britain. I do not think the name matters

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[1]. Wigglesworth (1976)

too much if one is able to identify the subject matter and problematics of the discipline. I prefer economic entomology because it is widely used by the dominant practitioners, and because it stresses the economic underpinning of the applied science. To summarise, economic entomology is applied entomology, generally concerned with the identification, study and control of insect pests (mites, which are Arachnids not insects, are also included) in agriculture and stored products. Most practitioners are concerned with insect suppression, often in a rather narrow fashion that contrasts with the potential intellectual and technical breadth of their discipline. A leading American economic entomologist[2] has said of his colleagues that they often "... select a given approach for insect control ... concentrate on the development of one approach to the solution of insect pest problems ... (and) often show little interest in any other approach".

To gain a deeper appreciation of the nature of economic entomology it is necessary to say something about insects as a life form, they are the dominant animal type, and also something about insects as pests. In this chapter I, therefore, define insects and those characteristics which cause them to make contact, especially conflictual, with Humanity. Then I outline how insects are defined as pests in the light of the damage that they create, and finally I provide a discussion of the technological possibilities available for controlling insect pests. With respect to the latter discussion, technological possibilities, I might be accused of adopting too narrow an approach, for surely economic entomology is more than that. To some extent that is fair comment and one has to say that in a study such as this one has to set certain practical boundaries, even to the extent of a degree of over-

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[2]. Knipling (1979)

simplification of a complex situation. On the other hand, I would argue that techniques actually represents much economic entomology as it is practiced, historically much of economic entomology research has been research into highly empirical techniques of pest suppression.

Insects

In this study I am examining the research trends in economic entomology; that is the applied science dealing with the pest problems created by insects and related arthropod groups[3]. It will be necessary, therefore to define precisely what we mean by an "insect". To do this I need to make a short digression into zoological classification. The Animal Kingdom can be divided into three unequal sections, or subkingdoms, the Protozoa, Parazoa and Metazoa. In turn these are further sub-divided into major groups, whose exact evolutionary relationships are continually in dispute. For example, the Metazoa are divided into Diploblastica and Triploblastica, their primary difference lies in the fact that the latter possess a third primary embryological layer, the mesoderm, as well as ectoderm and endoderm primary layers. Within the Triploblastica are found the great majority of animal species.

The Triploblastica contain two main stocks[4] - the annelid superphylum which contains the annelids (7,000 species), molluscs (80,000 species) and arthropods (863,000 species) and the echinoderm superphylum which contains the echinoderms (4,000 species), protochordates (2,000 species) and chordates (37,000 species). The Arthropoda, to which the insects belong, is the largest phylum of the animal kingdom. It includes several classes besides the Insecta; the

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[3]. e.g. Mites and ticks (Order Acarina) for convenience are considered entomological problems.

[4]. Borradaile et al. (1958) p.1.

Crustacea (i.e. lobsters, shrimps, crabs, etc.), the Arachnida (i.e. scorpions, spiders, mites, etc.), the Diplopoda (millipedes), the Chilopoda (centipedes), the Onchychophora, the Trilobita (extinct group), the Pauropoda, the Symphyla, the Tardigrada (Bear Aminicules) and the Pentastomida. The evolutionary relationships between these classes are extremely controversial[5], however, despite wide differences in structure, they agree in certain fundamental characteristics.

> "The body is segmented and invested with a chitinous exoskeleton. A variable number of segments carry paired jointed appendages exhibiting functional modifications in different regions of the body. The heart is dorsal and is provided with paired ostia, a pericardium is present and the body cavity is haemocoele. The central nervous system consists of a supra-oesophageal centre or brain connected with a ganglionated ventral nerve cord. The muscles are composed almost entirely of striated fibres and there is a general absence of ciliated epithelium. No animals other than Arthropoda exhibit the above combination of characters".[6]

Imms defines the Insecta (or Hexapoda) as

> "tracheate Arthropods in which the body is divided into head, thorax and abdomen. A single pair of antenna (homologous with antennules of the Crustacea) is present and the head also bears a pair of mandibles and two pairs of maxillae, the second pair fused medially: the thorax carries three pairs of legs and usually one or two pairs of wings. The abdomen is devoid of ambulatory appendages, and the genital opening is situated near the anal extremity of the body. Postembryonic development is rarely direct and a metamorphosis is usually undergone".[7]

Figure 2.1 shows the general organisation of a primitive winged insect.[8]

This basic structure has been extremely successful, perhaps in numbers of species the most successful of all known animal species.[9] The exact number is not known; Imms quotes a figure of 700,000 adding

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5. Imms (1957) pp.3-5.

6. Imms (1957) p.3.

7. Imms (1957)

8. Buchsbaum (1948) pp.277 and 281.

9. Imms (1957) p.7.

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"but it is doubtful whether this number represents even one fifth of those existing today".[10] [11] Sabrosky[12] gives a range of estimates from 625,000 to 1,500,000 insect species, of these about two-fifths are beetles, and moths and butterflies, ants, bees, wasps and true flies comprise another two-fifths. Table 2.1[13] provides a more detailed breakdown. Below I have abstracted some of the many facts about insect numbers provided by Sabrosky.

In his Systema Naturae (1758) C. Linnaeus listed 4,379 animal species of which 1,937 were insects. By the mid 19th century 100,000 species of insects were known. By 1900 the total was 300,000, and more than doubled in the following fifty years. Some 6-7,000 species are described annually.[14] There are about 20,000 insect species in the British Isles.[15]

The actual number of individual insects is an unanswered, perhaps unanswerable, problem. In any case it would be subject to enormous seasonal variation. However, samples have been taken which give us some idea. For example, Agriotes beetle larvae (i.e wireworm) populations have been estimated to be 3 - 25 million per acre.

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10. Imms (1957)

11. De Bach (1964) quotes Kerrick's estimate that only 10% of the Ichneumonidae of tropical Asia, Africa, tropical America and Australasia are known, and if the group was as well known as are Colleoptera there would be 500,000 described species rather than 50,000, and that there could be as many as one million Ichneumonidae in the world. p.10.

12. Sabrosky (1952) p.1.

13. USDA Yearbook (1952), p.6.

14. Sabrosky (1952)

15. Kloet and Hincks (1945) p.XVII include in their lists of British insects "4,714 genera and 20,024 species, to which may be added 53 genera and 220 species which are doubtful or casual".

Table 2.1 Relative Size of the Various Insect Orders as Shown by the Number of Species, as at the end of 1948.

Order	Number of Species in World
Protura	90
Thysanura	700
Collembola	2,000
Ephemeroptera	1,500
Odonata	4,870
Orthoptera	22,500
Isoptera	1,717
Plecoptera	1,550
Dermaptera	1,100
Embíoptera	149
Psocoptera	1,100
Zoraptera	19
Mallophaga	2,675
Anoplura	250
Thysanoptera	3,170
Hemiptera	23,000
Homoptera	32,000
Neuroptera	4,670
Coleoptera	276,700
Strepsiptera	300
Mecoptera	350
Trichoptera	4,450
Lepidoptera	112,000
Diptera	85,000
Siphonaptera	1,100
Hymenoptera	103,000
Total	685,963

From various sources, chiefly the USDA Yearbook for 1952, p.6; the figures in most cases are approximate.

A.S. Pearse[16] calculated that forest soils in North Carolina contained 124 million animals per acre of which 90 million were mites, 28 million springtail (an insect) and 4.5 million other insects. Hoffman[17] found 425 million arthropods per acre in Pennsylvanian forest soils. Various 'counts' have been made of the numbers of ants, bees and termites in a colony. Large ant nests in Europe contain on average 150,000 - 200,000

16. Pearse (1946).

17. Hoffman et al. (1949).

individuals. A colony of Nasutitermes surinamensis was reported[18] to contain 3 million individual termites. A good bee colony is said[19] to produce about 200,000 bees per year.

Of course, the figures for individuals contained in 'outbreaks' and 'swarms' are stupendous. One Nebraskan locust swarm was reported[20] to be half a mile in height, 100 miles wide and 300 miles long. It was calculated to contain some 124 billion locusts. Not surprisingly the Texan record is even more impressive. In 1921 C. H. Gable and W. A. Baker

> "recorded[21] a migration of snout butterflies, Libytheana bachmanii, which were so numerous that an average of about 1,-250,000 of them per minute flew across a front 250 miles wide. At the main observation point the migration continued at the same level of intensity for 18 days".[22]

Such numbers can only be provided by an extremely potent reproductive system; great reproductive capacity is common amongst insects.[23] For example, the descendants of a single pair of house flies, if all lived and reproduced would, in a breeding season lasting from April - August, make a grand total of 1.91×10^{20}. Aphids are even more prolific under similar conditions from March to October. A single female (many are parthenogenic) would produce 1.56×10^{24} descendants. Honey bee queens may lay up to 2,000 eggs per day, but the egg laying record is probably held by termites. Macrotermes bellicosus queens have been recorded as laying 43,000 per day. The

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18. Sabrosky (1952) p.5.

19. Sabrosky (1952) p.5.

20. Sabrosky (1952) p.5

21. Gable and Baker (1922)

22. Sabrosky (1952) p.4.

23. Sabrosky (1952) p.3.

phenomenon of polyembryony is found in certain parasitic insects (i.e. an egg once laid continually divides to produce more eggs), and in some insects 1,500 - 2,000 insects could result from a single egg. L. O. Howard[24] found nearly 3,000 small parasitic insects emerging from a single caterpillar, in which perhaps no more than a dozen eggs had been laid. Polyembryony in parasitic insects is a process of obvious importance to biological control.

Size is extremely variable within the species of insecta. Amongst Coleoptera (beetles) Megasoma elephas attains a length of 120 mm and Macrodontia cervicornis (including the mandibles) 150 mm. Pharnacia serratibes, a Phasmid (Stick Insect), can exceed 260 mm in length. The Lepidopteran Erebus agrippina has a wing span of 280 mm. At the other extreme certain Coleoptera (fam. Ptilliidae) do not exceed 0.25 mm and some egg parasites (fam. Mymaridae) are even smaller.[25]

We can see, therefore, that the insect's strength does not lie in size. Its success is owed to an immensely flexible basic design, combined with extreme fercundity, which enables the various insect species to range over all the terrestrial and fresh water habitats. Thus we need not be surprised that Homo sapiens, with a similarly wide terrestrial range - owed to flexibility and mutability of cultural behaviour patterns instead of morphological patterns - forms many ecological relationships with insect species. All too often such interactions are deemed inimical by man and an insect pest is born. Figure 2.2 summarises the various kinds of inimical interactions between man and insects.[26]

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[24]. Howard (1931)

[25]. Imms (1957) p.7.

[26]. Clark 91967) figure 41. p.192.

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The Concept of "Pest"

The concept of "pest" has no objective basis in a strictly scientific sense, it is a social construct based upon the perception of the relationship between the species user of the term (humankind) and another species. A wide spectrum of socio-economic and cultural factors may determine whether or not a particular species falls into this category. Often there is no consensus as to whether or not certain species are pests.

Beirne[27] defines pests as "... living organisms that we regard as causing harm to our health or well being ...". However, he notes that it is not usual to include within the ambit of the term those harmful organisms studied by medical, veterinary and marine scientists. The term does not cross certain professional boundaries which reflect social divisions of labour in science and technology. Other conventions which he notes have their roots, perhaps, in the historical evolution of applied biology. Thus nematodes harmful to plants are pests, whereas those which parasitise man and other vertebrates are not so described; micro-organisms which cause plant diseases are pests and those which cause human and animal disease, or rot our products, are not. Clearly, there is no logical reason based upon biological science why this should be so. Distinctions such as those adumbrated above result from customs and practices attending those specialist groups which first noted and examined the changing behaviour of the species involved.

This leads to a further observation by Beirne[28] that the use of the term "pest" reflects particular forms of knowledge and belief as to

[27]. Beirne (1969) pp.12-13.

[28]. Beirne (1969).

the nature of the relation between species x and humankind. The human interest at stake may of course be economic, and the definition of pests used by L. R. Clark et al. neatly encapsulates that viewpoint "... species whose existence conflicts with people's profit, convenience or welfare".[29] The terms "profit", "convenience" and "welfare", in so far as they have any scientific content, belong to the social sciences, and, thus, it is our contention that pests are socially determined. Now whilst this might at first sight seem obvious to some, and therefore of little significance, it becomes highly significant when we remember that the determination and elimination of pests, and most of the discussion about them, is done by specialists who believe that they owe nothing to the social sciences, and that they are "hard" scientists. Thus we have a socially determined object manipulated by scientists/technologists who believe that political debates about the pest - society relationship and its social and environmental impacts ought to be determined by "scientific facts". A science whose object of study is pests differs, in ways which are not immediately clear, but upon which we hope to throw some light, from those sciences whose objects are natural phenomena of nature. We are, of course, familiar with the philosophical view that such phenomenal existence is relative (and do not wish to enter that debate here), nevertheless, we hold to our distinction; for stars, atoms and cells are not created on the basis of "convenience", "welfare" or "profit" of those external to the scientific discipline in question whereas "a pest" is.

In examining the dynamics of research and development into pests and their control we are examining also perforce certain dynamics of

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[29]. Clark et al. (1967) p.182.

economic, political and cultural change. The American term for the applied science of insect pest control - "economic entomology" ingenuously recognises this to some extent. Indeed, apart from atomic power, probably no other single technology has led to such political furor and bitter recrimination as the debate surrounding the use of certain synthetic organic insecticides. Indeed DDT has become an archetypal symbol of technology "gone wrong". Therefore, I believe that an analysis of insect pest control techniques should throw up some valuable insights into the relationship between science, technology and society. The identification of those forces which caused chemical control methods to be more rapidly and more intensively innovated than biological control methods, is of particular importance. Such is the intensity of feeling generated between the protagonists in the chemical versus the biological control debate that I feel that the history of R & D in the field, in so far as it exists, cannot but reflect the debate. The extent to which the debate has caused a partisan distinction in such histories is hard to discern. Firstly, despite the "debate" over insecticides, there are few histories of economic entomology and secondly, most of those which exist might, with no disrespect intended, be termed "old fashioned" in that they are "internalist" and lie outside the new schools of history of science and technology which have tried to break out of the internalist-externalist dichotomy which long dominated historical studies. Thirdly, and finally, they - like most historical studies - adopt a qualitative approach and contain relatively little quantitative data and analysis.

This thesis therefore seeks to produce a history of R & D in economic entomology which, whilst being internalist in that it starts from the applied scientific discipline of economic entomology, seeks to identify the discipline's social and economic relationships with nonscientific institutions etc. and, in an attempt to increase its objectivity, provides a quantitative analysis of R & D trends. The latter is novel and necessitated the gathering of much original data which it is hoped will provide a sound basis for further historical studies in the field; especially for those who are able, as I am not, to go beyond scientific practices and theories of economic entomology to examine in depth actual agricultural and agri-industrial applications of insect pest control. That is to say, this thesis is bounded by its commitment to mapping and analysing R & D trends in the science of economic entomology, however, I shall try to make appropriate connections with agricultural and industrial practice, but will do so in the knowledge that beyond my self-imposed frontiers, I am venturing on less clearly mapped terrains

The Creation of Pests

Figure 2.2 illustrates the various situations, with examples, in which man-insect interactions may cause the creation of pests. Not every human-insect interaction results in the insect being labelled a pest. In most cases the damage, if there be any, is regarded as negligible or remains unnoticed and so the insect is considered merely a potential pest. What then turns a potential pest into a pest? According to Clark et al.[30] this occurs in four ways:

a. "Entry of a species into previously uncolonized regions".
   Such movements can be of three kinds:
   i. Actual colonisation of a new region by a species which owes nothing to any human agency
   ii. Deliberate distribution of a species e.g. Eichhornia

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30. Clark et al. (1969) p.183.

crassipes (the water hyacinth), a native of tropical America, was moved by garden lovers, to South Africa. It is now a major pest, infesting rivers in Africa from Zaire to Sudan.

iii. Accidental carriage of species by international travel etc. particularly with mass migrations such as that from Europe to America, New Zealand and Australia. These form a major group of pests, e.g. Diprion hercyniae (the European spruce sawfly) now a major pest in Canadian forests.

b. "Changes in the characteristics of species that did not previously compete or otherwise interact directly with man".
For example, an unknown species of cynipid wasp suddenly appeared in Japan, being noticed first in 1941. By 1950 - 55 it had spread over the whole S. W. half of Japan causing severe damage to chestnut trees. It is believed to be a recently evolved species.[31]

c. "Changes in man's activities or habits, which make him sensitive to the existence of species to which he was previously indifferent".[32] In such cases an organism becomes a pest without there being any change in its characteristics or abundance. A forest may always have suffered the depredations of a particular species but until man decided to exploit the forest that species would not be regarded as a pest. Clark et al. note that

"Increased injuriousness follows man's need for greater returns or for new resources. New problems arise constantly in this way because higher demands are placed on the quality of natural products, because technical progress creates new possibilities of conflict with previously negligible species, or because changing social and economic outlooks make even relatively harmless insects

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[31]. Nakamura et al. (1964) and Miyashita et al. (1965).

[32]. Clark et al. (1969) p.183.

increasingly objectionable".[33]

Beirne writes that

"Whether or not an organism is regarded as a harmful pest at any place or time depends more on the amount of harm that we tolerate than on the amount that it actually does".[34]

This tolerance point can be termed the economic threshold. Suffice to say at this point that the economic threshold's position "varies widely between victims, places and people" owing to an interaction of technical, economic and psycho-social factors.

d. "Increases in the abundance of species whose interactions with man were previously negligible because of the low numbers in which they occurred".[35] There are three reasons why this might occur: (i) the supply of a previously limiting resource e.g. food, is increased, (ii) the frequency or severity of inimicable environmental factors is reduced, (iii) a combination of (i) and (ii).

Human activity leads to environmental changes which increase or decrease the favourability of the environment for certain species. Agricultural activity, which is concerned with producing a concentrated and high population of useful plants and animals, generally replaces a previously varied ecosystem with a less diverse one. In this agricultural process we also find an increase in the numbers of organisms which are, or became, associated with crop species and in the process became pests. This happens in two ways:

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33. Clark et al. (1969) p.184.

34. Beirne (1967) p.14.

35. Clark et al. (1969) p.183.

(i) The disruption of the previous ecosystem leads to the loss of species which previously regulated potential pests. The loss of hedgerows can reduce the local capacity for supporting insectivorous birds and lead to increases in the population of some insects. Sometimes measures taken to control a pest may be killing off natural control agents leading to a resurgence in the numbers of an existing pest or creation of a new pest e.g. the red spider mite in British orchards.[36]

(ii) The development of monoculture leads to an extremely abundant food supply for organisms that feed, or become adapted to feed, on the crop. Such organisms find mortality factors resulting from food shortage, food and mate searching vastly reduced and are thus able to increase more rapidly their numbers.

Situations arise, of course, in which an increase in food supply is combined with a decreased effectiveness of natural enemies e.g. the Australian leafroller (Epiphyas postvittana) in Australian apple orchards.[37]

It can be seen that each of these methods of pest creation may contain a large human element and Beirne[38] goes so far as to state that "... the vast majority of pest problems are caused by man". However, such a bold statement is not universally accepted. Clark et al. argue that frequently the process of pest creation is far more complex than might be concluded from the examples we have so far given. For

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[36]. Collyer (1953).

[37]. Grier (1965).

[38]. Beirne (1967) p.20.

example, studies[39] have shown the Mirid pests of cocoa in Ghana - which are known locally as "Sankonnabe", whose literal translation is "go back to oil palm growing", (the alternative cash crop in Ghana) - create their havoc in association with five other elements; man's use of cocoa, a ubiquitous fungus, polyphagous mealy bugs, plant viruses and the susceptibility of cocoa under cropping conditions. They believe that the origin and nature of cocoa degeneration in West Africa demonstrate:

> "Firstly, the situation is seen to be the outcome of a network of natural events which man could not:
> **anticipate**, because what might appear in hindsight to be a consistent causal change is actually no more than the highly improbable, cumulative result of an infinite succession of random steps:
> **recognise**, before the situation had developed enough to reveal its full economic implications and biological complexity; or
> **avoid**, because complete prevention could have been ensured only by keeping cocoa out of West Africa.
> Secondly, of the conditions that contribute towards establishing the degenerative situation as an economic problem, some pertain to the specific characteristics of the six life forms involved. Those conditions are **absolute** and provide the 'constants' of the problem. Their economic significance as such is qualified, however, by conditions of another kind, whose nature is circumstantial. The latter act to determine the seriousness of the problem in space and time. Their effects in maximising or minimising the economic consequences of the regenerative situation result from the functioning of the life systems whereby cocoa and its pests co-exist under man's influence ...".

It is on the evidence of such studies that Clark et al.[40] conclude that man

> "Cannot hope to avoid pest situations ... (only) ... strive to minimise their repercussions on his economy by manipulating the life systems of the species concerned",

I have quoted these economic entomologists at length to emphasise the socio-economic determination and inevitability of pests. It is now necessary to say something about the social and economic perceptions of

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39. Tinsley (1964).

40. Clark et al. (1969) p.190.

pests that drive us into a never ending struggle with them.

The Necessity of Insect Pest Control

Insects can be classified[41] into three kinds of pests according to how they related to an "economic threshold".

i) Permanent pests normally causing regular economic harm

ii) Occasional pests sometimes, but not regularly, causing economic harm

iii) Potential pests do not cause harm, but have the capacity to do so should changes occur in the environment and/or the nature of the economic threshold.

Pests can be further classified into direct and indirect pests. Direct pests damage those parts of their victims which man requires, whereas indirect pests damage parts which are not used by man. However, indirect pests may have an overall adverse effect on their victims. Sometimes the term indirect pest is used to describe an organism which merely facilitates another organism's ability to cause damage e.g. a disease vector.

When a pest is identified as such it is not easy to give a figure,[42] or rather a reliable figure, to the harm which it causes. Such problems are magnified because, while many pests exert their damage indirectly they may, as we have noted in connection with cocoa degeneration in West Africa, form parts of a complex of interactions between many organisms. Furthermore, it is by no means easy to separate out the harm caused by the pest from that caused by other

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41. Beirne (1967) pp. 15-16.

42. A rough indication of the number of insect pests is given by the Commonwealth Institute of Entomology cumulative card index which in the early 1970s contained 70,000 species. Price Jones (1974) p.179.

factors such as poor husbandry, inclement weather etc. I shall cite the generally held views regarding the scale of damage caused by insects not because I believe they are perfect, but because they justify many of the activities of those who sought to control pests. However, from a strictly scientific point of view, i.e. whether the figures accurately reflect reality rather than symbolise a 'call to action', we believe Beirne[43] to be correct when he says

> "Monetary estimates of the value of pest losses can be virtually meaningless because of the great number of variable that are involved... The cost of pest damage is the cost of prevention, which can be measured approximately, plus the cost of unprevented losses, which is unmeasurable".

I cannot here discuss in detail the problems of estimating insect pest damage, a highly specialised topic. I shall confine myself to listing some of the estimates that are to be found in the pest control literature.

It is convenient to list damage figures under three headings (a) Crop damage (b) Human health (c) Damage to goods and materials, etc.

a. Crop damage

Cramer[44] has produced a most detailed survey of annual world crop production losses caused by insect pests, plant diseases and weeds.[45] He does not claim 'absolute accuracy' for his figures, but considers, however, his methods are "perhaps appropriate for arriving at the orders of magnitude within which the real values must be sought".

The United States has the longest record of attempts by individual

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[43]. Beirne (1967) p.18. see also Strickland (1956) and Parker (1942).

[44]. Cramer (1967) p.3.

[45]. Earlier surveys include Mayer (1959), who tabulates historical records going back to the 6th dynasty in Egypt (2,625 - 2,475 B.C.) . The Bible contains numerous references to pest damage to crops, some of it qualitative e,g, Haggai 2: 16-17.

countries to keep an annual record of pest damage to crops. In 1904, Marlatt estimated[46] that annual crop losses due to pests up to harvest were seldom less than 10%, and total insect damage to plant products, including those in storage were rarely under 14%. Given a value for agricultural produce in the order of $5,000 million at that time Marlatt was able to claim losses "exceeded the entire expenditure of the National Government". The USDA has for nearly 50 years published regular annual loss figures - see table 2.2[47] below. These losses have been said[48] to equal the wastage of an "acreage more than the entire area of California ... (and) insects alone nullify the work of a million men, 10% of the country's agricultural labour force".

TABLE 2.2

ANNUAL USA AGRICULTURAL LOSSES DUE TO PESTS AND DISEASES

Year of USDA publication	Losses (millions of $) in USA due to: Insect pests	Plant diseases	Total loss
1937	491	298	789
1954	1,066	2,914	3,980
1965	3,685	3,251	6,936

46. Marlatt (1904), later studies claimed that these figures were under estimates qv. Decker (1964) and USDA (1965).

47. Cramer (1967) p.22. These figures are discussed by: Wood (1953), USDA (1955), Gentry (1958), Yarwood (1962), McNew (1963), Mrak (1963), Barnes (1964), Decker (1964), Le Clerg (1964), McClellan (1964, Chiarappa et al. (1972).

48. Aldrich (1963).

Figures for other countries include Canada[49], losses equal $US 750 million, 19% of production. United Kingdom[50], 10% crop losses from pests and diseases, value about £140 million. In India[51] losses are estimated to be 10 - 30%, value £500 million. In Germany, 15% losses,[52] value DM 3,000 million[53]. Table 2.3[54] lists some of the estimates of losses in world agricultural production. The figures of Robinson, Schulze and Tielecket roughly agree in their order of magnitude, but those of Gunther and Jepson and Maier-Bode are higher, bearing in mind that they relate to insect damage only. USDA figures indicate that 35% of U.S. crop damage is caused by insects, thus if we assume this proportion is similar on a world scale we can obtain a <u>total</u> pest loss figure in the region of $57,000 million[55] for the Gunther and Jepson and Maier-Bode estimates. Cramer thinks that estimates of world losses "are based more on agreement of data in the literature rather than well-founded analyses".[56] Nevertheless, there seems little doubt that the pest-created losses are enormous, running into thousands of millions of dollars and that if they were significantly reduced the world food supply could, economic factors willing, (such figures need to be seen in relation to growers' current

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49. Brown (1956).

50. Lavington (1962) p.15.

51. Reddy (1967) p.147.

52. Morstatt (1929).

53. Tielecke (1963)

54. Cramer (1967) p.24.

55. Loc. cit. p.27.

56. Cramer (1967) p.25.

prices), be increased.[57]

TABLE 2.3

ESTIMATED LOSSES IN WORLD AGRICULTURAL PRODUCTION

DUE TO PESTS AND DISEASES

Author	Estimates Global losses due to Pests & Diseases to crops.
Ling (1961)	20% up to harvest 10% in storage
Robinson (1963)	15-30%, $27,500 - 55,000 million
Schulze (1964)	$30,000 - 60,000 million
Tielecke (1963)	$22,000 million
Gunther & Jepson (1960)	$21,000 million (only insects included)
Maier-Bode (1966)	$20,000 million (only insects included)

b. Insects and Human Health

Probably 10,000 kinds of mites, ticks and insects infect man directly or indirectly with disease.[58] Most are only occasional or accidental carriers. Insects transmit diseases in many ways:

i. By their presence alone, causing damage to body tissues either directly e.g. screw worm larvae boring through the body or indirectly by itching or allergies e.g. lice bites, wasp stings etc.

ii. Mechanical carrying of disease laden material which may be deposited on food through insects crawling, vomiting or defecating on it e.g. housefly.

iii. Disease vectors, in this case there is a special, often

57. ICPP (1983) contains several papers which discuss Cramer's study - Ahren et al. pp.65-73, Reed, pp.74-80 and Teng and Shome pp.81-89. These show that the global database is still imprecise and that Cramer (1967) still remains the key, but historically dated, work.

58. Bishop and Philip (1952)

obligatory, relationship between insect, disease organism and man e.g. the plague-rat-flea-man relationship or the Plasmodium (malaria)-anopheline (mosquito)-man relationship. Insects carry many types of disease organisms, including viruses, bacteria, protozoa, tapeworms, roundworms. Not surprisingly, the disease-vector-man relationships are often extremely complex; the unravelling of such relationships have often been regarded as landmarks in the development of parasitology.

Among the diseases spread by insects are: malaria, yellow fever, plague, encephalitis, eliphantiasis, verruga or Oroya fever, leishmaniaisis, anthrax, sleeping sickness, cholera, yaws, trachoma, myiasis, trench fever, Q fever and very many others.

Obviously control of the insect vector is an important aspect of controlling such diseases amongst the human population. Table 2.4[59] shows how control of anopheline mosquitos, largely by means of DDT, led to enormous reductions in the incidence of malaria.

Table 2.4 MALARIA MORBIDITY IN COUNTRIES BEFORE AND AFTER CONTROL OR ERADICATION OF MALARIA

Country	Year	Number of cases
Cuba	1962	3,519
	1969	3
Venezuela	1943	817,115
	1958	800
India	1935	Over 100,000,000
	1969	286,962
Bulgaria	1946	144,631
	1969	10
Italy	1945	411,602
	1969	37

59. Based on Wright et al (1972) p.80.

c. Damage to goods and materials etc.

Insects, as a group, are able to digest a wide range of substances, e.g. wood, plant products (such as cotton), silk, and keratin (wool and fur). They are, therefore, in a position to cause great damage to many products including clothes and structures. For example, perhaps over 70% of buildings in Britain are infested by Anobium punctatum (common furniture beetle) and in 1966 over £10 million was spent to protect buildings against insects and fungi. Hicken[60] believed, at that time, that the total loss was "... many times that figure". There is a further specialised branch of applied entomology, or rather technology, called commercial entomology which deals with such problems.

The Control of Insect Pests[61]

The previous discussion has surely indicated sufficient reason for mankind to attempt to control insect pests. However, the actual implementation of a system or strategy of pest control presupposes a motivation to do so, which in turn is derived from socio-economic circumstances and state of knowledge. Firstly, one requires some standard which one can compare to the situation under consideration, such standards have socio-economic and 'knowledge' components. One must know, or rather believe one knows; the causes of the adverse situation, how they could be remedied, and the means whereby the remedy could be implemented.

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60. Hicken (1967) p.10

61. For an excellent and suggestive discussion of the general implications of the concept of 'insect pest control' see Clark et al. (1969) pp.191-204, and Beirne (1967) pp. 25-42.

This pest appreciation process has been divided by Clark <u>et al.</u>[62] into three major stages, which I paraphrase below:

1. The recognition of a pest situation. This involves the identification of the causal agent, together with its characteristics and attributes etc. For example, the nature of the injury caused by the pest to the target species or product. The range of such effects, in space and time, also has to be determined.
2. The practical assessment and functional analysis of the pest situation. It is at this stage that many of the weaknesses of current practices lie. The determination of the scale of control effort any pest situation merits is not easy. There are many imponderables. Some relate to ignorance of nature, others of society, and all to the peculiar and ill conceived nature of the nature/society complex. Practitioners claim to work out the economic effects of the damage resulting from the pest situation; in that process there are ideological as well as scientific factors at work. Further, the threshold of appreciation has a biological component, pest abundance, and an economic component, the economic threshold. As we saw in the case of cocoa degeneration in West Africa, a pest situation can, and often does, involve the interaction of many species. Thus much effort is put into evaluating the contribution of individual species to the damage in the hope of identifying the key pest(s) on which to concentrate one's means of control. Such a highly empirical approach in part reflects a socio-economic pressure - the profit imperative and its related ideological connotations, and in part

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[62]. Clark <u>et al.</u> (1969) p.191.

the current level of ecological science (in its practical form as applied to insect pests this is referred to as bionomics).

The analysis of the evolutionary and ecological aspects of a pest situation is limited by both willingness and ability. Practitioners argue that successful investigations in those aspects will provide a means for predicting future patterns of injury resulting from a given pest situation, i.e. the variability of injury in space and time. Such predictive visibility would encourage the proper timing of control measures in preparation for future increases in injury and pest numbers.

3. The definition of the aims and purposes of control. This phase has to draw on the data derived during stages 1 and 2. It involves answering such questions as: What is the maximum level of injury that is tolerable?[63] Which of the conditions determining injury to the target species or product can be modified, and how? Finally what strategy, or "pathway(s)" leading to reduction in the injuriousness of insect pests[64] should be adopted?

Broadly speaking, four strategies are identified by Clark et al.[65], two are directed chiefly towards the victim, or target, and two to the pest.

i. Enable the target to evade pest damage by moving it out of range.

ii. Eliminate those characteristics and properties of the target which make it susceptible to pest damage.

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63. Clark et al. (1969) p.196 observes "The extent to which man is prepared to tolerate the existence of a pest has never been evaluated in a strictly objective way".

64. Clark et al. p.197.

65. Clark et al. p.197.

iii. Suppress properties and characteristics of the pest which make it injurious to the target.

iv. Reduce the numbers of the pest to a level below which it ceases to be injurious.

All these strategies have been investigated for use, but only (iv) reduce pest numbers, is widespread and systematically studied; it is in fact what most practitioners mean by pest control. Figure 2.3[66] indicates the general means by which this can be done either by altering biological properties of the pest itself, or of its environment. These methods can be further classified[67] according to their effectiveness based on the criteria of "long term reliability" and "frequency and intensity of human intervention". Figure 2.4[68] summarises this classification. There is an increase in efficiency of pest control procedures from

> "bottom left to top, and from left to right, in the chart. The upward progression is straight forward, because it reflects increased economy of maintenance, following generally greater capital outlay in research and development. The horizontal trend requires some comment. Basically procedures in column A are the least reliable, because they allow subject populations the most chances of escaping containment. Procedures in column B each represent, in the ecological sequence, the most immediate improvement on their opposite number in column A ... Procedures in column B are rated 'satisfactory' in long term reliability ... less liable to breakdown following ecological or evolutionary changes in the co-determinants of abundance than are procedures in column A. They are less secure in this respect than the procedures in column C ..."[69]

This brief synopsis of control methods has indicated their highly empirical nature, often deriving from an interplay of socio-economic determinants and ignorance. Questions about pest control can be

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66. Clark <u>et al.</u> (1969) fig. 42. p.199.

67. Clark <u>et al</u> pp. 200-204.

68. Clark <u>et al.</u> fig. 43. p.201.

69. Clark <u>et al.</u> (1969) p.203-204.

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divided into nine main categories says Bórne.[70]

> "Five of them relate basically to actions of people: (1) who applies the controls; (2) why; (3) against what; (4) in what ways; and (5) with what results. Three of them relate basically to properties of the controls themselves: (6) what are they; (7) what do they do and (8) how do they do it ... a final one (9) ... (relates) to combinations of people's actions and control properties by relating both to the categories of each and to natural regulatory factors".

In this section we have attempted to answer questions (1) to (4), although question (1) has been answered by a cursory assumption that "man in general" controls pests. Some specific aspects of question (1) "who applies the controls", with particular respect to R & D investigations rather than agricultural practice, will be dealt with in later discussions. This will also throw more light on question (4) "in what ways". Questions (6) to (8) will form the subject matter of the next section on "technological possibilities". Detailed separate discussions of issues raised by questions (5) and (9) are, unfortunately, beyond the scope of this study, but will perforce enter my concluding discussion.

Technological Possibilities

The Insecta as an order are able to impinge upon mankind in an enormous variety of ways, many, as we have seen, are damaging to man. However, they are by no means invulnerable and a wide array of possible means of controlling them has been developed. So far we have only indicated these in general terms, (see figures 2.3, 2.4) but in this section they will be examined in detail. We are here concerned with the properties of the various techniques of control in order to answer those questions raised in the previous sections: what are they?; what do they do? and how do they do it?

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70. Bórne (1967) p.26.

TABLE 2.5

SUMMARY OF MAJOR AVAILABLE AGENTS AND METHODS FOR INTEGRATED PLANT PROTECTION

I CHEMICAL AGENTS FOR CROP PROTECTION

acaricides
insecticides
fungicides
rodenticides
herbicides
nematicides

II PHYSICAL TECHNIQUES

heat
mechanical

III BIOTECHNICAL TECHNIQUES

1. Physical

sound
light

2. Chemical Stimulants

hormones
pheromones
repellants
attractants
feeding deterrents
feeding stimulants

IV BIOLOGICAL TECHNIQUES

autocidal techniques
importation beneficial species
encouragement beneficial species
microbiological control
biological weed control

V CULTURAL TECHNIQUES

soil preparation
fertiliser application
crop varieties
pruning

Based on Franz (1972) fig. 1. p.2.

There are three kinds of control agent (i) biological,[71] (ii) physical and (iii) chemical. The biological category may be further subdivided into biological, biotechnical and cultural categories. This has been done in Table 2.5 (an alternative, but conceptually less well organised classification is shown in Table 2.6. It does, however, list several methods omitted in Table 2.5. Table 2.7[72] takes this classification a stage further by indicating the historical development of the various methods using 1939[73] as a 'watershed', and it also subdivides several of the categories in Franz's[74] classification, as well as adding integrated control as a separate category. It can be noted that the last four to five decades have seen a vast development in our anti-pest armoury. The reasons for the particular selection, both at the level of research and that of field control, from this armoury, throws light upon the social relations of science and technology. This classification in a modified version (sections concerned with "problems of insecticides" and "biological" research were added) was utilised to analyse research trends (see discussions in Chapter 4).

When considering such classifications one must heed Beirne's[75] stricure that

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[71]. The definition of biological control as the use of any living organisms to control pest-caused damage is not universally accepted, sometimes the term is confined to control of pest populations by predators, parasites and pathogens, both natural and deliberate. Occasionally the term may be restricted to the use of imported predators and parasites. See discussion in Beirne (1967) p.32, DeBach (1964) pp. 5-8, Van den Bosch and Messenger (1973) pp.2-3.

[72]. Rothman (1967) pp.8-9.

[73]. This was the year that Geigy A.G. began their epoch-making research on the insecticidal properties of DDT.

[74]. Franz (1972) p.2.

[75]. Beirne (1967) p.38.

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"they tend to indicate that entities are clearcut, whereas they sometimes intergrade. The use of sex attractants is an example. It is biological control when living females of a pest are used to attract the males as part of a control procedure. It is chemical control when a synthetic chemical compound is used. But is it biological control or chemical control to use extracts from the bodies of dead females, or to use a manufactured replicate of the natural pheromone?"

I dealt with this problem in my analyses by creating a special pheromone category of chemical attractants, and regarding the use of chemostimulants as a form of a "biotechnical"[76] method. However, behind a seemingly sterile debate about categories lies a much more fundamental question of philosophy and ideology. It has been argued[77] that it is not merely a question of categorising agents into either chemical or biological; that such distinctions overlie the existence, within economic entomology, of two distinct modes of approach, i.e. a chemical approach and a biological approach. Consequently, some critics have termed economic entomology a "two strand science".[78] Further, my research demonstrates[79] that the predominance of one strand over the other fluctuates over time, and that in the 'post-war' period the 'biological strand' after a period of complete dominance by the 'chemical strand' began to show signs of resurgence (see Fig. 2.5)[80].

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[76]. Djerassi (1974) refers to these as "Biorational chemical agents" ... "to avoid the great confusion in the literature between chemical and biological control of insects". p.599.

[77]. Ullyett (1951), Kennedy (1953).

[78]. Geier (1966)

[79]. Rothman (1969) and also Geier (1966).

[80]. Rothman (1969) p.13, and Rothman and Woodhead (1971). This graph was based on published research in the Journal of Economic Entomology and is not necessarily reflected by actual field practice. See also Rothman and Woodhead (1968) for trends in publication of papers on biological control.

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Are these trends, as many believe,[81] signs of a unifying presence at work, whereby the two strands by means of a triadic dialectic of chemical control "thesis" plus biological control "anti-thesis" produce integrated control 'synthesis'? In my conclusion I will seek to examine whether J.S. Kennedy made a correct appraisal of the situation when he wrote[82] in 1953, long before the swing back to biological control research had got underway, that:

> "Between the **different methods** (my emphasis H.R.) of crop protection a satisfactory compromise may be difficult but it is certainly possible. Between these **two different approaches** (my emphasis H.R.) to it, it is my contention that compromise is in the very nature of things impossible. Any attempt at compromise here is simply unscientific".

What Kennedy means by "approach" sounds something like the general use made of **paradigm**. There has been a tendency recently to extend the use of **paradigm** beyond science into technology as talk of **technological paradigms**[83]. I shall take up this issue again in my concluding chapter but first, however, I shall examine briefly the available methods/agents of control and the trends of research into them.

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[81]. See for example Scientific Aspects of Pest Control, NAS-NRC (1966) a generally optimistic document, which possessed an essentially mechanical notion of the changing pattern of research "... we stand today, on the verge of a renaissance in our <u>concepts</u> (my emphasis H.R.) of insect control..." p.65. The author of these words writes in 1972 (Pest Control - Strategies for the Future NAS-NRC 1972) "In seeking to compare the mood of the 1966 symposium (ibid) with the present, I sense less optimism today ... now one feels a tinge of frustration and impatience to convert promising concepts to practical programmes". "We seem to have operated on the assumption that knowledge, once acquired, will flow to the site of need, but I believe this matter needs critical review." p.44.

[82]. Kennedy (1953) p.1329.

[83]. Dosi (1984).

Resume of Insect Control Technology

Chapter 5 provides a detailed case study on insecticides. I have provided a discussion of problems arising from the use of insecticides, and alternative control techniques to insecticides in my article "The Changing Pattern of Research in Economic Entomology",[84] which is in Appendix A.

I propose, therefore, to briefly outline the basic elements of non-insecticide controls and provide some key historical references, together with reviews of current developments.[85]

Biological Control[86]

Biological control is the use of predators, parasites and disease to control insect pests. It is sometimes divided into **classical** biological control with predators and parasites and **microbial** control using insect pathogens.

In my analysis of research trends I have divided biological controls into seven groups.

a. **Predators.** The use of other species to eat the insect pests. Entomophogous insects, for example, ladybirds are insects which eat other insects, but not all predators are insect species; they could be, for example, birds or fish. Historically the use of predators goes back to ancient times.[87]

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[84]. Rothman (1969).

[85]. For excellent, and accessible, reviews dealing with alternative pest control techniques to insecticides see: NAS, 1975, especially V.1 pp.340-400; Knipling, 1979 and OTA, 1979. Also Martin and Woodcock, 1983, for a more pesticide oriented survey.

[86]. The most comprehensive and authoritative review is DeBach (1961). Other useful reviews include Beirne (1967), Doutt (1967), Van den Bosch and Messenger (1973), DeBach (1974), Coppel and Mertins (1977).

[87]. See Doutt (1964) and Hagan and Franz (1973.

b. Parasites. The use of parasites as a conscious agent of control came later than predators.[88] The parasites used for control are more accurately termed parasitoids since they kill their hosts. They are insect species who parasitise other insects. They have been used more often than predators for classical biological control.

Microbial control[89] is, as I have said, often distinguished from classical or macrobial control. The possibilities of microbial control were first noted during the 19th century and its historical development has been chronicled by Steinhaus.[90]

c. Fungi. The scientific study of insect pathology has its origins in 19th century attempts to discover the cause of muscadine disease in silkworms. It was found to be the fungus Beauveria bassiana. This was the first of many species of fungi found to attack insects. Their use in biological control has, however, rarely been successful.[91]

d. Bacteria. The principal bacterial pathogen that is used for control is Bacillus thuringiensis, it was first used in 1924 in Germany.[92] Since the late 1950s it has been produced commercially, in 1971 it was estimated that there were a dozen manufacturers in five countries.[93] B. thuringiensis has an

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88. Doutt (1964).

89. The term was coined by Steinhaus (1949).

90. Steinhaus (1954).

91. Martin and Edwards (1983) pp.59-68.

92. Steinhaus (1949) pp.278-9.

93. Falcon (1971) pp.72-73.

insecticide effect[94] on many pests and is sometimes used in combination with orthodox insecticides. Other species of bacteria have been examined for control purposes, but these have received nothing like the attention given to B. thuringiensis. It has been argued that short term commercial interest is tending to a neglect of these.[95]

e. Viruses.[96] The idea of using viruses for biological control is not new. For example the introduction of the myxoma virus of the rabbit. Viruses have been extracted from over 400 insect and mite species.[97] Four types of insect viruses have been extensively tested in the field: nuclear polyhedrosis viruses; cytoplasmic polyhedrosis viruses; granulosis viruses; and non-inclusion viruses.[98] The novelty of viral control preparations has led to worries about their safety, however, some are now registered for use.[99]

f. Nematodes.[100] It is known that nematodes play a part in naturally controlling insect populations, and their use for control purposes

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[94]. It often only provides, like conventional insecticides, short term control but relatively less effort has been made to develop them for practical control.

[95]. Falcon (1971) p.70.

[96]. Reviews of insect virology are given in Steinhaus (1949), Bergold (1958), Smith (1959), Smith (1967), Stairs (1971), Cantwell (ed.) (1974).

[97]. Knipling (1979) p.208.

[98]. Heimpel (1972).

[99]. "Elgar" a product using Heliothis NPV was approved by the USA N.P.A. in 1976 for use against the cotton bollworm.

[100]. Poinar (1971) provides a thorough review of the status of nematodes as insect control agents.

was suggested as long ago as 1918.[101] Successful application has been limited so far.

g. Protozoa.[102] Protozoa, especially Microsporidia, can kill insects, often in association with viruses and other disease organisms. Most authorities do not expect that protozoa will be used on a practical scale in the near future, furthermore any that were used would need to be stringently screened for safety.

Integrated Control[103] The term refers to control where chemical control is blended with, and subordinated to, biological control. Some see it as "simply rational pest control"[104] and others as the latest "fad".[105] It has come increasingly, in official circles, to be

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[101]. Poinar (1971) p.181. quotes Glasser and Wilcox (1918) "... we firmly believe that nematodes accomplished an immense reduction in the numbers of grasshoppers ... this worm might offer possibilities for introduction with regions where it does not occur and where grasshoppers are a pest".

[102]. Excellent reviews of protozoa as insect pathogens and of their potential as control agents can be found in Tanada (1959), Hall (1963), Lipa (1963), Tanada (1963), McLaughlin (1971).

[103]. Integrated control was pioneered by the Canadian entomologist Pickett, see Pickett (1949). He began his investigations in 1943 on the long term effects of insecticide upon population trends in apple insect pests. He concluded 1. Routine repetitive 'insurance' spraying could create more serious problems. 2. Some pests become economically significant because the insecticides interfered with their natural control. 3. It can take several years for natural control by predators and parasites to be re-established. 4. It is not practicable for them to be re-established in small areas. 5. The development of pesticide resistance further emphasises the importance of combining biological control with chemical control. 6. Pickett's control approach emphasised selective insecticides, timing of sprays to damage pests and not their natural enemies, minimum doses of pesticide and knowledge of appropriate population dynamics. See also Stern et al. (1959) and Ullyett (1948) who termed his approach the "combined method" "combining chemical control with biological control in a rational manner".

[104]. van den Bosch (1950) p.151.

[105]. Jones (1973).

referred to as pest management.[106] This has been defined as " ... the intelligent selection and use of pest control actions that will ensure favourable economic, ecological and social consequences".[107]

Attractants (Baits and lures)[108]

A number of chemicals influence insect behaviour as they search for food, egg laying sites or mates. Such chemicals can be used to lure insect pests into traps or poison. For example, the Japanese beetle may be trapped by a mixture of eugenol and phenethyl propionate.[109]

Pheromones[110]

Insects naturally produce chemicals that attract sexual partners. Generally they are produced by the female and when released they can attract males of the same species from a great distance. Pheromones have been identified and synthesised for some important pests. They are used in control either to lure males to their death or to confuse the natural mate finding process.

Repellants[111]

This is the opposite of the attractant, some chemicals repel insects, in some fashion they make the environment unattractive to the

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106. Luckmann and Metcalf (1975) and Geier (1966).

107. Luckmann and Metcalf (1975) p.4.

108. Dethier (1963), Knipling (1979) pp.421-490.

109. Metcalf (1978).

110. Jacobson (1972) and Knipling (1979) pp.421-490.

111. Metcalf (1978) pp.474-479.

pest without necessarily being poisonous. Some repellants such as creosote have been in use for a long time. They are often used to deter blood sucking insects, or insects which lay eggs on domestic animals.

Autocidal Control[112]

Insects can be used to destroy themselves by taking advantage of their mating behaviour. This so called autocidal control involves the release of artificially cultured insects into the environment. Prior to their release these insects have been sterilised, or genetically altered, to disrupt the reproduction of the normal wild population. The treated male insects compete with the normal wild insects for mates and their mating results in sterile unions. If the treated insects are released often enough and in sufficient numbers they can, in theory, wipe out the targeted species. The technique was first suggested in the late 1930s but was not attempted until 1949.[113] There are three major approaches to autocidal control:

Sterilisation by radiation in which the cultured insects are sterilised by ionising radiation prior to release.

Sterilisation by chemicals[114], here the sterilisation is done by chemicals, chemosterilants. Much research has been done on finding and developing chemosterilants. These could be sprayed or put in feeds etc. but they are generally mutagens, far too dangerous to be indiscriminately put into the environment.

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[112]. Reviews of the technique can be found in Knipling (1979) pp.315-393.

[113]. Knipling (1958), Bushland and Hopkins (1951).

[114]. Campion (1972), Knipling (1979) pp.281-314.

Genetic controls[115]. This involves the introduction of genetically deleterious mutations, lethal genes, and translocations into the cultured insects, which are released to mate with the wild population and so genetically weaken the wild population. This technique was first suggested by a Russian biologist[116] in 1940 but has only been practically studied since the 1960s.

The success of autocidal techniques is dependent on several factors: the availability of techniques for large scale culture of specific pests; the ability of the treated cultured insects to disperse adequately and compete successfully for mates; and in the case of the sterile male technique there is a need for a species in which the female only mates once in her life. It is an expensive technique which requires careful administration and organisation.

Antifeedants and feedants[117]

The feeding of pests is controlled by various stimuli, including chemical stimuli from the host plant. There is therefore the possibility of developing substances which interfere with this pattern of stimuli, thus preventing or discouraging the insect from feeding on its host plant. Early research in the 1930s concentrated on obtaining compounds from plants, but later interest lapsed until the 1960s when it revived in response to the need for insecticide alternatives.[118]

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115. Whitten and Foster (1975) and Smith and von Borstel (1972) review the genetic methods for insect pest control.

116. Knipling (1979) writes "Serebrovsky first proposed that deleterious genetic translocation might be utilised as a new method of insect control. Other scientists did not consider this proposal until some years after the principles of suppression by the sterility procedure had been demonstrated". p.362.

117. For reviews of this concept see Wright (1967), Chapman (1974).

118. Chapman (1974) p.355.

Metabolic analogues[119]

Insect metabolism has a number of specific characteristics which can be exploited in the production of control agents. Attention has focussed on factors controlling insect metamorphosis[120], growth, and chitin production. Insect growth is characterised by metamorphosis through a series of stages marked by moulting. Insect exoskeletons are made from chitin. Two main trends have developed:

a. Juvenile hormones and ecdysones (moulting hormones) and their mimics which control insect development.[121] A large number of chemicals have been synthesised and investigated for juvenile hormone activity. The goal is to produce control agents with specificity, high activity, and safety. Methoprene is a commercial JH analogue.

b. Chitin inhibitors.[122] Interference with chitin[123] deposition in insects has been an obvious, if elusive target, for pesticide design. A group of compounds, the benzoylphenyl ureas, have been shown to inhibit chitin synthesis. The best known is diflubenzuron.

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119. These are sometimes called "morphogenic agents", Menn and Pallos (1975). They are also called Juvenile Hormone analogues (JHA), Juvenoids, Insect Growth Regulators (IGRs), Insect Development Inhibitors, and Juvenile Hormone Mimics.

120. This could be traced back to Wigglesworth's research in the 1930s which showed the moulting and metamorphosis of Rhodnius nymphs to be under hormonal control, see Wigglesworth (1970).

121. For reviews see Menn and Pallos (1975), Staal (1975), Menn and Beroza (1972), Bowers (1976), Robbins (1972).

122. Verloop and Ferrell (1975).

123. Locke (1976) writes "With relatively little more work on the integument we might know more certainly whether there are some special features that would make insects vulnerable to reagents that we could devise for their control". p.397.

Electromagnetic radiation[124]

The electromagnetic spectrum includes: radio frequencies, infrared, visible light, ultraviolet, x-ray and gamma ray. All have been utilised in experiments on pest control without great success.

Radio frequencies.[125] Interest has concentrated on treatment of stored products, grain and other foodstuffs and wood. The systems normally involve heat effects on the target species.

Infrared radiation.[126] Has been used for control by heating of stored product pests, this is thought to be too expensive for widespread use.

Visible light and ultraviolet light[127] is utilised in light traps that attract species and destroy them. There is also interest in using light to control diapause.

Ionising radiations. The use of radiation for sterilisation in the autocidal control approach has been described. It has also been used for disinfestation of stored grain.

Reflectants. Reflective materials such as aluminium have been used for control. They are regarded as repellants rather than attractants.

Cultural control[128]

Classical cultural practices include:[129] stalk destruction, ploughing, harrowing, crop rotation, timing of harvests and planting, barriers, flooding, and planting of special plants to increase natural

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[124]. A very extensive, though dated, review is provided by Nelson (1967). See also Knipling (1979) pp.486-490.

[125]. Nelson (1967) pp.91-105 and Nelson (1973).

[126]. Nelson (1967).

[127]. Knipling (1979).

[128]. Knipling (1979) pp.397-419.

[129]. Stein et al. (1976)

enemies. These are associated with traditional good farming, water management and forestry practices. They are relatively simple and inexpensive. They are not favoured by certain contemporary trends in agricultural technology.[130]

Plant resistance.[131]

Plants have evolved defence mechanisms against insect attack. These include: barriers to oviposition, interference with feeding, unfavourable nutritional characteristics, toxic substances, and presence of hormonal antagonists. Another approach is to develop means of tolerating an attack or damage. It is possible to select for resistance, and a great amount of work goes into the development of resistant varieties.[132]

Quarantine and legislative controls

Many of the most troublesome pests are aliens, and therefore less subject to local natural control agents. Keeping pests out of a country or region by rules, regulations and appropriate inspection is a first line of defence.[133] It is especially favoured by countries which are islands or ones separated by sea and distance from potential pests. For example, in Australia all aircraft (and passengers) are sprayed by insecticide prior to disembarkation.

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[130]. Knipling (1979) writes "Full benefit of a given cultural practice will not be realized unless it is carried out in a unified and coordinated way". p.398.

[131]. Beck and Maxwell (1976).

[132]. This described for cereal crops by Gallun et al. (1975).

[133]. Knipling (1979) p.7.

Research Trends in Biological Control

My analysis of pest control trends in the 1960s, see Appendix A, revealed fundamental research in the utilisation of entomophagous insects, fundamental research on arthropod pathogens, and autocidal control research were the most rapidly growing fields. The content analysis of the Journal of Economic Entomology in Chapter 4 graphically shows the growth of biotechnical, biorational techniques, during and since the 1960s.

CHAPTER 3

SCIENTOMETRIC ANALYSIS OF KEY PAPERS ON PESTICIDES AND PAPERS ON BIOLOGICAL CONTROL

General description

The data and analysis discussed in this chapter have not been previously published, however, Simon[1] referred to their general characteristics in his bibliographic analysis of Biology. The sampling frame used for the biological control literature has been discussed in Rothman and Woodhead[2].

As I have already noted in Chapter 1, scientific papers contain, besides their intrinsic scientific content, a variety of socio-cognitive data e.g. institutional addresses, country of origin, author(s) name(s) etc. These data are amenable to a variety of analyses. I have been concerned to identify variations in such data between different fields of pest control literature. For example, does one find national differences in activity, are industrial laboratories more active in some fields than others? This was done in the belief that many assertions have been made about social forces at work in pest control research without empirical basis, and that empirical scientometric analysis might throw some light on several controversial issues.

This chapter concerns two separate analyses; one of papers about pesticides and the other papers on biological control. They are separate because they were sampled differently, however, because the

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[1]. Simon (1977) - I had previously sent Simon some copies of my SPSS printouts.

[2]. Rothman and Woodhead (1968).

data was analysed for essentially similar reasons I feel that, on balance, both should be discussed in the same chapter.

The papers that have been analysed fall into two broad categories, which in turn are further subdivided.

PESTICIDE AND CHEMICAL CONTROL

* Insecticide - history
* Insecticide - biology
* Herbicides
* Fungicide - history
* Fungicide - biology
* Rodenticide - history
* Rodenticide - biology

BIOLOGICAL CONTROL

* Entomophagous - basic
* Entomophagous - applied
* Microbial - basic
* Microbial - applied
* Integrated control
* Autocidal control

<u>Nature of Information</u>

The data that I use are derived from papers sampled from each field. From these papers I obtained, wherever possible, the following information.

* AUTHORS
* COUNTRY OF ORIGIN
* FINANCE SOURCE
* RESEARCH INSTITUTION
* SOURCE JOURNAL
* YEAR OF PUBLICATION

* CORPORATE ACKNOWLEDGEMENTS
* CITATIONS

From these data I have been able to calculate for each research field statistical data on:

* Author frequency
* Multiple authorship
* National distributions
* Research funding: broken down into
  - Private
  - Government
  - University
  - Foundations
  - Others
* Institutional and corporate frequencies
* Journal frequency
* Distribution over time.

Sampling

Chemical Control and Biological Control literature were sampled differently.

Chemical Control papers were sampled from Martin Guide to the Chemicals used in Crop Protection. This contained systematic details of several hundred pesticides, classified into types, insecticides, herbicides[3], fungicides, rodenticides. I was particularly interested in the sections, for each pesticide, which dealt with "historical" and "biological properties". Each of these sections generally listed one

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[3]. I was not able to maintain a consistent division of the herbicide papers into "historical" and "biological"; in some parts of the analysis the distinction was made, e.g. with journal frequency, however, most of the statistics for the herbicide group combined the two categories.

or more papers, thought by the author to be key papers. These formed the basis of my sample, and I collected all the papers so cited by Martin, subject to their availability - less than 5% proved unobtainable. I thus obtained two sets of papers "historical" and "biological", each of which was in turn subdivided into papers dealing with each of the four types of pesticide.

For the Biological Control fields I took a stratified sample of papers from the Annual Biological Control Bibliographies published in the journal **Entomophaga**. The sampling frame is described in Rothman and Woodhead (1968).

The total number of papers sampled was 1,434. Chemical Control totalled 635 (Insecticide History 174, Insecticide Biology 179, Herbicides 125, Fungicide History 84, Fungicide Biology 56, Rodenticide History 10, Rodenticide Biology 7). Biological Control papers totalled 799 (Entomophaga Basic 292, Entomophaga Applied 96, Microbial Basic 201, Microbial Applied 84, Integrated Control 61, Autocidal Control 65).

It should also be noted that the time spans covered by the Chemical Control and Biological Control samples also differed. The Chemical Control sample went back in some cases to early years of the century, whilst the Biological Control sample covered about a decade. I have not sought, on the whole, to attempt to analyse time series and the resulting 'snap shot' analyses are in fact often spread over many years. I realise that some of the social variables that I have sought to analyse may well vary over time and that must be born in mind when reading the resulting analyses; it is possible that appropriate statistical techniques might be used to disaggregate data over time - unfortunately I lacked time to investigate this.

Survey Design

There are a variety of alternative ways in which I might have sampled and surveyed the research fields. Ideally one would have liked to identify the total paper population for each given field and sample randomly, perhaps stratified over time. There are a number of obstacles to such an approach in practice. Complete, or even fairly complete, bibliographies are not always readily available. When I originally collected this data, in the early 1970s, they were not available for Chemical Control. To have created my own was beyond my resources. Secondly, because of my interest in the historical development of pesticides, I wished to sample according to specific pesticides, and ideally for as many different pesticides as possible. Again ideally it might be argued that I should have created complete bibliographies for each pesticide and sampled these. Such an approach, ignoring the not unimportant matter of resources, would have interfered with my historical objectives. I was interested in historically important papers and random sampling is not the way these are obtained. A further point to be considered is that I was concerned to examine various ways in which scientometric data might be used to aid historical and sociological investigations. Completeness is not the only criterion for evaluating my approach, the development of cheap, and quick, methods should not be ignored; complete perfection always has a price and it may not always be worth paying. In the overall study I have sought to experiment with a range of scientometric techniques, from simple and crude to relatively sophisticated, with which to explore the historical and social dimensions of research fields in pest control.

It was in the search for simple and quick scientometric historical insights that I discovered the textbooks of Hubert Martin. The use of textbooks as sources of scientometric data tends to be neglected[4], perhaps because textbooks themselves are not highly regarded by those at the research front, however, the better ones go through many editions over several decades and the different editions may provide valuable historical evaluations of the fields surveyed. Martin's The Scientific Principles of Plant Protection is such a work[5], I have discussed this in Rothman and Lester (1985)[6]. The availability of Martin's "Guide", listing most pesticides in use, plus my respect for his historical knowledge of pesticide development drew me to it as a source of key papers for certain aspects of pesticide development and use. I allowed Martin, rather than chance, to sample papers. It is possible that in so doing I have drawn into my analysis bias stemming from Martin's ignorance and or preference. I have not been able to investigate this possibility, perhaps one area which may be affected is demographic data and one might find that a German or French "Guide" had a somewhat different set of key papers. Again I would argue that it devolves into a question of judgment and resources.

I did not use Martin for my sampling of Biological Control papers, and it might seem illogical not to have done so. There are several reasons why it seemed better to go to another source for Biological Control. Martin's "Principles" covered all aspects of pest control, biological as well as chemical, and its successive editions provide a

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4. In Rothman and Lester (1985), which is included in the Appendix of Published Papers, we were able to show that a 'quick and dirty' reference count of Martin's "...Principles..." gave a neat picture of the periodisation of insecticide history, fig. 1. p.249.

5. Martin's "The Scientific Principles of Plant Protection" has gone through seven editions since 1928 to 1983; the last edition is co-authored with D. Woodcock and is called The Scientific Principles of Crop Protection.

6. Rothman and Lester (1985) pp.249-250.

vivid picture of changing technical trends, but Martin never produced a Biological Control equivalent of his "Guide" to pesticides. Also it might be argued that he was a representative of the "chemical school" of pest control, and that his insights into pesticides were "richer" than his insights into Biological Control. I was much concerned with the struggle, as I saw it, between competing paradigms of chemical and biological control and felt that there were better textbooks to analyse for Biological Control[7]. At the World Congress of Entomology in Moscow 1968 I met Professor J.M. Franz, editor of the journal Entomophaga. He kindly gave me a complete set of the Entomophaga bibliographies on biological control, at that time these were the most comprehensive available. Using them I was able to analyse research trends in biological control, see Rothman and Woodhead (1968). I also used these bibliographies as a population to sample for biological control papers. They were already classified by the compilers into the fields used in this study. I have no way of knowing how complete the Entomophaga bibliographies were; I have discussed the matter with H.R. Simon, who is an expert on Entomological Bibliographies[8], and who was responsible for the compilation of the bibliographies, and am of the opinion that they were extremely comprehensive. Furthermore, they covered the 1960s, an extremely exciting decade for innovation in biological control. Their use in this study offered the opportunity for experimenting with yet another scientometric approach - that based upon the sampling and analysis of comprehensive subject bibliographies.

In the analyses that follow, great care has to be taken in

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[7]. I did in fact make extensive analyses of the bibliographies in Paul DeBach (ed) (1964), unfortunately there is not space to include them.

[8]. H.R. Simon, Entomophaga, 12, 81, 1967.

interpreting any comparisons between Chemical Control fields and Biological Control fields, because of the different sampling frames for papers, although, of course, within each of the two broad fields, comparison ought to be more firmly based.

Coding of Data

Coding can always be a source of errors; wherever possible two people, myself and a research assistant, did the coding and mutually crosschecked a sample of the coded material. Wherever possible papers were examined in their complete form, and photocopies made of the relevant parts of each paper: author, title, abstract, addresses etc. This material was read and the items listed above were extracted and punched onto cards and a database was created on a mainframe. This database was sorted and analysed using SPSS[9].

Accuracy

I have already discussed the most important sampling error sources. There are, however, certain non-sampling error sources. The bulk of the coding of bibliographic data was relatively straightforward. The most important exception being the data concerning origins of finance and classification. I sought to classify funding bodies and institutions into the following: private industry; government; university; foundations; others. This is not a trivial task since it requires knowledge of national research structures; classification proved easier with UK and US papers than those of countries such as the USSR. Wherever possible, in doubtful cases, I have tried to check out organisations in library reference books, nevertheless, a certain number of errors may have slipped into the coding. The whole area is a rather fuzzy one, and my classification

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[9]. Statistical Package for the Social Sciences, see Nie et al. (1975).

scheme - which is quite standard in R & D statistics - is a culturally conditioned one. For example, is the distinction between industrial and university research centres in USA and say the USSR the same? There seems to be no readily available solution to this problem, which I have discussed with various other experts in the science indicators field. Ideally, several people might have been employed to carry the classifications, and their results compared to get some idea of the variation although one would be none the wiser as to which sets were the more "true" classifications. Again, one is forced to use judgment, and I shall argue below that when inter-field institutional comparisons are made, the distinctions between certain fields are such as to lead one reasonably to conclude that they indicate real social differences.

In certain cases of multiple authorship, papers could have several sites of institutions and country or finance. To be quite correct a fractional attribution should be given; this has not always been carried out, because it was of rare occurrence, the data are available in the tables.

ANALYSIS INTRODUCTION

I intend to examine the following characteristics of the chemical and biological control papers; for the reasons mentioned in my discussion of sampling I will, initially, examine the chemical and biological control papers separately.

* National Demographics
* Institutional location of research, specific and by general category
* Finance, Source of Research, specific and by general category
* Journals, source and cited journals.

Table 3.1 Distribution of Papers by Research Field

	No. Papers	% chemical control database	% biological control database
INSECTICIDE HISTORY	174	27.4	
INSECTICIDE BIOLOGY	179	28.2	
HERBICIDES	125	19.7	
FUNGICIDE HISTORY	84	13.2	
FUNGICIDE BIOLOGY	56	8.8	
RODENTICIDE HISTORY	10	1.6	
RODENTICIDE BIOLOGY	7	1.1	
ENTOMOPHAGA BASIC	292		36.5
ENTOMOPHAGA APPLIED	96		12.0
MICROBIAL BASIC	201		25.2
MICROBIAL APPLIED	84		10.5
INTEGRATED CONTROL	61		7.6
AUTOCIDAL CONTROL	65		8.1

NATIONAL DEMOGRAPHICS

Chemical Control

Complete details are given in Table B.1. If one examines all the Chemical Control papers it is clear that the USA dominates with 63.5%, followed by the UK (15.1%), Germany (4.9%) and Switzerland (4.3%). In all 15 countries are represented.

All four kinds of pesticide are dominated by US papers, and the next countries are UK, Germany and Switzerland; with the exception of rodenticides (a very small group of papers). The dominance of US and UK papers is even more pronounced with the sets of "biological" papers.

The distribution within national sets of papers can also be analysed. Thus, the US is around 60% for most groups, with a slightly greater effort in the "biological" groups. The UK shows greater activity in herbicides that other pesticides, and in "biological". Germany was more active in insecticides than herbicides.

Biological Control

As may be seen from Table B.2, this presents a radically different picture from the national demographics of Chemical Control. The number of countries represented in the sample was 57, their distribution was highly skewed.

The US was first with 21.9% of all papers, followed by the USSR (13%), Canada (8.9%), Japan (7.4%), Germany (6.8%), France (6%). The UK ranked 7th with 4.6%.

More countries published in the Entomophaga Basic field, 40 out of 57, than in any of the other. Followed by microbial basic (29), Entomophagous Applied (21), Microbial Applied (20), Integrated and Autocidal Controls (17). Fundamental entomological research appears to be a more global activity than actual applied research, and the more recent developments, autocidal and integrated present the most restricted levels of diffusion.

In Entomophagous Basic the USA ranked first with 17.9%, followed by Canada (12.7%), Japan (9.6%), Germany and the USSR (8.2%). The UK ranked 6th (5.8%). The situation is changed somewhat when one examines Entomophagous Applied. The USA still dominates with 21.9%, then one finds the USSR (17.7%), Poland (8.3%), Germany (7.3%), Canada (5.2%). Japan and the UK provided only 1% of the papers. Clearly, applied publication activity is not always linked to basic strength. The US is strongest in both areas, whilst the USSR's and Poland's applied output is greater relatively than their basic output, the reverse is the case with Japan, Canada and the UK.

The USA is ranked number one in Microbial Basic with 17.9%, followed by USSR (13.4%), Japan (12.4%), France (10.4%), Canada (8%) and the UK (7%). In Microbial Applied one finds that the USSR ranks first with 28.6%, then the USA (21.4%), Germany (8.3%), France (4.8%). The USSR and Germany show an applied output greater than their basic, whereas Japan (2.6%) and the UK (0%) are relatively weaker in their applied output.

Integrated Control, as I have noted in Chapter 2, is a response by biologically minded pest controllers to problems and opportunities of chemical control. It indicates a certain sophisticated coming to terms with technological and socio-economic realities. The USA ranks first with 21.3%, followed by Germany (13.1%), Netherlands and the USSR (11.5%), Canada and the UK (4.9%).

Autocidal control is a novel control technique, which as I later describe, was pioneered in the USA in the late 1950s. The field was hardly ten years old at the time of my sample, so naturally the diffusion curve was still immature. Not surprisingly the USA dominates the sample with 55.4%, followed by the USSR (7.7%), India, Mexico, Canada and the UK (3.1%). The predominance of two Third World countries is unexpected; it might reflect sampling from a relatively small population, or the activity of international agencies. In India's case it might be a by-product of its atomic energy programme.

If one examines national outputs across the six bio-control fields one can see that the USA is very strong in all fields. The USSR is also relatively strong across the board, and especially in Microbial Applied. The UK has a relatively stronger basic than applied output, as does Japan. French output is also greater in the basic than applied fields, and is strongest in Microbial Basic, perhaps this is a reflection of a strong historical tradition. The Netherlands, has its greatest output in integrated control.

Interesting contrasts emerge from a comparison of the Chemical Control and Biological Control fields; one must not forget earlier strictures stemming from differences in sampling. Certain countries, the USA, Germany, France and the UK have strong outputs in both areas. The USA being, with a single exception, ranked first across the board.

The USSR ranked second in Biological Control but had no output in the Chemical Control fields. More surprisingly, neither does Japan; if I had sampled pesticide papers published over the last decade then Japan would certainly have been strongly represented since its chemical industry has become larger and more innovative. The Soviet chemical industry manufactures a wide range of pesticides without being notably innovative, apart from microbial insecticides. Switzerland with one of the largest chemical control outputs had only a low biological control output, perhaps reflecting its very strong chemical industry, which is extremely large for a country of its size.

INSTITUTIONAL LOCATION

I collected data on the institutional addresses of papers in the sample. I shall deal with the two aspects; type of institution, and specific research institutions. First I will examine data derived from the Chemical Control sample and then deal with Biological Control data plus comparative analyses. When examining these data it should be noted that it was not always possible to obtain specific institutional data for each paper, percentages therefore refer to a total which includes "unknowns", which are listed in the appropriate tables.

Chemical control

Table B.3 summarises data on institutional type (Industry, University, Government, Foundation, and combinations of these) against Chemical Control research fields.

The "history" papers are key papers describing pesticides, innovative reports. Industrial institutions, not surprisingly, were the dominant producer of these; Insecticide History (42.5%), Fungicide History (33.3%), Rodenticide History (30%). Government centres are also strong producers of "historical" papers; Insecticides (16.1%), Fungicides (21%). University productivity in the "historical" fields is far weaker than for industrial and government centres; Insecticides (7.5%), Fungicides (8.3%) and Rodenticides (40%) (these are special cases)[10].

When one examines data for "biology" papers one finds a quite different institutional distribution, indeed it reverses the one described for "historical" papers. University output, rather than industry, is the major one: Insecticides (22.9%), Fungicides (33.9%). Government centres also produced more than industry; Insecticides (29.6%), Fungicides (23.2%). Industrial production was: Insecticides (16.2%), Fungicides (17.9%). Clearly there has been a change in the division of labour between these institutions, although one cannot tell what research remained unpublished; university researchers are under greater pressure to publish than scientists in the other research centres and it would, therefore, be unwise to conclude, for example, that industry is necessarily backward in studying the biological properties of pesticides. However, it does appear that as far as the public domain goes the university and government outputs are exceedingly important. Unfortunately, I have not disaggregated the Herbicide papers into "history" and "biological" and one is not able to examine the situation with respect to herbicides; it would be surprising, however, if it turned out to be substantially different.

I also sought data on industry/university and government/university collaboration in publication. I found surprisingly little, such papers formed less than 1% of the total sample, and were too few to produce a disaggregated analysis with.

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[10]. Researchers at Wisconsin University, Wisconsin Alumni Research Foundation (WARF), pioneered the development of anticoagulant insecticides e.g. Warfarin, whose name is derived from WARF.

I was able to examine data on institutional type with respect to countries of origin, see Table B.4. Chemical Control papers from the USA were fairly evenly divided between industry (21.1%), government (23.1%) and university (20.3%). Quite different distributions are found for other "highly active" countries. For Germany and Switzerland one finds only industrial producers. For the UK the distribution is industry (16.7%), government (26%), university (24%). The bulk of foundation research was from the US, as was the bulk of collaborative papers; neither was numerically large. It is not easy to explain these results without entering into a discussion of national research cultures, which I am not equipped to do.

I obtained data on some 99 specific research locations[11] that produced Chemical Control papers, which are listed according to research field in Table B.5. Most centres appear too infrequently to make any sensible statements about their distribution; indeed to appear at all they needed to have published a "key" paper, not in itself a frequent occurrence.

Table 3.2 Leading Corporate Research Centres

Industrial Centres	Insecticide	Herbicide	Fungicide	Rodenticide
American Cyanamid (1.3%)	87.5		12.5	
Bayer (2.5%)	66.6		20.0	13.3
Dow Chemical (2.1)	69.3	7.7	23.1	
Geigy (1.2%)	90.0			10.0
ICI (1.4%)	22.2	33.3	44.4	
Shell (1.1%)	100.0			

In the analysis below I have, therefore, examined only centres contributing at least 1.1% of the total papers; the % appearing after

[11]. Inevitably there has been some under and over-counting of research centres, for example, corporate research centres may actually represent laboratories on several distinct sites, and the USDA appears in several guises in the Tables.

the centres' names represents their percentage of total paper production. The most prominent centres are generally industrial ones. The major industrial research location are listed above, the figures in brackets after the corporate name indicate their percentage contribution to the total Chemical Control publications. The column figures indicate, for each company, the internal percentage distribution of "key" publication output between each pesticide type. Companies are not equally active across the pesticide spectrum; they show a certain degree of specialisation. The elucidation of the reasons for this would make a valuable contribution to pesticide history, and to innovation studies.

Table 3.3 Corporate Activity by Pesticide Type

Industrial Centres	Insecticide	Herbicide	Fungicide	Rodenticide
American Cyanamid	2.9		1.2	
Bayer	4.6		3.6	
Dow Chemical	1.7	0.8	1.2	
Geigy	4.0			10.0
ICI	0.6	2.4		
Shell	2.9			

In the above table I examine a slightly different aspect of corporate activity. The columns show the percentage contribution by each company to the total output of "historical" papers for each pesticide type. Thus one can see that, according to the data, Bayer and Geigy have made a greater innovative impact on insecticides than other companies in our database, whereas ICI appears to have been more successful than the others with herbicides (care must be taken in accepting this figure at face value because we were not able to disaggregate "historical" and "biological" papers for herbicides).

Table 3.4 Leading Government Research Centres by Pesticide Field

Government Centre		IH	IB	H	FH	FB	RH
Boyce Thompson Inst	(2.4%)	33.3	6.7	40.0	20.0		
Conn. A.E.S.	(1.3%)	12.5			37.5	50.0	
USDA	(4%)	45.4	36.3	6.0	9.0		

I have listed the most dominant Government centres in the above table, and they are all American centres; unlike the corporate centres which showed Europe to be strong, if not stronger, than the USA. The USDA data consolidates the separate USDA centres found in the database. The bracketed figures show the centre's percentage contribution to the total number of Chemical Control papers. The column figures show each centre's distribution of output between each field (insecticide historical, insecticide biology etc.) as a percentage of the centre's total output. The USDA has concentrated more on insecticides than herbicides, whereas the reverse is the case with Connecticut AES, who seem to be more concerned with fungicides. The Boyce Thompson Institute seems to have spread its effort across the board.

Table 3.5 Leading University Centres by Pesticide Field

Universities	IH	IB	H	FH	FB	RH
Cornell Univ (1.1%)		71.4	14.3		14.3	
London Univ. (2.2%)		21.4	57.1	14.3	7.1	
Univ. California (3.5%)	22.7	27.3	27.3	4.5	18.2	
Wisconsin (1.1%)	14.3	42.9			42.9	

From the many university research centres in our database the table above lists the four most productive, showing, like the previous table, their percentage contribution to the overall total of papers and their own distribution of effort between fields. London University, the only non-American centre in the table, places a large fraction of its output in the herbicide field. Whilst these universities are strongest in "biology" fields they also produce in "historical" fields, and Wisconsin's innovative success in the rodenticide field is widely acclaimed as a classic of university commercial innovation.

Biological control

The data on the location of biological control papers are rather incomplete. I was unable to obtain data from about half the papers in out database. Table B.6 lists the institutional types by research field. Industrial productivity in this database is almost absent; the output being divided between universities and government institutions. The division of labour between them is not identical, universities being more biased towards the basic than applied fields although the division is not sharp in most fields. Autocidal control was an exception in being highly skewed towards government centres.

I attempted to examine research institution types by nation, (Table B.7); unfortunately in many cases I am not able to classify centres. It is therefore not possible to make many sensible comparisons between nations for this parameter. In the case of Canada, the UK, and the USA I was able to classify over 80% of their output in the database. Canadian Biological Control papers were dominated by government institutions, 78.9% of their total. The UK and USA distributions were rather similar, universities produced 48.6% in the UK and 40.6% in the USA, government centres accounted for 32.4% in the UK and 36.6% in USA; industry produced 1.7% of the US total.

The database contains information on specific research centres output by research field, Table B.8, for about 60% of the papers and one is able to examine the distribution between research fields for specific centres. It is clear, however, that generally in this area that few centres have overwhelming dominance. Amongst the few centres which stood out were:

University of California, 5.4% of total output, which was active in all fields.

USDA (5.2%), with much of its output in autocidal control.

Sault Ste Marie (1.5%), mostly on microbial basic.

Belleville (2.5%), whose emphasis was on entomophaga basic.

SOURCES OF FINANCIAL SUPPORT

The sources of research finance are of great importance, and I sought to examine the possibilities of developing indicators of research support from the bibliographic database. It has to be said at the outset that such an approach has major limitations for it is impossible to identify sources of finance unless papers explicitly acknowledge them. Chemical Control papers were more helpful in this respect than Biological Control papers; I was able to obtain acknowledgment data for 76.7% of the former and only for 45.2% of the latter. The reason for this difference is not clear, perhaps it has something to do with the wider spread of source journals and countries in the Biological Control literature.

The previous section on research location provided indicators of industrial, government, and academic interest in various fields of pest control research. These cannot be taken as fully indicative of interest since a university location may be the site for government or industrially funded research. Likewise an industrial location could be the site of government supported research, or a government laboratory could be in receipt of industrial support and so on. If one can obtain further data from acknowledgements the findings will be more soundly based. In so far as the acknowledgements data allowed I attempted to come to some fairly tentative conclusions about institutional interests with respect to specific research fields. The resulting imperfect indicators should be read in conjunction with those developed from the institutional location data.

Chemical control

Table B.9 compares location of research with finance source acknowledgement. Centres of industrial and government research mostly acknowledge industrial and government sources respectively. The sources cited by university located research are of greater interest; university sources are cited by 38.4%, government (10.7%) and industry (8%). That universities are more dependent than industrial and government research centres is not surprising; what is unexpected is the low extent of outside support contained in the database; one must assume an unknown degree of under-acknowledgement of support. 25% of papers emanating from foundations acknowledged industrial support.

The acknowledgement data by national origin of papers was extremely spotty, see Table B.10. Countries acknowledging high levels of industrial support included Germany (87.1%) and Switzerland (88.9%), both homes of major chemical firms interested in pesticides development. Of UK papers 29% reported industrial support and 26% government. In the US papers industrial support was mentioned by 39% and government by 23%. The bulk of papers (85.7%) mentioning support from foundations were American, but these only accounted for 3% of all publications.

When one examines the data from the point of view of research fields the observed pattern confirms that noted for research locations. Pesticide "history" papers were associated with industry more frequently than were "biology" papers; see Table B.11. Government support (38%) was more frequent than industrial support (19.6%) for insecticide biology papers. University sources were higher with "biology" than with "history" papers, apart from the exceptional case of rodenticide history. Joint industrial and university support was quite high for fungicide biology (16.1%).

Table B.12 lists specific organisations acknowledged. These include most of the well-known pesticide manufacturers. For example: Bayer (predominantly insecticide and fungicide "history"); Dow and DuPont (supportive across the board); Geigy (insecticides and herbicides); ICI (across the board, but with a greater emphasis on herbicides and fungicides); Shell (insecticides); Union Carbide (insecticides and fungicides). The USDA was the most cited government support source.

Industrial support is quite commonly acknowledged for Chemical Control papers, although skewed towards pesticide "history", i.e. innovative pesticidal property research; one might have expected to find a higher percentage of support for "biology" papers, on the grounds that industry would be more likely to farm out studies of biological properties than development work on new pesticides. Government support was very significant across the board despite the commercial value of many of the research fields, where one might have expected "market forces" to organise research.

Biological Control Database

Table B.13 cross-tabulates research location with support acknowledgement. From this it is clear that industry was not funding research that it did not do in its own laboratories, and that it was in any case responsible for little biological control research. The data were rather incomplete, most of the university papers gave no acknowledgement of support; where they did government predominated (24.2%) followed by university (6.1%). Government support dominated all the biological control fields, see table B.14. The little industrial support indicated was concentrated in microbial applied and integrated control, although actual numbers are, perhaps, too small to make much of this. Foundations, which one might have thought would be an important source of support for basic research fields, were absent. National data are shown in Table B.15; unfortunately they are incomplete for most countries. They are reasonable for the UK and USA. In the UK government support predominated, and there was even slight industrial support; a similar situation was found in the USA, though industrial support, at 2.3%, was even slighter than in Britain. The UK and USA accounted for 75% of all papers acknowledging industrial support. Incomplete as the data are on this aspect of research, they do appear to provide a further indicator of low industrial interest in biological control as compared to chemical control during the time period covered; they also serve to indicate the extent to which biological control research depended on publicly financed research e.g. the USDA was cited by 7.1% of all the papers, and by 56% of the autocidal control papers.

JOURNAL STRUCTURE

Journals are an important part of the social structure of science; in this section I shall examine the extent to which the differences between research fields may be indicated by the sets of journals which published the papers representing each research field in the databases. A further aspect of journal structure which I have examined concerns journals cited by the database papers. Before discussing the findings it is necessary to say a little about journal distribution in research fields[12]. Different research fields are characterised by the possession of particular cited journal sets, which indicate the

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[12]. For a detailed discussion see Narin (1983).

disciplinary and research areas from which the research fields draw their information etc. De Solla Price[13] suggested that the study of relations between journals threw light on the structure and dynamics of science. My attempts in applying this approach to economic entomology ought to be regarded as rather tentative, and suggestive of further lines of research.

Chemical control

Table B.16 lists journals by method, that allows one to examine the journal structure for each field. One is able to examine the frequency and distribution of journals between fields. Patents, particularly US patents, are the most frequent sources for pesticide "historical" fields. Certain journals are paper sources for all types of pesticides, e.g. Hilgardia, Plant Disease Reporter and Phytopathology - the latter two are more frequently sources of fungicide papers. The Journal of Economic Entomology was one of the most frequent source journals, but only for insecticides. Nature and Science were also important source journals for all fields, these are important general and highly prestigious journals and their presence as source journals might be an indicator that pesticide research has, or had, general scientific interest. If one looks at the "biology" papers one can find a number of medical toxicology journals such as Archives of Industrial Hygiene and Health, and Journal of Pharmaceutical Experimental Therapy.

It is not possible, given the size of the database, to gain more profound insights into the journal structure of the Chemical Control research fields using the source journals alone. I therefore examined another approach which drew upon journal citation data. The database

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[13]. De Solla Price (1965).

contained most of the journals, names and frequency by research field, for each source journal. From this data I was able to classify the source journals in each field according to the journals that they cited, i.e. create "source journal maps". I also, using the same data, created "cited journal maps", these classified cited journals with respect to the source journals which cited them.

The frequency distribution of journal citation is highly skewed for all the research fields I examined; i.e. a few journals are highly cited whilst the majority are cited three or less times. A set of curves illustrating this, for each field, is provided in Appendix B (Figs. B.1 - B.12). Given such a distribution my analysis of cited journals only involved a fraction of the total number of cited journals associated with each field. By inspection of frequency curves I decided only to include in the analysis journals cited at least six times. I, therefore, only analysed a small set of "core" cited journals, generally around 10-12% of cited journals for each field.

Table 3.6 Citation Data for Research Fields

FIELD	HIGHEST NO CITATIONS	JOURNALS >=6 %	JOURNALS >=6 NO.	TOTAL NO JOURNALS	NO. SOURCE JOURNALS
Ins. Hist.	108	13.8	18	130	46
Ins. Biol.	194	15.8	42	265	80
Herb. Hist.	55	19.0	19	100	44
Herb. Biol.	29	15.6	21	134	Same
Fung. Hist.	76	13.4	11	82	41
Fung. Biol	95	8.4	18	213	34
Entom. Bas.	179	10.8	105	977	131
Entom. Appl.	65	4.9	10	203	62
Micro. Bas.	178	10.7	66	614	109
Micro. Appl.	77	11.3	27	237	62
Integrated	118	7.0	17	242	50
Autocidal	269	7.6	12	157	38

I have assumed that this "core" set offers a key to characterising a field. I am not, of course, arguing that the "tail" of 90% of cited journals is unimportant; indeed it is possible that within this tail lie valuable clues to cross-linkages and relationships between fields. Unfortunately, at the time of the research I did not have the time to develop techniques for analysing such "weak" signals of scientific structure. The table above summarises for all the fields, source and cited journals data.

Classification of Source and Cited Journals

The source journals and their frequencies are listed in Tables B.16 and B.17, according to research fields. For each research field I created a database on cards of cited journals; the cards listed under the name of the cited journal the source journal citing it and the number of times it cited the cited journal. For the reasons already discussed I created, using a citation threshold of at least 6, a subfile of the database, which I called the "core cited journal database" (CCJ). The data in the CCJ was used in classification studies of source and cited journals for each field.

Source journals were classified according to the "core cited journals" which they cited; and the core cited journals were classified according to the source journals which cited them. That is to say source journals were grouped according to how similar their core cited journal sets were, and core cited journals were grouped according to the similarity of the source journal sets citing them. The number of times a journal was cited the stronger its role in determining a relationship. Ideally one should normalise citation scores to take into account the global total of citations received by each journal, since such data was not available to me I was forced to use raw unnormalised data. This will create a certain amount of distortion in the final classifications.

The data were classified using programmes developed by Bertrand Michelet at the Centre de Documentation et Technique de CNRS in Paris, as part of the Leximap software used for co-word analysis.

Before presenting and discussing the results that I obtained it is necessary to make certain comments about the approach. As far as I am aware it is the first time that this method has been used to classify journals (I have assumed that classifying journals is in principle no different than classifying keywords, the design function of the software). The data used in the study were rather crude, and have drawbacks as a testbed for Michelet's method. Unfortunately, I originally gathered the data with other objectives in mind; these were historical, and the long time scale associated with them creates comparability problems in a citation study, since journal citation patterns can change over time. On balance, however, I felt that the potential value of Michelet's technique overrode such a priori objections.

The purpose of classifying the source and cited journals was to see whether any patterns emerge which might throw some light on the structures of the research fields, e.g. the clustering of journals according to discipline - chemistry, ecology, physiology etc. - or non-cognitive characteristics such as country of origin.

The programme lists the journals pairwise with a figure giving the strength of their linkage. The pairs are listed in descending order of linkage strength (1,000 - 0). For example, in the Insecticide History data set the first few results of clustering are listed below (the journals are coded).

Table 3.7 An Example of Journal Clustering Linkages

Source Journal 1	Source Journal 2	Linkage Strength
107	139	996
102	110	847
101	106	846
110	124	692
136	137	692
102	117	672
102	124	633

A cluster diagram (Fig. 3.1) showing the relationship of source journals can be built up from the pairs. The resulting diagrams can become exceedingly complex, defeating the purpose of their creation, and in practice Michelet found that it was best to break clusters when they contained 7-10 linkages. I realise that this is somewhat arbitrary approach, and whilst appreciating Leydesdorff's[14] recent criticism of such "trial and error" approaches, one is forced, until an appropriate theoretical basis is developed, to progress in an ad hoc manner. Nevertheless it does serve to underscore my earlier strictures for caution when interpreting such indicators.

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107------------------------------139

117-------------102-----------------124

                       110


101-------------106

136-------------137
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Figure 3.1 A Cluster Diagram

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14. Leydesdorff (1987).

My results are presented in two ways:

1. Listings of groups/clusters of journals without indicating linkages.
2. Diagrams which group journals and draw links between them (only strongest links are shown, or as many as are allowed prior to implementing the cutoff threshold). Not all journals cluster, some are dropped by the programme because they do not form sufficiently strong linkages with other pairs.

Type 2 can be illustrated by an examination of the data for Insecticide History. There are two diagrams - one for source journals and one for cited journals. If one examines the source journal diagram, Fig. B.13, one can see that it shows the source journals clustered into four groups. The dotted lines between the first three indicate that links exist - but have been omitted, for reasons already given.

Group 1 shows five journals, four of which are highly interrelated. These are dominated by the J.E.E., the second most cited journal in this field. With a single exception the journals in this group are applied biology and agriculture journals. Descending the diagram (note that in all discussions of cluster diagrams we will move down the diagram, numbering of clusters will be in descending order with No. 1 at the top), cluster 2 contains five closely interlinked chemistry journals. Group 3 contains 3 journals and US Patents - Contrib. Boy. Thom. Inst. is a journal of a leading agricultural research centre, the significance of this grouping is not clear, it does possess weaker links with the chemistry clusters. Cluster 4 contains 2 plant disease journals.

The cited journals diagram (Fig. B.14) also contains 4 clusters. Cluster 1 comprises 2 chemical journals and BIOS Reports (these were intelligence reports which published details of German pesticides at the end of World War II). Cluster 2 is a further grouping of chemical journals, J. Amer. Chem. Soc. is the second most cited journal in the field; Soap is a specialist journal strongly linked with only one journal in the cluster, the other 4 are strongly interlinked. Cluster 3 contains five publications, three of which (US Patents, J.E.E., and USDA Publs.) are in the Top Five most highly cited journals in the field. Cluster 4 contains 2 generalist journals, Science and Nature, and two plant journals. Descending the diagram we seem to be moving from chemistry dominated clusters to agriculture/plant science.

In both the source and cited journal diagrams the only entomology journal is the J.E.E., it appears linked to both chemistry and plant protection/agriculture journals.

Insecticide Biology, summarised by Figs B.15 a/b, is concerned with the biological and toxicological aspects of individual insecticides. One would hope, therefore, that the clustering routine would be able to distinguish medical and agro/entomological structures in the field.

In the source journal structure Fig. B15a, we find two clusters. Cluster 1 contains five journals and has a peculiar bi-polar structure, the top half of which is characterised by plant protection journals - including the J.E.E. (the most frequent source journal in the field) - and the bottom half by toxicological and biomedical journals - including the second most frequent source journal, Archives of Industrial Health. The two poles of cluster 1 are linked by the J. Agric. Food Chemistry.

Cluster 2 consists of four journals, biomedical, entomological and general science (Nature); it has weaker links, through the biomedical journals, to cluster 1.

The cited journal clusters are shown in Fig. B.15b, here the links between journals are not shown, nine clusters are listed. Examination shows that a distinction emerges between journals dealing with plant protection, biomedicine, and chemistry, albeit imperfectly. Thus the most highly cited journal, J.E.E., is clustered with two agricultural publications and two chemical journals. The most highly cited biomedical journal, J. Pharm. Expt. Therap., is clustered with five biomedical journals. Cluster 7 brings together two chemistry and two agricultural chemistry journals. The significance of such combinations can only be speculated upon; having been highlighted by the technique they might be explored in future research.

I examined the cluster diagrams for Fungicide Historical, Fig. B.16a/b, and Herbicide Historical, Fig B.17a/b, to see whether a similar separation between chemistry and plant protection journals emerged. In the fungicide clusters one observes a mixture of plant protection and chemistry journals. In the herbicide clusters, however, a distinction is to some degree apparent, and with the cited journals one finds three clusters, one mixed applied biology and chemistry, a second of chemistry journals, and a third cluster of plant science journals.

I also examined the Herbicide Biology clusters, Fig. B.18, and the Fungicide Biology clusters, Fig.B.19, for any signs of a division between biomedical and plant protection journals. This could be shown slightly for the herbicide source journals, though none was apparent with the cited journals. With the fungicide source journals distinct divisions emerge between a group of plant science/plant pathology journals and biomedical journals. The former also included a chemistry journal, and the latter a plant protection journal. The fungicide cited journal structure shows a cluster of plant pathology, botanical, and chemical journals. Another cluster contains a strongly interlinked group of biomedical journals joined through Industrial Engineering Chemistry to a plant protection and chemistry journal.

The journal structures for Insecticides, Fungicides and Herbicides which emerged from this exercise showed certain similarities: chemistry clusters, entomology/plant science clusters, agricultural clusters, and biomedical clusters were distinguishable. The journal analysis technique was able to expose, although crudely and imperfectly, the underlying disciplinary structure of six chemical control fields. If I had been able to utilise a more comprehensive journal citation base, within a consistent time frame, based upon the Citation Journal Reports (CJR) databases, the Michelet programmes could no doubt have produced less noisy maps.

Biological Control Fields

I analysed the Biological Control fields in the same fashion.

* Source journal structure between fields and journal frequencies.
* Journal citation structures, using Michelet's programme.

Before discussing my findings I must mention the need to bear in mind previous comments about the sampling frame differences between the Chemical Control and Biological Control databases. These differences mean that any comparisons have to be treated with care.

Table B.17 cross-tabulates 140 journals by method; journals which only appeared once in my sample are combined under the heading "others", they totalled 323 (40.4% of all journals in the sample). The prevalence of such "singletons" is worth noting, for in the Chemical Control database they accounted for only 19% of total journals.

An initial observation, therefore, has to be that the Biological Control fields have a more splintered structure. It might be that the prevalence of "singletons" is a crude indicator of field "coherence", that fields with more compact journal sets are in some way more cognitively focussed. One is speculating about an issue which the sociology of science has not yet come to grips with, nevertheless, what I term "coherence" is an observable and quantifiable phenomenon; different research fields may show different degrees of coherence in their journal sets. In the case of the Biological Control database the applied fields; Microbial Applied, Entomophagous Applied, and Integrated Control, are rather less coherent than the basic fields (Entomophagous Basic and Microbial Basic) and Autocidal Control. This could be something to do with relative states of maturity, although I suspect that the relative coherence of autocidal control reflects its small size, and the social fact that, during the time period I sampled, research was chiefly carried out by a relatively small group of American workers who had pioneered the technique.

In the database only 13 journals account for more than 1% or more of the total journal set. The most frequent is the J.E.E. (7%), followed by Canad. Entomol. (5.3%), and J. Ins. Path. (= J. Invert. Path.) (4.5%). These have quite distinct distributions between the research fields in the database. The J.E.E. is ubiquitous, providing source papers for each field, it provided over 27% of the Autocidal Control sample, and made relatively smaller contributions to basic than to applied fields. Canadian Entomol. was especially strongly represented in Entomophagous Basic, and to lesser degrees in Entomophagous Applied and Microbial Applied. The J. Insect Pathology (now J. Invertebrate Pathology) was found predominately in Microbial Basic and to a lesser extent in Microbial Applied - it is the dominant journal in insect microbiology, having been founded by Steinhaus.

My comments about the J. Ins. Path. raise the issue about journal concentrations in a field. Some journals like J.E.E. might appear ubiquitous, but only, of course, in databases of insect pest control. Others such as Science and Nature are truly omnipresent. Others may specialise in only a single field. The occurrence percentage of a journal in a field might be taken as an indicator of the journal's "specialisation". I therefore examined the database for journals whose occurrence was 90% concentrated in a single field, such journals might be considered highly specialised. Furthermore, the presence of such journals in field, assuming a reasonable amount of frequency, might be an indication of its maturity. As Moravcsik[15] has said " a new field is not really a new field until it has its own journal". All the fields in the database possessed journals with 90% specialisation, apart from Integrated Control and Autocidal Control, this observation raises the question whether, at the time of our survey, these two fields were research fields in their own right.

The Classification of Biological Control Journals

I used the same procedures as for the Chemical Control database. For two fields, Entomophagous Basic and Microbial Basic, the journal structures, for both source and cited journals, is far more complex than that found for any of the chemical control fields. This may be something to do with their lower coherence, as postulated above, or a greater cognitive complexity. With respect to the latter hypothesis one should note that the studies of entomophagous insects and insect microbiology have a very high observational, and systematic, content. Such papers tend to cite reports which are often published in specialised (obscure even) national and regional society journals, this leads to a highly varied network of journals, many journals being cited

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15. Moravcsik (1987).

only infrequently.

My concept of coherence raises many questions which I have not been able to investigate in this study. Coherence may be a result of political pressures, socio-economic forces, or cognitive factors, or amalgams of these.[16] For example, the development of a strong paradigm may lead to journal coherence, so might a focussing of resources by interested political or commercial groups. One might speculate further that strong paradigms might lead to tightly organised coherent journal networks, and conversely that difference in coherence reflect differences in paradigm strengths. On the other hand one should not ignore the role of socio-economic factors, thus if the Insecticide Control networks appear more coherent than those for Entomophagous Control it might be a result of economic rather than cognitive factors (in so far as one can make such a distinction). The evidence from journal relationship data alone is insufficient to answer such questions, a much broader base of information is required.

Using Michelet's programmes I was able to create a set of journal cluster diagrams for each field, and I shall now examine each of these diagrams in turn. Figs. B.20a/b show the source and cited journal clusters for Entomophagous Basic. In the source journal diagram cluster 1 includes the J.E.E. and several other applied journals, but it cannot be said to be a sharply demarcated plant protection cluster. Cluster 2 brings together applied journals plus the J. Insect of Physiology. Cluster 3 is heterogeneous and includes conference proceedings. Cluster 4 provides a set of European entomology journals.

[16]. These have been, to some extent, examined by Granberg (1981) in his study of biological control in Sweden. He notices that biological control lacks cohesion and is fragmented; this he argues is due to the "heterogeneity of problems, small isolated academic research groups, knowledge gaps in ecology, lack of appropriate R & D policies". pp. 26-33.

Cluster 5's are not entomological, but biological or zoological journals plus Science.

The cited journals have been classified into 9 clusters and are hard to interpret because they do not correspond to any obvious lines of distinction such as: systematics, ecology, experimental or physiology, applied control etc. Journals from such groupings were frequently found clustered together. There is, perhaps, evidence of clustering along lines of national origin of journals; cluster 1 are all European, and Cluster 4 are all North American.

The Entomophagous Applied data Figs. B.21a/b often failed to cluster, and only three small clusters emerged in both the source and cited journal diagrams. Source journal cluster 1 is interesting in that it brings together J.E.E. and Hilgardia - both prominent in the Chemical Control database - and Ecology. In the Chemical Control database the two former journals would link up with chemistry journals, in the Biological Control database chemistry is replaced by ecology; this would seem to be a characteristic distinction between the two databases.

Microbial Basic (Figs. B.22a/b) is characterised by the presence of applied entomology and microbiology journals. These two types are not separated by the clusterings, and almost all clusters provide a mixture of entomological and microbiological journals. The significance of the resulting clusters is unclear, apart from, in both source and cited journal diagrams, the clustering of Soviet journals together.

The journal clusters for Microbial Control Applied are comparatively simple (Figs. B.23/b). Cluster 1 in the source journal diagram brings J.E.E. and J. Ins. Pathol. together; the former is the leading economic entomology journal and the latter is the main journal for insect microbiology. The cited journal cluster 2 is particularly interesting because it strongly links four of the most significant applied entomology journals, including J. Ins. Path. Significantly, few of the wide range of journals which were also associated with Microbial Basic clustered. It would appear that apart from the four journals in cluster 1, along with some conference proceedings, Microbial Applied drew upon a relatively unstructured set of journals.

Integrated Control journal classifications are shown in Figs. B.24a/b. The two largest source journal clusters 1 and 2 comprise mixtures of entomology and pest control journals which are not easily interpreted. For the cited journals cluster 1 is composed of a pair of German journals. Cluster 2, the largest, links J.E.E. with entomology, agriculture, general science, and industrial chemistry journals. Cluster 3 comprises the pair Annals of Applied Biology and J. Animal Ecology, the cluster has a weak link to Cluster 2. Integrated control is concerned with using insecticides in an ecologically sound fashion, so it is important that we have been able to indicate through this latter link the connection between chemistry and ecology. In cluster 4, Entomophaga, a major biological control journal is linked to J. Horticultural Science. The pioneers of integrated control (e.g. Picken, Milne) used a highly ecological rhetoric but our source and cited journal clusters are composed for the most part of standard pest control journals, not ecology journals; perhaps this is an indication that the ecological ideas underlying integrated control succeeded, to some extent, in penetrating mainstream economic entomology R & D (this is explored somewhat, at the individual journal level, in a content analysis of the J.E.E.).

Autocidal control draws on genetic, radiological and chemical mutagenic techniques to sterilise or lower the fecundity of insect pests. Figs. B.25a/b show how journals in those fields relate to pest control journals. The source journal data show the main pest control journals grouped together in cluster three. Clusters 1 and 4 bring together radiation publications and a variety of biology and entomology journals. In the cited journals cluster 1 Nucleonics and J.E.E. are linked, and in cluster 4 the journal Entomology Expt. Applied is linked with journals from radiation research and genetics.

In conclusion, the pictures that emerged from the Biological Control database were messier and noisier than those obtained from the Chemical Control database. There are several possible explanations for this. The databases used different sampling frames, the Chemical Control source papers were "key papers" selected by Martin from a time period of over 50 years, the Biological control source papers were selected at random over a ten year period. The journal structures were different, Biological Control drew from a wider journal set. The cognitive structures of the fields differed, the biological control fields were less coherent than the chemical control ones.

Despite these difficulties a distinct signal did emerge through the noise. A similar core of pest control journals tended to be clustered for both Chemical Control and Biological Control. In the Chemical Control fields these journals linked with chemistry, chemical industry publications, patents, and agriculture. Whereas, in the Biological Control fields they linked more strongly with ecology, microbiology, genetics, radiation science. It has to be said, however, that the technique I have used was very time consuming; the database creation was done by hand, taking many man-weeks, and the results obtained were not, perhaps, commensurate with the effort. One hoped for results which produced relatively easy to interpret indicators of "hidden" research field structures. The interpretation of the resulting "pictures" is not obvious, not always amenable to simple examination, it may be that special procedures need to be devised, as with multidimensional scaling, to analyse fully the results; such a task is beyond this study. On the positive side one succeeded in identifying certain characteristics about the research field structures, although they were seldom unsuspected or surprising, which taken with data from the earlier parts of this chapter help one understand more fully factors underlying the division of insect pest control into chemical and biological controls. One characteristic which failed to emerge as strongly as I had anticipated was disciplinary distinction; each field might conceivably have shown very sharply characteristic clusters along disciplinary lines, however, clusters tended to be fuzzy. Of course, it is quite possible that is how they actually are, sharp distinctions may be abstract idealisations of the disciplinary structure of science in action. For this reason I sought an alternative means of looking at the disciplinary structures relating to economic entomology, one which could draw upon a database shorn of the drawbacks associated with the two databases I have just discussed.

Journal-Journal Maps of Economic Entomology and Related Disciplines

I drew upon the ISI Journal Citations Report 1984 for journal citation data. I used two sets of journals;

* Core cited journals from the Chemical and Biological Control databases. The six most frequent journals were selected from each field, some were not listed in the JCR and had to be abandoned, a total of 56 journals was so selected. This journal set was deemed most representative of the Chemical and Biological Control research fields. I called this the "core set".

* A further set of entomology journals was obtained by selecting the journals cited most frequently by the Annual Review of Entomology, some of these were also members of the previous set. This journal set was deemed most representative of entomology. I called it the "ARE" (Annual Review of Entomology) set.

The journals comprising both sets are listed by Table B.18.

The aim was to produce two sets of cited journal maps: from the first set of journals maps of economic entomology in relation to related disciplines; and from the second set maps of entomology. The former would allow one to situate the various insect control fields in relation to other disciplines, and the latter were intended to establish the internal structure of entomology itself.

I examined another approach in dealing with this data, multi-dimensional scaling (MDS). I used the form allowed by the Statistical Package for the Social Sciences (SPSSX).

Multi-dimensional Scaling (MDS)

"MDS is a set of mathematical techniques that enable a researcher discover the hidden structure of databases"[17]. In the study I used the ASCAL software on SPSSX. The MDS techniques

> "use proximities among any kind of objects as input. A proximity is a number which indicates how similar or different two objects are, or are perceived to be ... The chief output is a spacial representation consisting in a geometrical configuration of points, as on a map"[18].

The citations between journals given by the JCR are the proximity data.

Preparation of Data for Processing

I will deal with both sets of data together since they were treated in the same way. The journals were arranged in the form of a

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17. Kruskal and Wish (1978) p.5

18. Kruskal and Wish (1978) p.7.

square matrix and the number of times, according to the JCR, that each journal cited any other in the set was entered in the appropriate cell. The citation number was normalised with respect to the total number of citations accorded each journal. One then has a citation matrix for a journal set. There were often two sets of numbers in each cell, because citation between any journal pair is not necessarily symmetrical. This created a problem as to which figure to use in any calculation. I experimented with two approaches to dealing with this: I used the variance between the two figures, and I used the mean of the figures. The variance gave the most satisfactory results, that is produced patterns of which sense could be more easily made, so it was adopted. Kruskal and Wish, as I have noted, refer to MDS maps as a "geometric configuration of points", each point corresponding to an object, in our case a journal. They state that the purpose of such maps is to "reflect hidden structures" in the data in a more comprehensible manner, "by reflecting the data structure we mean that the larger the dissimilarity (or the smaller the similarity) between two objects, as shown by the proximity value, the further apart they should be in the special map"[19]. Maps may have two or more dimensions; clearly it becomes increasingly difficult to represent more than three graphically. In the hope of keeping things simple I used 2 dimensions, but at the risk of introducing distortions. I have also adopted a simple minded approach for analysing the maps, more systematic approaches exist, their choice requires specialist skills which I did not possess. As further support I would cite a standard introduction to MDS which argues that one "... of the most important methods of examination is simply to look at the arrangement of points, where each

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[19]. Kruskal and Wish (1978) p.7.

point has been labelled to indicate which object it represents"[20]. The danger with such an approach is that one is tempted to see patterns where none exist, or one overlooks them. I believe, and this is generally accepted by those who use MDS regularly, that where relationships are very strong both these errors are avoidable to someone familiar with the material being studied. I shall now discuss maps produced by MDS, in which the points represent journals.

Core Journal Map

Fig. B.26 is a 2 dimensional configuration produced from the core journal citation data. When one looks at the journals one assumes that one is able to situate a particular journal in a certain discipline or group of disciplines, that is one hopes to be able to use journals as a proxy for disciplines or sub-disciplines when considering the structure of research fields.

One way of interpreting this map is to superimpose on the axes two sets of characteristics. On the vertical one descends from "chemical" to "biological" and on the horizontal from the left one moves from "non-entomology" to "entomology". If one then examines the top right hand quadrant one can see 9 journals with a strong chemical "tinge", dealing with chemistry, pesticides, or biochemistry. Moving down to the bottom of this quadrant and slightly overspilling into the top of the bottom right hand quadrant one finds economic entomology and insect physiology journals. These include some of the most notable insect pest control journals such as J.E.E. The central area of the bottom right hand quadrant is occupied by entomology journals, some such as Entomophaga deal with insect control, however, as one moves down the quadrant they take on an ecological "tinge" e.g. Agric. Ecos. Ent. If

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[20]. Kruskal and Wish (1978) p.9.

one moves leftwards into the bottom left hand quadrant one enters a region occupied by ecology journals, which become less entomological as one travels to the left, e.g. J. Expt. Marine Biol. The top left hand quadrant contains at the bottom a set of micro-biological journals, and then as one moves upwards one enters a set of agricultural journals. This does not mean that agriculture and microbiology are close to each other, because of limited dimensionality the maps are spatially distorted to fit things in; it could be that a third dimension would separate them in more intuitively acceptable fashion.

If one examines key insect pest control journals in relation to chemistry, microbial, and ecology journals the picture seems intuitively sensible. I would expect the J.E.E. to lie somewhere between chemistry and ecology, and somewhat closer to the former, whilst being within the set of entomology journals. The J. Invertebrate Pathology is close to J.E.E., and within the entomology journal set, but slightly closer to microbiology journals (because I have used cited journal data I would not expect to find J. Inv. Path. within the microbial journals set, they would not cite it strongly, however, had I utilised citing data it may have moved closer to the microbial journals). Entomophaga and Canadian Entomol. are also in the entomology group but lie closer to the ecology journals than does J.E.E., and conversely further from the chemistry journals. This appears to be a most satisfactory representation of the core journal relationships. It is simple and a great deal more work could be done if one had the time, such as time series, and manipulating the data in further dimensions and so forth.

Entomology Journals Map

I used MDS to examine the cited journal relationships of some 50 predominantly entomology journals to examine where insect pest control journals lie within entomology as a whole. The resulting map is shown in Fig. B.27. This map presents greater interpretational problems than the preceding map; this is to be expected because the whole journal set deals fundamentally with the same subject - insects. Nevertheless one would expect the map to disclose certain distinctions between them. Thus, one might hope to see disclosed journal characteristics such as:

* basic and applied research
* insect physiology, biochemistry, and experimental
* theoretical
* systematics and classification
* entomological society publications, national etc.

Most importantly one would wish to see where the major insect pest control journals were situated, and in relation to specific control methods.

At first sight, as I have said, the map is not easily interpreted, however, if we rotate[21] the configuration striking characteristics emerge. Rotating the vertical axis 45 degrees one is able to observe a separation between applied and basic journals; or more precisely between entomological society journals and non-society journals. If one retains the existing horizontal axis one is able to note a tendency

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[21]. According to Kruskal and Wish (1978) pp.34-5. "The co-ordinates printed and plotted by the computer are not generally susceptible to direct interpretation ... (because) they represent the positions of the points along the coordinate axes, that is, the projections of points on the axes. Now it is permissible to rotate the configuration and if we do so these projections change quite drastically. The reason rotation is permissible is that configuration is based on the distances between the points. These distances do not change when the configuration is rotated, so they contain no information whatsoever as to what rotational position is "correct" for the configuration ... It is important to remember that solutions to ordinary multidimensional scaling ... are always subject to rotation. Since the configuration may be freely rotated, the coordinate axes are no more meaningful than lines in any other direction. Thus the coordinates as printed out are no more likely to be meaningful than the projections of the points on any arbitrary line".

for experimental journals to be on the left hand side and observational (i.e. dealing with systematics and classification) to lie to the right.

Using these axes one is able to make several observations about the journals found in the Chemical and Biological control databases. Six journals: Z. Angew. Ent., J.E.E., J. Invert. Path., Canad. Entomol., Mosquito News and Entomophaga are situated in the "applied" half, with the first three in the list being further into the "experimental" zone than the last three, which might be more observational. Also one can see that Z. Angew. Ent. and J.E.E. lie closer to a group of insect physiology journals.

One finds most of the national entomology society journals lie at the opposite pole of the "applied-basic" axis to the insect control journals; an exception is the Act. Ent. Sin., perhaps in China they are expected to carry out applied research.

The experimental, biochemistry, physiology, and morphology journals lie in the extreme left hand side of the "experimental-observational" axis.

To summarise the MDS map has distinguished the following characteristics in the entomological journal structure: applied, insect control journals; experimental journals; systematic, classification journals; entomology learned society journals. This picture would appear to make sense, to accord well with the accepted structure of entomology.[22]

A second group of observations which might be drawn from the MDS

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[22]. To check this I examined the standard entomological text book, Imms (1957) "A General Textbook of Entomology"; it is divided into three major sections: I Anatomy and Physiology, II Development and Meta-morphosis, III The Orders of Insects (Classification and Phylogeny). Parts I and III accord with my "experimental" and "observational" axis, since Imms is a "pure" textbook the "applied pest control" and "pure" division has no equivalent in the textbook.

data concerns the relationship of applied entomology to "experimental" and "systematic" entomology journals. Applied entomology journals relate to both groups, but there are faint indications that a more detailed analysis might subdivide the economic entomology journals into those that are more experimental in orientation and those which are more observational, or closer to systematics; J.E.E. is an example of the former, and Entomophaga of the latter.

CHAPTER 4

RESEARCH TRENDS BASED UPON A CONTENT ANALYSIS OF A CORE JOURNAL - THE JOURNAL OF ECONOMIC ENTOMOLOGY 1910 - 1985

Berelson[1] has defined content analysis as "a research technique for the objective, systematic and quantitative description of the manifest content of communication". It has a long history as a technique in social sciences[2]. It seemed appropriate for me to use content analysis to study research trends in a core journal dealing with economic entomology, on the assumption that the historical evolution and turning points would be made evident, and in a quantifiable manner.

Content analysis of the scientific literature is a well established, though relatively little practised, technique for tracing the development of scholarly research trends[3] In chapter 3 I presented an analysis of papers in Chemical Control and Biological Control; it was not sampled in a way to illuminate research trends, and my paper on trends in biological control confined its attention to a single decade. In short those databases were not suitable for use with content analysis. I considered taking a longitudinal sample of the economic entomology literature to produce a set of papers that might be subjected to content analysis. The statistical and logistic problems

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1. Berelson (1954) p.489.

2. Krippendorff (1980) pp.13-20. See Merton (1977) for a history of his own use of content analysis pp.24-16.

3. For example: White (1915), mathematics; Rainoff (1922), 18th and 19th century physics; Stevens (1932), botany; Allport and Brunner (1940), psychology; Shanas (1945), sociology.

(obtaining and translating papers) involved in a random longitudinal sampling of the whole literature looked insuperable. An alternative was to concentrate attention on a few journals or even a single journal, assuming that journals, or a journal, could be found which reflected the research spectrum of economic entomology over a long period of time. I identified two such English language journals, the Journal of Economic Entomology (USA) and the Annals of Applied Biology (UK).

The contents of both journals were analysed; however, in this chapter I will deal only with the analysis of the J.E.E.. A comparison of the two journals is provided in my paper "The Use of Citation Counting to Identify Research Trends".

A core journal is a journal which, for a given field, is central to the citations of other journals in the field. Such a journal will have certain characteristics: it will have a relatively high citation rating in comparison with other journals in the field; it will be prestigious in the sense that leading exponents of the field or discipline publish in it; it will publish land mark papers or at least keep abreast of important new trends and developments. A further characteristic for this study would be that the journal dealt with a broad spectrum of economic entomology research, and covered a long historical period. The journal analysis given in Chapter 3 shows that the J.E.E. meets these criteria. The major drawback of choosing a single source, even one which enjoys the advantages of the J.E.E., is that it may be biased by editorial policy, national background and so forth, and not be an adequate indicator of global trends. Let me deal with the last point first; my journal analysis data in Chapter 3 shows that the J.E.E. covers the spectrum of economic entomology sufficiently well to be used as an indicator of research trends. As to editorial bias, it may well have existed, however, that is not necessarily a disadvantage in the context of the study. The J.E.E. may well, and we believe that this can be shown, have been editorially committed to chemical control in some historic periods. How is one to interpret this - as a local bias going against the global trend or as a general bias derived from what was a global trend? I believe that the evidence points towards the latter. The question of a national bias is an important one. The journal is American and strongly reflects the American R & D scene in economic entomology. I have shown elsewhere that there is a distinct American bias which is reflected in differences between it and trends in the British journal Annals of Applied Biology[4], though the differences were a matter of degree. The American bias is therefore a characteristic of this study but it is not necessarily a disadvantage. American research exemplified to a sharp degree the "good" and the "evil" of insect pest control trends - they made the sharpest turn towards the latest insecticides, they experienced the resultant problems, and they were highly innovative in certain biotechnical alternative controls. The J.E.E. would, I assumed, reflect all this and in so doing provide valuable insights into the historical development of insect pest control.

The design of the study involved examining the contents of the J.E.E. over a complete year. A stratified sampling technique was used for the period 1910 - 1936, analysing the volumes for the years 1910, 1911, 1915, 1916, 1920, 1921, 1925, 1926, 1930, 1931, 1935, 1936. Thereafter the contents of all volumes were classified i.e. 1937 - 1985.

Within each annual volume the recording unit was a paper, I

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[4]. Rothman and Woodhead (1972) p.293.

excluded editorials, letters, short notes and obituaries etc. Each paper was classified according to a special scheme. Wherever possible a paper was placed within a single classificatory category. The actual classification was done by myself and a research assistant, trained by myself. A high degree of inter-observer agreement was obtained, and in the event of disagreement I was the final arbiter. The coding process was also tested for intra-observer constancy by coding certain volumes twice over a period of time. I will now discuss in further detail various aspects of the system. First the unitization scheme.

A classification scheme was used to analyse journal annual volumes into categories or thematic units. The size of a particular category or theme was determined by the number of papers assigned to it by the coder. The nature of the classification is of vital importance since, as Berelson has said[5] "Content analysis stands or falls by its categories". I have already discussed several potential classifications of economic entomology, and also insecticides. None of these schemes proved to be quite right for this content analysis and the one which was adopted has utilised elements from several schemes. Classificatory schemes should be "designed in terms of the particular problems under investigation"[6]. I was interested first of all in the division into "chemical and biological approaches", then in the kinds of chemical and biological approaches, and in the breakdown between classical biological control techniques and biotechnical techniques, especially novel techniques. Finally I wanted to see whether there were research trends on problems associated with the chemical approach.

Table 4.1 shows the subject classification that was finally

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[5]. Berelson (1954) p.510.

[6]. Berelson p.510.

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adopted as meeting my requirements. It can be seen that not all the categories are control methods. Categories 11 - 19 are to do with problems of insecticide use - a topic briefly touched upon in Chapter 2. Categories 21 -22 are on the biology of insect pests. A final category 55 is for papers which could not be categorised; these were often on bees.

Usually it was a fairly straightforward task to classify a paper into one of these categories, however, there were problematic papers and I developed a set of guidance notes for coding. Furthermore, in the light of experience, certain categories were found hard to distinguish from each other.

Categories 1 - 9 were concerned with insecticide control measures. Some papers dealt with insecticides in general and were assigned to group 1. Where many different kinds of compounds were discussed papers were coded as 1, however, in recent years it became clear that their emphasis was predominantly on organo-synthetic compounds and that the bulk of papers coded as 1 after 1945 might as well be coded as 6 - organic synthetic. Category 8, silica gel, included sorptive dusts. I made a distinction, perhaps not too logical but consistent with practice, between spraying techniques and fumigation, also most of the latter tend to be inorganics and my distinctions tended to pull such compounds out of the specific category for inorganic insecticides. I did not break insecticides into very fine detail since I already had a special case study on insecticide development. Acaricides were coded with organic synthetics.

My biology categories were problematic, apart from insect culture. Insect culture involved techniques and media, and is an important part of research into control methods, providing appropriate specimens for research on and testing of control compounds and control techniques.

The distinction between bionomics and biology became less clear in more modern times. My guidelines specified that bionomics would include papers dealing with: distribution of pests; character of injured crop; description of egg, larvae, pupae and adult; control measures which were combined with these, usually very rudimentary cultural or inorganics. Biology was coded for ecological studies, surveys and distribution, water content and desiccation, behavioral. In practice the dividing line became very fuzzy and it was hard to maintain a high level of coding consistency.

Biological control, categories 25 - 32, included a general category for articles which covered the whole spectrum of biological control techniques, or its philosophy. The others were categorised according to type of organism used. The very few papers dealing with control of plants by insects, were coded under parasites. Parasites referred to insect parasites e.g. Ichneumonidae, Braconidae etc. The categories Bacteria and Viruses also included papers where they were combined with chemicals.

Categories 34 - 54 included a wide variety of control techniques. I had hoped that they encapsulated all that were available, however, a few escaped the net. For example: mating disruptants, substances which adversely affect mating behaviour were coded under category 36, pheromones. Sterilants were divided into radiation and chemical, which should have included a third category, genetic, to deal with lethal genes and sub-sterility factors, and were coded in 55 - others.

Findings

First I shall indicate broad aggregate trends.

Insecticide papers increased from 10% in 1910 to over 60% by the mid 1940s; after 1950 they declined sharply from 63% to 56% in 1960 and rose in the mid 60s through the 1970s and mid 1980s.

Biology papers decline from 58% in 1910 to 40% in 1920, to 30% by the early 1940s, reaching their lowest level of 8% in 1950. Thereafter they rise to around 25% over the next five years, keeping that level throughout the sixties and seventies, rising in the eighties to 37% in 1985.

Insecticide problems and physiology papers as a category never rose above 8%, and were often few, until the late 1940s. During the fifties they sometimes rose to over 20%. Since the early 1960s it has declined steadily through to the mid 1970s since when it has remained at about 8%.

Biological Control papers have never been much above 8% during the journal's existence. Apart from odd years it has been fairly steady around 4 - 6%.

Other control methods (including biotechnical). This category is a mixed bag of techniques which, from the 1920s, account for a steady 10% or so. After 1945 they declined to 5 - 6% in the 1950s. Their recovery began in the 1960s, rising to 17% in 1965, and 33.8% in 1975, since when they have declined to around 20%.

These findings clearly demonstrate the swing away from biological research towards chemical control in the 1940s and 1950s. From the mid 1950s onwards the biological papers began to recover and were dominant again by the 1970s. Many people have argued that this turn around is a result of the pesticide controversy in the mid 1960s. This would appear, from this data, to be an oversimplification since biology was already making its comeback into the journal by the time the public debate began in America. This was probably a response to the problems which began to manifest themselves by the mid 1950s. The more biological approach of recent years has not led to any greater emphasis by the journal on biological control, although there has been a quintupling of papers on other alternative control methods since the insecticide peak in the mid 1950s. I thus find these major broad cycles in the history of the journal - prior to 1940 a mixture of chemistry and biology; after 1945 to 1960 the complete dominance of insecticide control and a third swing away from this to a new mixture of chemistry and biology.

My conclusions for the first two cycles of research are supported by the findings of Geier[7] and Jones[8]. Geier used a different classification scheme to mine; it was far more general. He broke papers down into two categories "essentially technological" and "substantially biological". He obtained

> "the yearly percentage of papers on pest control in which a purely technological approach was adopted ...compared with those of papers on similar subjects in which biological facts are given substantial and explicit consideration".

Table 4.2 Geier's Classification of Papers in J.E.E.

Year	Essentially technological		Substantially Biological		Others	
	No	% total	No	% total	No	% total
1933	69	27.8	71	28.7	108	43.5
1934	69	29.5	74	31.6	91	38.9
1943	96	37.2	74	28.7	88	34.1
1944	166	53.7	69	22.3	74	24.0
1953	162	46.0	92	26.1	98	27.9
1954	143	41.0	104	30.4	95	27.8
1963	92	28.7	122	38.0	107	33.3
1964	107	25.2	169	39.8	149	35.0

This distinction roughly corresponds to my categories "insecticides" and "biology" plus "biological control". He does not obtain the degree

7. Geier (1966).

8. Jones (1973) pp.326 - 327.

of decline for biology that I found, but he does confirm my findings as to the relative positions of the chemical and biological approaches. His findings are summarised in the above table.

Jones' findings provide further support for my analysis. He has also examined, in a general fashion, the patterns of research as mirrored by the J. Econ. Entomol. Jones table below shows the percentage of papers published in four categories. "Papers not specially concerned with control measures were classified under general biology; those concerned with control measures were assigned to insecticides, biological control or other measures or, occasionally apportioned to two categories".

Table 4.3 Jones' classification of papers in the J.E.E.

	Papers (percent) 1927 - 1970									
	1927	32	37	42	47	52	57	62	67	70
General Biology	45	40	27	28	13	13	23	16	20	22
Insecticides	44	46	58	60	76	79	64	62	42	43
Biological Control	3	7	6	8	4	3	7	8	9	6
Other measures	8	7	8	3	7	4	6	14	29	29

Jones concluded

> "Papers on general biology (including reports of pest incidence and damage, bionomics, ecology and physiology) were frequent during the 1920s and 1930s but by the late 1930s were being out numbered by reports on laboratory and field testing of insecticides, these latter heralding developments in the 1940s and 1950s, when pesticides clearly dominated the contents of the journal. In the 1960s the proportion of pesticide papers fell to prewar levels but without any apparent increase in papers devoted to biology".

Jones attributes the relatively low level of biology papers in the 1960s to the growth of interest in "other methods of control", which were of a biotechnical nature. Thus Jones concludes that "...On the whole the biological content of the journal increased greatly in the 1960s". He believes that biological control looks static, partly because of "... the seduction of contributions by the Journal of Invertebrate Pathology". Jones sees the outstanding change in the 1960s to be the growth of research on "novel methods" of control. Despite our different schemes of classification, and the general problem of subjectivity when classifying, the general picture which Jones draws is the same as my own; this provides some confirmation of the generalisability of the technique used.

Number of Papers Analysed

Papers were sampled from 49 volumes of J. Econ. Entomol.: 1910, 1911, 1915, 1916, 1920, 1921, 1925, 1926, 1930, 1931, 1935, 1936, and every year thereafter until 1973. The total number of papers classified was 13,403. Table 4.4 shows the average number of papers over five yearly periods from 1910 - 1985.

Table 4.4 Number of Papers Published by J.E.E.

Year	Five yearly averages
1910-14	77 *
* 1915-19	94 *
1920-24	78 *
1925-29	122 *
1930-34	179 *
1935-39	179
1940-44	177
1945-49	147
1950-54	180
1955-59	229
1960-64	274
1965-69	384
1970-74	369
1975-79	238
1980-85	278 **

(* n = 2) (** n = 6)

The largest number of papers for any one year was 501 in 1970 and the smallest 75 in 1911. The mean number of papers per year increased by over 230% from 1910 - 1939, and by another 230% between 1940 and 1970.

The "mean number of papers per year" increased by 361% between 1910 and 1985. Table 4.5 shows the percentages of papers contributed in various time periods. The journal published the greatest number of papers in the period 1960 - 1969.

Table 4.5 Percentages of Total Sample for a Series of Time Periods

Year	%
1910 - 19	2
1920 - 29	3
1930 - 39	9
1940 - 49	12
1950 - 59	15
1960 - 69	25
1970 - 79	23
1980 - 85	12

Papers concerned with Chemical Control and Insecticides

(Categories 1-20)

A total of 6,190 papers fell into these categories i.e. 46% of all papers classified.

Their distribution over time is given in table 4.6.

Table 4.6 Distribution of Chemical Control/Insecticide Papers over Time

Period	Number	% of total papers in period
1910-19	61	17
1920-29	105	26
1930-39	450	36
1940-49	962	60
1950-59	1,347	67
1960-69	1,571	50
1970-79	1,146.5	38
1980-85	548	33

In the early years of the period investigated only a minority of papers were classified into these categories, however, as one approached, and then entered, the 1930s the percentage of such papers grew steadily. In the 1940s it grew very rapidly, until the majority of papers were in the chemical control and insecticides categories, peaking at 67% in the 1950s period. Thereafter, the percentage declined and by the 1980s period the percentage of papers falling into the categories under discussion was 33%, almost down to that of the 1930s period.

The classification categories 1 - 20 can be sub-divided into 2 major sub-divisions:

a) "Insecticides" (groups 1 - 10)

b) "Problems of insecticides" (groups 111 - 20).

Their distribution over time is shown in Table 4.7.

Table 4.7 Distribution of Papers Between Insecticides and Problems of Insecticides

	Insecticides		Problems of insecticides	
Period	No.	% of total*	No.	% of total*
1910-19	53	87	8	13
1920-29	102	97	3	3
1930-39	409	91	41	9
1940-49	865	90	97	3
1950-59	1,009	75	338	25
1960-69	1,057	67	514	33
1970-79	811.5	71	331	29
1980-85	382	70	166	30

* % of total number of papers in categories 1 - 20 in this period

Until the 1950s the "Insecticide" group provided at least 87% of the papers in categories 1 - 20. "Problems with insecticides" was not a major part of the chemical control and insecticides group (categories 1 - 20) until the 1950s, however, the % of "problems" steeply increases to 25% and rises to 33% in the 1960s period, levelling off in the 1970s and 1980s to around 30%. There was a period in the 1930s when insecticide problems research increased, mostly covering arsenical insecticide residues on fruit crops.

"Insecticides" (Categories 1 -10)

Analysis of this group provides some insight into the changing research interests in the major categories of insecticides. In classifying papers I used the following categories for insecticides: natural plant; analogues, plant; inorganic; organic, synthetic; oils; silica; and fumigants, and I also have data on soaps (which turned out to be of minor importance). Their distribution is shown in Table 4.8.

Table 4.8 % of Papers on Insecticides in the Period for Each Category

Period	Natural plant	analogues plants	inorganic	organic synthetic	oils	silica	fumi-gants	soaps
1910-19	0	0	35	0	13	0	17	0
1920-29	10	0	42	4	19	0	9	0
1930-39	23	<1	28	10	11	0	9	1
1940-49	11	0	14	49	5	0	9	0
1950-59	5	1	1	87	1	<1	3	0
1960-69	1	<1	2	92	2	<1	2	0
1970-79	2	2	<1	84	1	<1	9	0
1980-85	6	16	<1	69	1	0	9	0

The pattern of research interest has changed considerably over the period 1910 - 1985. Interest in inorganic and oil-based insecticides had peaked by the 1930s and thereafter declined. Inorganics being ranked number one research interests through the first three decades, and oils was ranked 2nd in the 1920s. In the 1920s there was a growth in research papers on natural plant-based insecticides, whose publications reached a peak in the 1930s, when it ranked 2nd in interest after inorganic insecticides (having overtaken oils). In recent years there are signs of revived interest in botanical insecticides. Plant analogues, e.g. synthetic pyrethrum, made only scattered appearances from 1950 -1979; since then they have made a remarkable growth. Fumigants were the second ranked research area in the first period and although they declined there has been a fairly steady low key interest in them throughout the whole period, with signs of a revival since 1970.

The synthetic organic insecticides first begin to make a mark in the 1920s, rising to 10% of insecticide papers in the 1930s. During the 1940s they rise sharply to 49%, and first ranking interest - which they maintain thereafter. In the 1950s their percentage grows to 87%, rising to 92% by the 1960s at which level it remained until the 1970s. Since then it has declined by 20%. No other group so dominated insecticide types; there are now signs that this dominance is declining. It must be remembered that the available compounds are much greater in this category. The dramatic rise to ascendancy of organic synthetic insecticides can be seen by a detailed disaggregation of the 1940-49 period (Table 4.9), in which they are compared with inorganic insecticide papers, inorganics having previously been the dominant type.

Table 4.9 % of Category Insecticides: Inorganic and Organo-Synthetic. 1940-49

Category	1940	1941	1942	1943	1944	1945	1946	1947	1948	1949
Inorganic	33	24	30	36	14	10	6	1	0	0
Organo-synthetic	14	8	14	9	55	73	84	85	83	90

The sudden and dramatic growth in the percentage of papers on organic synthetic insecticides occurs in 1944. In 1943 the percentage of papers dealing with inorganic insecticides was four times that of organic insecticides, yet one year later their relative situations are completely reversed i.e. the percentage of papers dealing with organic insecticides is about four times that of inorganic. The reasons for such a dramatic change no doubt relate to the fact that synthetic organic insecticides were military secrets thus delaying publication, and also no doubt intensifying research effort so that when the "wraps" were taken off such research there would be an "explosion" of papers in a short time period. (The war time research has been touched upon in the insecticides trends case study.)

The analysis of the J.E.E. completely confirms the findings of the insecticides trends case study. It is important to note that it picks up the origins of organosynthetics in the 1930s, the decade preceding DDT etc.

Naturally there has been research into techniques of delivering insecticides to their targets and the papers in J. Econ. Entomol. reflect this research interest. However, it proved difficult to classify such papers since they were often concerned with particular compounds and so tended to be classified with insecticide types. In the 1920s there was a great interest shown in the respective merits of dusts and sprays. In the 1950s papers on insecticide granules appear and in the 1960s papers on high volume sprays, and surfactants. Unfortunately, given the manner of classification utilised this aspect of research may have been underestimated.

Problems of Insecticides (Categories 11 - 19)

This category comprises 9 sub-categories: insecticide resistance; pest replacement and resurgence; synergy; insecticide residues; effects on operators; effects on domestic and wild-life; effects on useful insects; physiology and metabolism of insecticides; effects on plants. The relative percentages of these categories within the group "problems of insecticides" is given in Table 4.10.

We may discount the first two periods because the actual samples of papers are so small, although one may note that papers on most of

Table 4.10 Categories as Percentages of Total Numbers of Papers Classified as Members of the Group "Problems of Insecticides"

Period	Resistance	Replacement & resurgence	Synergy	Residues	Effects: Operators	Effects: domestic & wildlife	Effects: Useful Insects	Physiology	Effects: Plants
1910-19	13	0	0	13	13	0	13	13	38
1920-29	67	0	0	0	0	33	0	0	0
1930-39	2	0	0	39	0	5	20	15	10
1940-49	14	2	0	25	0	12	19	21	9
1950-59	23	2	0	22	1	4	9	31	7
1960-69	32	1	1	26	0	6	4	29	3
1970-79	20	<1	1	32	<1	6	8	29	3
1980-85	42	<1	4	21	<1	2	13	10	6

the major problem areas are, in fact, to be found. In the 1930s "residues" were the major topic, followed by "effects on useful insects" (in those days invariably bees) and "the physiology and metabolism of insecticides". "Residues" remain a major category throughout the period of our investigation, usually comprising at least a quarter of papers on "problems of insecticides". After the 1940s the percentage of papers on "effects on useful insects" falls off, although numerous papers are still to be found throughout the later periods. Papers on "effects on domestic and wild life" reach their peak percentage in the 1940s, although they show a steady increase in the latest periods, since their lowest point - which was reached in the 1950s. "Physiological and metabolic studies" begin to become important in the 1930s and grow to 31% by the 1950s remaining fairly steady thereafter, however, a decline is apparent in the 1980s. Papers on "resistance to insecticides" are to be found even in the first period, nevertheless, it is clear that they become a significant research interest only by the 1940s. Thereafter the percentage of papers on this topic continues to grow until the 1970s when there is a falling off both in the percentage and absolute numbers of papers, until the 1980s when the percentage begins to grow. Papers on the "effects on plants" were relatively most important in the 1930s and 1940s, however, papers continued to be published, spasmodically, in the later periods.

"Residue problems" were undoubtedly of major importance in the pre-organic insecticide era, whereas resistance and physiological studies, despite an "existence" throughout the whole period of investigation, seem to have grown along with the rise of publications on synthetic organic insecticides. "Effects on operators" was not prominent, no doubt because such papers tended to be published in specialist journals of industrial health (there is evidence of their role in the chapter on the scientometric analysis of "Chemical control key papers - biological".

Biology (Categories 21-23)

Our sample included 3,617 papers which were classified into the category "Biology" and they comprised 27% of the total number of papers examined. Their distribution over the period 1910 - 1985 is shown in Table 4.11.

Table 4.11. Numbers of Papers in Biology Category

Period	Total	Mean	%[1]
*1910-14	83	42	55
*1915-19	103	52	55
*1920-24	75	38	49
*1925-29	96	48	39
*1930-34	141	71	40
1935-39	315	63	35
1940-44	204	41	23
1945-49	108	22	15
1950-54	123	25	14
1955-59	267	54	24
1960-64	309	62	23
1965-69	468	94	24
1970-74	391	78	21
1975-79	315	63	26
**1980-85	619	103	37

[1]. % of total number of papers in J.E.E.
* 2 years sampled ** 6 years sampled

During the first three periods (1910-24) "biological" papers dominated the journal, and throughout the 1930s they still provided at least 35% of papers. Throughout the 1940s the percentage of biology papers rapidly falls, reaching its lowest level - 14% - in the first half of the 1950s. Thereafter it rose to a level of over 37% by the 1980s. The last ground had been recovered. In absolute terms 315 papers were published in the second half of the 30s and it was not until the 1960s that this figure was again approached or surpassed within a similar time span. The fall in interest in "biology" during the 1940s and

1950s would appear to be associated with the intense interest in synthetic organic insecticides.

I experienced some difficulties in subdividing the "biology" group and various attempts were made to classify into groups such as "bionomics" and "ecology" etc. - none were very successful. Generally, 30-50% "biology" papers could be grouped as dealing with bionomics. The more specifically ecologically-based papers would appear to have increased absolutely and relatively from the late 1930s to the 60s; rising from 2% of biology papers to over 20%. However, this is based on a sampling of 16 out of 28 years from 1937-1964. Unfortunately no comparison is possible between "bionomics" and "ecology" because the 12 years in the overall period covered which were not examined for "ecology" papers were the years for which the classification unit "bionomics" was used. In any case for our purposes ecology would have been considered a subdivision of "bionomics".

"Insect culture" methods have an important role in economic entomology and this forms yet another sub-division of the "biology" category and the distribution of papers on this topic is shown in Table 4.12.

Table 4.12 Papers on Insect Culture

Period	Total insect culture	Insect culture as % biology
1910-19	1	<1
1920-29	2	1
1930-39	12	3
1940-49	10	3
1950-59	27	7
1960-69	91	12
1970-79	90	13
1980-85	48	8

< means 'less than'

Since the 1950s there has been a continuous growth, absolutely and relatively, of papers dealing with insect culture, and in the 1970s period 13% of the biology category was concerned with insect culture, however, there seems to have been a decline in the late 1970s and 1980s.

Biological Control (Categories 25-33)

Our sample contained 749 papers classified as "biological control"; their distribution over time is shown in Table 4.13.

Table 4.13 Papers on Biological Control

Period	Total	Mean	%[1]
1910-19	22	6*	6
1920-29	18	5*	5
1930-39	51	7**	4
1940-49	68	7	4
1950-59	110	11	5
1960-69	178	18	5
1970-79	179.5	18	6
1980-85	122.5	20	7

1. % of total number of papers in J.E.E.
* n = 4 ** n = 7

Prior to the 1950s the number of papers on biological control in J.E.E. averaged 5 - 7 per year, since then the number has steadily increased to a mean of 20 papers per year in the 1980s period. The percentage of papers on biological control per period in the journal remained constant at 5% throughout the bulk of the periods, and rose to 6% in the 1980s - the proportion as during the journal's first decade.

The Biological Control category was broken down into the following subdivisions: general; predators; insect parasites; fungi; bacteria; viruses; nematodes; protozoa. The distribution of the various biological control agents is shown in Table 4.14.

Table 4.14 % Distribution of Various Categories Within Biological Control

Period	Pred-ators	Insect parasites	Fungi	Bact-eria	Viruses	Nema-todes	Protozoa
1910-19	5	64	18	0	0	5	0
1920-29	6	61	0	6	0	0	0
1930-39	6	84	0	4	0	0	0
1940-49	4	60	3	15	3	3	0
1950-59	17	39	6	14	7	0	1
1960-69	17	46	1	14	11	3	1
1970-79	14	32	2	29	20	<1	<1
1980-85	7	20	3	37	22	6	<1

The most popular topic on biological control was "control by means of insect parasites" which accounted for over 50% of the papers on biological control in J.E.E. However, in the later periods it became less dominant than in the earlier ones as the percentages of papers on biological control via predators, bacteria and viruses grow. This growth began in the 1940s and 1950s. If one groups bacterial and viral control under the single heading of "microbial" control they become the second most popular biological control agent, rising to over 20% of the papers on biological control by the 1950s and almost 60% by the 1980s. Interest in fungi, nematodes and protozoan agents, as indicated by numbers of papers published is small, no more than 6% of the total, indeed they seem to have suffered a relative decline, although nematodes rose to 6% in the 1980s. However, the sample of such papers in J.E.E. is very small absolutely and the picture which emerges may be atypical of the situation outside this particular journal. The study of "Trends in Biological Control " indicated that in the 1960s microbial control research was one of the most rapidly growing fields.

Other Categories (34-55)

Integrated control as a concept had a great deal of popular support in the 1960s and first makes an identifiable appearance in the J.E.E. in 1947. Its publication trend was as follows.

Table 4.15 Integrated Control Papers

Period	1940-49	1950-59	1960-69	1970-79	1980-85	Total
Number	1	4	10	32	21	68

As can be seen it shows a steady growth rate, which appears to be still growing at the point where our analysis ends, however, as a percentage of total papers in the journal it never rises above 1%.

Attractants, repellents, and pheromones (categories 35,36,37) can be considered related control methods in so far as they are concerned with affecting insect movement by chemical means, although of course pheromones do so by a more scientifically based fashion, and are a relative newcomer to control.

Table 4.16 Number of Papers on Attractants etc.

Period	Attractants	Repellents	Pheromones
		Number of Papers	
1910-19	2	0	0
1920-29	12	5	0
1930-39	21	9	0
1940-49	21	25	0
1950-59	22	20	0
1960-69	21	25	74
1970-79	100	12	107.5
1980-85	54.5	0	41.5

The numbers of papers on attractants and repellents remained steady from the 1940s, except for the latest periods examined - where the papers on attractants more than doubled. Overall papers on attractants and repellents have each comprised about 1% of papers published by J.E.E., and int the 1970s the percentage rose to about 3%.

The growth in papers on pheromones is remarkable; over 220 being published since the first paper in 1960, they provided over 2% of all papers in the 1960s and over 3.5% in the 1970s. Their rate of growth is better indicated by a series of five year periods:

Table 4.17 Number of Papers on Pheromones

Period	1960-64	1965-69	1970-74	1975-79	1980-84
Papers	10	64	69	38.5	34

No other form of control exhibited such a rapid growth except synthetic organic insecticides in the 1940s and 1950s, and sterilants in the 1960s. The rate of growth has declined since the mid 1970s.

Antibiotics. Papers on this topic made their first appearance in the 1960s, but they never amounted to more than 2 papers in any single year.

Sterilants. (categories 39-40). Papers on this control concept first appeared in J.E.E. in 1951 and total of 457 papers were noted in the period under investigation. There are two major approaches to sterilising insects that are released for control; the actual mode of control is the same.

a) radiation sterilisation (39)

b) Chemical sterilants (40).

Their relative growth over time are shown in Table 4.18.

The radiation-based sterilisation papers started five years before the chemical sterilant papers, however, the latter rapidly overhauled the former so that by the end of the period under investigation, over 60% of the papers that had been published in this field were on chemical sterilants. The papers on this topic have made a large impact on the overall content of the J.E.E. Thus in the period 1960-69 the Table

4.18 Numbers of Papers on Sterilants

Period	Radiation	Chemical	Total
		Number of papers	
1950-54	1	0	1
1955-59	4	1	5
1960-64	1	28	29
1965-69	46	126	172
1970-79	103.5	112	215.5
1980-85	21	13.5	34.5
Total	176.5	280.5	457

"sterilants" category made up 6% of all papers and in 1970-73 this had risen to 20%, almost as high a percentage as papers on synthetic organic insecticides (23% over the same period). Research on autocidal control via sterile insects seems to have passed its peak by the mid 1970s and is in relative decline.

Antifeedants and feedants (41)

Papers on this topic begin to appear in the early 1960s and 50 papers had appeared in J.E.E. up to 1985; their distribution is shown below.

Table 4.19 Papers on Antifeedants etc.

Period	1960-64	1965-69	1970-74	1975-79	1980-84
Number	4	15	6	8.5	13

It seems that after a small flurry of papers in the period 1965-69 interest waned in the 1970s, but increased again in the 1980s.

Metabolic analogues (42)

Papers on this topic do not appear until the latter half of the 1960s; some 131 papers were recorded; 5 in the period 1965-69 and 108 in the period 1970-79 and 18.5 in the period 1980-85. This is obviously a rapidly growing research area in the early 1970s when it represented about 3% of the total number of papers in J.E.E., but in the late 1970s and 1980s the interest has waned somewhat.

Barriers (43)

The number of papers on this topic was 54, these were fairly evenly distributed over the whole period under investigation, which perhaps a slight upsurge in the early 1970s, dying down in the late 1970s and early 1980s. Obviously a topic of enduring, if not very exciting, interest.

Insect control using electromagnetic radiation (categories 44-50)

This is a conglomerate of categories containing 198 papers i.e. about 1.5% of J.E.E. papers analysed. This group was subdivided into further groups: light traps; infrared and heat; ultra violet; reflectants; radio waves; ionising radiation; electricity. The distribution of papers between those categories is given in Table 4.20.

Table 4.20 Number of Papers in "Electromagnetic Radiation" Category

Period	Light traps	Infrared & heat	U.V.	Reflect-ants	Radio	Ionising radiation	Elec.	Total
1910-19	1	1	0	0	0	0	0	2
1920-29	0	0	0	0	0	0	0	0
1930-39	15	0	0	0	3	0	2	20
1940-49	6	1	0	0	1	2	0	10
1950-59	8	2	3	0	1	5	0	19
1960-69	25	3	3	2	7	25	0	65
1970-79	27	5	4	5.5	1	20	4	66.5
1980-85	7.5	4	0	1	0	0	3	15.5
Total	89.5	16	10	8.5	13	52	9	198
% total	45	8	5	4	7	26	4	

Only 2 categories are of importance - "light traps" and "ionising radiation", the latter being a relatively recent newcomer to J.E.E., whereas light trap papers have appeared throughout the period of investigation.

Cultural Control (51). A total of 133 papers were classified as being on the topic of cultural control; that is, less than 1% of all J.E.E. papers. Papers appeared throughout the whole period investigated, peaking in the 1930s and showing a slight revival in the 1960s after a steep decline in the 1950s, and new peaks in the 1980s. Clearly this is an old approach which is being revitalised. The distribution if shown in Table 4.21.

Table 4.21 Numbers of Papers on Cultural Control

Year	Total	Mean
1910 - 19	7	1.75
1920 - 29	1	0.25
1930 - 39	21	3.0
1940 - 49	16	1.6
1950 - 59	5	0.5
1960 - 69	19	1.9
1970 - 79	23.5	2.3
1980 - 85	40.5	6.75
Total	133	

Quarantine and legislative controls (52)

During the early periods i.e. up to 1930s, this was a highly significant section of J.E.E., averaging over 5% of all papers.

Table 4.22 Papers on Quarantine etc.

Year	Number
1910 - 19	15
1920 - 29	21
1930 - 39	15
1940 - 49	17
1950 - 59	5
1960 - 69	4
1970 - 79	0
1980 - 85	0
Total	77

Thereafter, the percentage of papers declined, although the absolute number remained steady until the 1940s. Since the 1950s papers falling into this category have almost disappeared from J.E.E., see Table 4.22.

Plant resistance (53-54)

Papers have appeared on this topic since the 1920s. Their grand total is 461 in the sample, that is about 3.4% of the total. During the 1960s period there was a quadrupling of the number of papers published, and their percentage composition rose to nearly 4% of all papers in J.E.E., increasing to 6% in the 1980s. This is clearly a research area of increasing importance and represents an intensification of effort in an "old" research area. The topic was further analysed into "genetic" and "nutritional" aspects. The "genetic" type papers overwhelmingly predominated, although care has to be taken in interpreting this since classification was occasionally difficult. Table 4.23 summarises the situation with respect to "plant resistance".

Table 4.23 Plant Resistance Papers

Period	Genetic	Nutritional	Total	% of J.E.E.
1910-19	0	0	0	0
1920-29	3	0	3	1
1930-39	15	2	17	1
1940-49	24	5	29	2
1950-59	20	10	30	1.5
1960-69	114	15	129	4
1970-79	141.5	13.5	155	5
1980-85	85	13	98	6
Total	402.5	58.5	461	

Conclusions

The content analysis enabled me to distinguish a number of major trends and changes in research emphasis in the J.E.E. over a 75 year period.

1. The cyclical changes in the relationship between chemical and biological approaches. Initially the latter dominated, then after World War II the former gained the ascendancy and for a few years the biological approach dwindled to a very low level. It began to recover by the 1960s and today it might be said to predominate slightly.
2. The evolution of chemical types used as insecticides exactly confirms the findings of our more detailed case study on insecticides, furthermore it showed that organosynthetic insecticides were being studied by J.E.E. authors in the 1930s.
3. The rise of studies of control by organosynthetics was closely followed by a vast increase in publications on problems created by pesticide usage.
4. As these "problem" papers increase I found a growing trend, not only back to "biology", but also new toward biotechnical controls. The analysis shows most clearly the use of such techniques, as autocidal control (sterilisation) and the use of pheromones and metabolic analogues. After the 1960s there was a reinvestigation of "old" techniques of cultural control and plant resistance to pests.
5. Biological control after a post-war decline makes a comeback but does not reach the levels associated with some of the new bio-technical methods, further, microbial control appears to be growing more rapidly than traditional control by predators and parasites. This finding seems to support observations made in our

earlier study "Trends in Biological Control".

6. Content analysis has proven adequate, despite the difficulties outlined in the introduction, to present the changing pattern of research in the J.E.E. and confirm the belief that that journal mirrors surprisingly well the historical development of economic entomology.

CHAPTER 5.

HISTORICAL TRENDS IN INSECTICIDE RESEARCH: A CASE STUDY

Introduction

Our (Rothman and Lester, 1985) paper "The use of bibliometric indicators in the study of insecticide research" describes the techniques which I have used for identifying and analysing publication growth curves for insecticidal compounds. That paper, however, only provides a sketchy outline of the detailed results that I obtained. I have therefore written this case study, which draws upon the quantitative data provided by our scientometric techniques and discusses them in the light of a more wide ranging historical discussion.

It is necessary to make certain qualifications about the study. As a history it is exceedingly limited, as it does not deal fully with the socio-economic factors which have been intimately involved in the historical development of insecticides. Also it has little to add to what is already known about the individuals and companies concerned, drawing mostly on secondary sources, apart of course from my own quantitative data, which is quite unique. It is this uniqueness which in part explains some of the shortcomings of my study. I had to develop a methodology, or rather a series of techniques, collecting an enormous amount of data for analysis (the analytic work suffered from a change in computers which rendered useless special software developed by George Lester to carry out my analyses before it was completed). Furthermore, the history of insecticides is surprisingly underdeveloped. There is no standard reference work, material being scattered throughout many publications, usually dealing with other aspects of insecticides, or with specific compounds, companies, or periods. It was therefore not easy to design my study with respect to key historical problems in the development of insecticides. In any case my main task was to examine the suitability and utility of scientometrics for studying the project. It is my contention that this case study demonstrates the practicality of my approach, and opens the way to some future novel historical studies.

My approach involves providing: a brief overview of insecticide use from Classical to Modern times; a summary of insecticide research trends in the form of a historical series of insecticide research "league tables"; a discussion of insecticide classification schemes within which a historical study might be situated; finally, a systematic analysis of "important insecticides".

Throughout, I have illustrated the discussion with growth curves for the insecticides. These have been updated (compared to my (Rothman and Lester, 1985) published findings) to the year 1984, in order that major changes over the last decade could be noted.

Insecticides

Insecticides are chemical compounds that are used to kill insects. By the early 1970s more than 500[1] chemicals were available as insecticides. However, only a relatively small number dominate pest control practice and research.

A General History of Pesticides

Here I intend to briefly sketch out the history of the discovery and use of the insecticidal properties of chemical substances. It can be divided in periods

a) Ancient

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1. WHO (1974).

b) Post Renaissance, but pre-industrial revolution

c) Post-Industrial Revolution, - "First Generation" insecticide period

d) "Second Generation" insecticide period.

a. Ancient

The earliest pesticides to be used were probably organic materials of natural origin. A number of substances of botanical origin possess insecticidal properties and whilst we can fairly precisely indicate their first use by our own society we have little knowledge of the extent of their use by other societies, doubtless some were known. For example, certain South American tribes use preparations of the plant sabadilla as louse powders[2].

"Ancient classical society" based as it was on a well developed agriculture, had the need to develop some form of insect pest control. In the process of meeting this need they developed various control systems (probably mostly ineffectual, hence the key roles played by prayer and magic in warding off plague)[3], including some chemical controls[4]. The extracts of a wide variety of plants were also mentioned by classical writers[5].

Ancient Greece, we learn from Homer and Aristotle, knew of the therapeutic action of sulphur fumes. Democritus of Abdera writes of

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[2]. Mrak (1969) p.44.

[3]. The folklorist M.A.Murray (see Folklore, 1955) says that "there was an ancient belief that if a virgin performs certain ritual actions in the fields in spring, especially at dawn she destroys the pests which attack the crops ... one of the oldest recorded dances of this kind is in the Bible" ("Go and lie in wait in the vineyards; and see, and behold, if the daughters of Shi-loh come out to dance in dances" Judges XXI).

[4]. Much of this section is based on Van der Veen (1967).

[5]. A.E.Smith and D.M.Secoy "Forerunners of pesticides in classical Greece and Rome", Agric. Fd. Chem. 23, (6) 1050-1055, 1975.

treating seeds with "extract of dizoon" (probably Sedum acre, stonecrop).

Pliny the Elder (AD 23-79) living under the Roman Empire suggests the use of arsenic as an insecticide, pointing out also that care must be taken not to have the remedy cause disease by applying it too often or at the wrong time.

Ancient China also practised chemical controls, knowing of the insecticidal properties of arsenic, lime and potash as well as certain botanical substances.

Van der Veen comments[6]

> "From all this it is clear that a method of control by no means merits the epithet "modern" simply because it is chemical. One might with equal justification use the term "classical"; it is only in formulations such as sprays, dusts and aerosols that marked advances have been made. Although it is true that the number of agents used has increased enormously, several of the old agents, such as sulphur and arsenic are still in use".

b. Post Renaissance by Pre-Industrial Europe

In this period Europe recovered some of the lost knowledge of insecticides and began even to go beyond the knowledge of the ancient world. Partially this was a result of the economic success of mechantile capitalism in causing a flow of new knowledge and materials into Europe and the capitalisation of agriculture, and partially a result of the gradual replacement of superstition by scientific thought. After the collapse of the Roman Empire knowledge of pest control had fallen and the major agent of control was the Catholic Church. Various saints (including St. Bernard in 921) cursed insects to death! A later advance was to institute court action against pests, who were threatened with anathema on failure to appear. Van der Veen

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[6]. Van der Veen (1967) p.123.

cites[7] trials of cockchaffers (Arignon, 1320), locusts (Basle, 1481), caterpillars (Valence, 1585), Baumantan (1733), the last trial being in Denmark in 1830.

The development of the microscope and taxonomy led to increased understanding of the biology of pests and plant diseases. Tobacco extract was found to be insecticidal. The insecticidal properties of arsenic, sulphur and pyrethrums were discovered or rediscovered. Even a modern sounding decree appeared in Karlsruhe in 1808 "making it an offence to trade in toxic substances such as arsenic and corrosive sublimate (mercuric chloride $HgCl_2$) for insecticidal purposes, as there were other less dangerous preparations that could be used in their stead"[8].

The most useful guide to early insect control practices is to be found in a series of papers by Smith and Secoy dealing in turn with inorganic substances[9], organic substances[10], and plants[11].

c. Post-Industrial Revolution - First Generation Insecticide Period. c. 1850-1939.

The modern history of insecticides begins in the mid 19th century. The rise and growth of the industrial city, whose inhabitants could not feed themselves, led to the intensification and specialisation of agriculture, continuing to the present day, and a need to control

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7. Van der Veen (1967) p.125.

8. Van der Veen (1967) p.128 citing K.Kayer, 4500 Jahre Pflanzenschutz, Ulmer, Stuttgart, 1959.

9. Smith and Secoy, "A Compendium of Inorganic substances used in European pest control before 1850". Ag. Fd. Chem. 24 (6), 1180-1186, 1976.

10. Smith and Secoy "Organic material used in European crop protection before 1850", Chem. & Ind. 5 Nov. pp.863-869. 1977.

11. Smith and Secoy "Plants used for agriculture pest control in Western Europe before 1850", Chem & Ind. 3 Jan 1981, pp.12-17.

disease-carrying vermin in the closely-packed cities. Further, the development of modern imperialism[12] took the European into new territories, bringing him face to face with new diseases (often vector carried) and also creating new pests by transporting insects to new habitats. Thus the need for and the means of control (the products of the new and growing chemical industry) were part of the same macro-economic process, the development of industrial capitalism.

This was an era in which sensitivity to pest-created damage increased, appropriate scientific knowledge (about insects, plant pathology and medicine) increased, and the ability of industry to manufacture a wide range of chemical substances (on a scale and at a price suitable for mass markets) also increased. Thus one need not be surprised that it was at this period that the first stage in the increase in the number and range of insecticides, the "first generation" began. However, there is no evidence to show that this development ever owed as much to scientific deduction as it did to accidental discovery and empirical application. Initially there was a tendency to draw on compounds known to human toxicology[13], thus compounds of arsenic, lead and copper were amongst the first to be tried. Furthermore, such compounds were already produced in bulk as painters' pigments[14] e.g. Paris Green (a mixture containing a double arsenite and acetate of copper) and London Purple (a mixture containing arsenate and arsenite of copper).

Howard noted[15] that prior to c. 1860, when arsenical stomach

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[12]. Worboys (1972) particularly Chap. 3 "Imperial Science" pp.21-37.

[13]. Lefroy (1915) p.289.

[14]. Wardle and Buckle (1923) p.71.

[15]. Howard (1930) p.63.

poisons and dilute petroleum emulsions as contact poisons were introduced, the effective insecticides

> "were limited in number ... and not especially effective... Decoctions of quassia chips, hellebore, limewater and mixtures of ashes and several other things, together with what seemed to be an early use of nicotine fumes and tobacco water for plant lice, comprised about all".

Because of the great dearth of effective poisons available there was great scope for charlatans. A wide and various range of quack remedies were advertised.

> "In fact, the advertising of quack remedies went to such an extent that the real entomologists were inclined to frown down the whole idea of chemical insecticides. So strong was this feeling that it was expressed very forcibly in the opening editorial in the first number of The Practical Entomologist (October 30, 1865): 'The agricultural journals have from year to year, presented through their columns, various recipes, as preventive of the attacks, or destructive to the life, of the curculio, the apple moth, the squash bug, etc. The proposed decoctions and washes we are well satisfied, in the majority of instances, are as useless in application as they are ridiculous in composition, and if the work of destroying insects is to be accomplished satisfactorily, we feel confident that it will have to be the result of no chemical preparations,[16] but of simple means, directed by a knowledge and habits of the depredators".

At this point we may note two ironies of history arising out of this somewhat inauspicious birth of chemical pest control: Chemical means of control rather than the hoped for "simple means" based on biology eventually dominated pest control practice. The reasons why this occurred will be examined in our concluding chapter. Nowadays one tends to assume insecticide legislation to be a result of conservationist or medical lobbies. However, it was the preponderance of fake or charlatanistic remedies for insect pests in the last century which led, in the United States, to the earliest legislation to control the sale of insecticides. The first National Insecticide Act 1910 was intended to protect the consumer "against those products which bear

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[16]. Howard (1930) p.63.

misleading claims, which are absolute fakes, and which, while killing insects and fungi, may be injurious to the vegetation on which they are intended to be used"[17]. The struggle to incorporate into the Insecticide Act measures to protect the health of the consumer and the environment was a much later development[18].

For over 60 years relatively few compounds served as the standard insecticides and a change from one to another was as much influenced by fashion as by scientific understanding. Thus Lefroy wrote[19] in 1915, in a plea for a more scientific study of insecticides:

> "There is, I believe, a fashion in insecticides: at one time Paris Green and London Purple ruled; then came Lead Arsenate in America; this apparently giving place to Zinc Arsenate and Barium Arsenate ... So too for contact poisons. I remember the era in America of paraffin emulsions and resin washes; then came whale oil soap; lime salt and sulphur followed, then the heavy oils and then "miscible oils". The vogue of lysol and similar mixtures on the Continent has to be noted ..."

During the decade 1889-1899[20], Paris Green and London Purple reached their maximum use. Other substances in use included: pyrethrum, hellebore, whale oil, soaps, kerosene emulsions with soaps and milk, flowers of sulphur, carbon disulphide (fumigant), dinitro-orthocresol[21], resin washes, cyanide gas (fumigant), lead arsenate, and lime sulphur. The latter two substances were more recent innovations. The next decade 1900-19 saw[22] the full establishment of these two

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[17]. The most important features of the 1910 act are described in Howard (1930) p.145.

[18]. Whorton (1971) gives a detailed history of this struggle from 1865-1938.

[19]. Lefroy (1915) p.280.

[20]. Marlatt (1940).

[21]. It is a commonly believed fallacy that synthetic organic insecticides were not introduced until World War II.

[22]. Caesar (1940).

compounds, as well as a great increase in HCN fumigation.

The decade 1909-19 saw the introduction of calcium arsenate and zinc arsenate as well as paradicholorbenzene, naphthalene, sodium fluoride, chloropicrin (fumigant), borax, rotenone and nicotine dusts and compounds (particularly nicotine sulphate). Significantly Metcalf notes[23] "Investigations of the insecticidal value of certain lethal gases used in the war was the stimulus to insecticide innovation[24]. In Britain of this period Lefroy reports the following agents were in "fairly general use": lead arsenate, Paris Green (for caterpillars); soft soap and quassia (aphids); sulphur (red spider), caustic alkali wastes (for tree trunks); paraffin with water or soap (garden pests); lime, salt and sulphur mixtures (apple sucker); lime washes; nicotine ('a general panacea')[25].

The innovations of the decade centred on removing the disadvantages of oils by refining out the damaging (to the plant) unsaturated hydrocarbons.

Nothing startling occurred from 1918-1929[26] in the way of new agents, refined petroleum oil sprays were well established, as were lead arsenate, pyrethrum, derris and nicotine products. In the USA the 1927 regulations limiting the residue levels of arsenic on fruit acted as a spur to find arsenic substitutes and fluosilicates became an 'in' research area. Other compounds mentioned as important included; sodium fluosilicate, oryolate, barium fluosilicate, and as fumigants: calcium

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[23]. Metcalf (1940) p.23.

[24]. After all "The armaments industry is in the pest control business ... The definition (of a pest) is easily extended to the 'enemy' and so we need not be surprised if their is a carry over in technique between the two". Rothman (1972) p.182.

[25]. Lefroy (1915) pp.288-289.

[26]. Essig (1940).

cyanide, HCN, carbon disulphide, naphthalene, paradichlorbenzene, chloropiorine, carbon tetrachloride, and ethylene dichloride.

However, there had been no startling breakthroughs, perhaps for the reasons expressed in a standard work[27] of the period.

> "The restriction in choice of insecticides to substances whose toxic properties were more or less obvious, and the unfortunate tendency towards imitation of results have brought about a striking paucity in the variety of substances that are employed. The insecticide manufacturer and the agriculturalist have preferred to imitate and repeat the results of some chance discovery rather than investigate the insecticidal value of fresh substances"

The next decade, 1930-39, was different and it was than that the groundwork was prepared for the leap forward to what have been called "second generation insecticides". None of the compounds whose birth was publicly announced during the decade, however, matured to achieve the "fame and glory" that later accrued to DDT etc., and compounds such as calcium arsenate and botanical insecticides still dominated pest control research. Nevertheless the new growth in research effort, which was to bear a heavy fruit, was apparent. In 1940 Rohwer[28] wrote:

> "Insecticide chemists working closely with entomologists have developed new materials and reinvestigated old ones in the effort to find insecticides which do not leave objectionable or hazardous residues. **It is the decade of organic insecticidal research** (my emphasis H.R.). Ten years ago only an occasional patent was issued for a synthetic organic insecticide, and most of these were for moth-proofing wool. Today the greater part of the 100 patents issued annually for new insecticides relate to synthetic organic compounds for use in fly sprays or for the control of agricultural pests".

These included the organic thiocyanates (lethanes), which had some success as fly sprays.

d. <u>"Second Generation" Insecticide Period: Post 1939</u>

The 1940-50 decade included the Second World War, an added

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[27]. Wardle and Buckle (1922) p.72.

[28]. Rohwer (1940) p.61.

incentive to rapidly innovate those laboratory discoveries made in the 1930s. The Swiss firm of Geigy had already (in 1939) uncovered the rich insecticidal vein in organochlorine compounds, and G. Schräder's German team was opening up an even richer vein, organophosphorus compounds. Since I will examine the key innovations of this period at length later, it is necessary only to outline them at this stage.

i) Organochlorine compounds: DDT and derivatives, BHC, toxaphene, chlordane, aldrin, dieldrin, and endrin.

ii) Organophosphorus compounds: parathion, schradan, etc.

iii) Synthetic pyrethrin e.g. allethrin.

iv) Synergists, which increase the toxicity of scarce, expensive compounds such as pyrethrum.

The discovery of the synergistic properties of sesame seed oil (in 1938) led to the synthesis of related compounds which included piperonyl cyclodene and piperonyl butoxide.

Something of the new spirit can be derived from the article by Cahn in the 1946 edition of Progress in Applied Chemistry[29].

> "It is generally recognised that an "heroic age" of rapid development has set in for insecticides ... From the chemist's point of view, development of insecticides has been much slower than that of drugs, one reason being that insecticides must be available in exceedingly large quantities and that they had until recently to be very cheap... It is now fully realised by the chemical manufacturer that pest control is economically worthy of his consideration, and by the agriculturalist that it may be profitable to use relatively expensive chemicals... The stage is now being reached in which conflicting claims are made for a variety of synthetic chemicals, and it is clear that the field, large as it is, cannot find room for them all. The fierce competition already existing in curative medicine is extending to pest control and it is likely that this competition will continue with increasing vigour".

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[29]. Cahn (1946) pp.504-505.

This "Golden Age"[30] of economic entomology was crowned with the award of a Nobel prize for medicine to Müller, the discoverer of the insecticidal properties of DDT.

Brook[31] has pointed out the uniqueness of the innovative decade 1940-50, which saw the development of three distinct groups of insecticides: organochlorines (which are in reality three groups, DDT group, BHC, and cyclodienes), organophosphates, and carbamates. He opines the "reasons why these major discoveries occurred together at this particular point in time should make an interesting study for scientific historians".

It seems to me that the answer may begin in the late 1920s.

1. 1927 - Arsenical residue problems plus new legislation in the USA.

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[30]. Anon (1944) "In certain respects this might be called the 'Golden Age' of Entomology. Never in the history of this science has it risen to such heights of importance and recognition".

[31]. Brook, V.I. (1974) pp.140-1 raises an important historical question: "... we have a situation in which no less than four distinct groups of highly effective insecticidal chemicals were originated within ten years (DDT-group, BHC, cyclodiene, organophosphates - HR). Indeed, the number of groups increases to five if the carbamate anti-cholinesteroses are added to the list. The latter addition is valid since the development work on these last compounds was begun by the Geigy Company in 1947. One tends to wonder whether a similar situation will ever occur again. Whatever views may be held about the current use of modern insecticides, there is no doubt at all that the compounds which originated between 1940 and 1950 have made a major, but regrettably not widely appreciated, contribution to the well being of a large section of mankind, and the reasons why these major discoveries occurred together at this particular point in time should make an interesting study for scientific historians.

One must immediately admit that the interest in organo-phosphorus compounds arose from their military potentialities as anti-personnel toxicants; that the search for other anti-cholinesteroses should eventually lead to carbamates is logical, since water soluble examples of this class were already known to be effective cholinergic drugs. The origin of the organochlorine insecticides has no such basis, however, and although the war-time atmosphere undoubtedly accelerated the development of some of these discoveries, it must be remembered that one of the most significant contributions was made by a neutral nation. The lack of communications due to the war situation and the structural differences between DDT, cyclodiene, and HCH organo-chlorines emphasises the spontaneity of these discoveries in Europe and America".

2. The period 1930-39 in which chemists begin to search, partly because of the issue mentioned in (1), but also there seems to have been an interest in searching for moth proofing agents. The latter interest led, in certain companies, good dyestuff chemists to move in the insecticide field, they sought 'colourless' insecticidal dyes. It would be useful to know when general screening for several tasks (e.g. pest control) of all synthesised compounds within a firm begin to be routinised? I have not been able to find any published historical studies on this topic. The toxicological/structural studies on rotenone and pyrethrum also began in the 1930s, fed by a "scientific" approach to insecticides.

3. The immediate pre-war period was characterised by:

   i. Military toxicant studies.

   ii. Strategic fears about sources of raw materials e.g. Derris, Pyrethrum, and a search for synthetic alternative. It would be a useful historical study to find out exactly when this began.

4. The War time period. This seems to have been characterised by an improved ability to move from discovery to production quickly, a speed up in the tempo of innovation.

5. Immediate post-war period. The great success of DDT etc., led to willingness to invest in pest control R & D by many firms and government departments, and that intensified the rate of insecticide innovation.

6. The early 1930s were down in trade cycle - does this relate to basic research? The decade immediately preceding the decade of innovation i.e. the 1930s, was the low point of the third Kandratieff long wave, perhaps as Mensch and others have argued

this allowed the necessary creative process to open new areas of chemical innovation[32]. In the decade 1950-59 the range of organo-phosphorus compounds was extended in two directions

i. the development of systemic properties e.g. dimeton (systox), disulphoton, thiometon, phorate etc., and

ii. the development of organophosphorus compounds with a lower mammalian toxicity e.g. dicapton, fenitrothion, fenchlorphos, malathion, dichlorvos, etc.

A group of insecticidal compounds, the carbamates, was innovated e.g. dimetan, carbaryl.

Post 1960

The number of new organophosphorus and carbamate insecticides put on the market vastly increased, in part as a response to pressures to reduce the use of persistent organochlorine compounds.

New pyrethroids of very low mammalian toxicity were developed, these are more active than DDT and photostable (a drawback of pyrethrin itself was that it destabilised by prolonged exposure to light). A greater interest was taken in synergists: these include several of commercial importance piperonyl butoxide, sulfoxide, propyl-isome and Tropitol.

During the 1970s the declared aim of some researchers was the improvement of basic insecticides by better understanding of the biochemical processes involved in the intoxication and detoxication processes to produce safer Parathion type insecticides and develop biodegradable DDT analogues.

Finally, during the late 1960s and early 1970s there was a qualitative breakthrough, the isolation of substances which control the

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[32]. Mensch (1979).

growth and development of insects e.g. juvenile hormone. Such substances were hailed as [33] "third generation" insecticides. Because of their qualitatively distinct nature, I regard them as a distinct group - "biotechnical controls", I have not included them in this insecticide case study.

Research trends in Insecticides

These have been examined using bibliographic means, and present a picture which agrees quite well with that given above, which was derived from traditional historical sources. Full details of our bibliometric methodologies[34] are given elsewhere.

Figure 1 in Rothman and Lester (1985) is based on accumulated references in text books and covers the period up to 1970. It shows how arsenicals, rotenones, hydrocarbon oils, nicotine and pyrethrum had developed for decades before 1940, whereas chlorinated hyrdrocarbons and organophosphorus compounds begin after 1940, and carbamates in the 1950s. The "generation gap" is thus clearly expressed. The first generation compounds had a slower and more steady development, whereas the second generation insecticides show a more explosive growth rate. Further, it would seems that arsenicals and hydrocarbon oils having passed the inflection point, have essentially finished their development, and little new can be expected from them. The botanicals, rotenones and nicotine, and chlorinated hydrocarbons are rapidly approaching the inflection point, and interest may well be declining in their future development. However, pyrethrum, despite its long history would seem at that time to be still growing in its mature phase. Both organophosphorus and carbamates were still in their growth phase.

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[33]. Williams (1967).

[34]. Rothman and Lester (1985), this is included in the Appendix.

Table 5.1 shows a league table of 'research interest' in insecticides, lead arsenate was in a leading position from 1916 (when my data records begin) to the mid-1940s. The table clearly shows the emergence of interest in oil emulsions between 1920 and 1925, and the growing interest in botanicals, first nicotine (1925) and then derris and pyrethrum (1935). During the period 1916-1925 the old 19th century innovations, Paris Green, lime sulphur and fumigants hydrogen cyanide and carbon disulphide are phased out of the limelight. The change from first generation insecticides to second is shown dramatically in the period 1945-1950. Second generation insecticide compounds emerge from nowhere, so to speak, completely ousting the earlier insecticides from the centre of research interest.

The changes in the positions of compounds over the next 25 years shows that DDT and BHC were still highly researched but that there was a move towards non-organochlorine compounds, malathion entering the 'top five' in 1960, and the carbamate carbaryl in 1965. However, it is worthy of note that in 1970, the youngest compound, carbaryl, was introduced in 1956, and the dates of introduction of others, 1939, 1942, 1946 and 1950 - a fairly old 'establishment'.

By 1975 only DDT remains of that 'establishment'. Dimethoate heads the table, it is a moderately toxic organophosphorus systemic insecticide developed by American Cyanamid and Montecatini. Malathion and carbaryl are still listed, and have been joined by endosulphan. Endosulphan was developed in 1956 by Farbenwerke Hoechst, it is a broad spectrum, moderately toxic organophosphorus compound.

Table 5.1 "A League Table of Research Interest"

The five most frequently indexed insecticides in the Rev. Appl. Ent. (Series A)

Year	Compound	References No.	% of total of top five	Year of Origin (according to Martin)
1916	lead arsenate	111	29	1894
	paris green	84	22	1867
	carbon bisulphide	82	21	1854
	hydrogen cyanide	56	15	1886
	lime-sulphur	50	13	1886
1920	lead arsenate	139	29	
	lime	125	26	
	carbon bisulphide	75	15	
	hydrogen cyanide	74	15	
	paris green)	73	15	
	(soap))	71	15	(1842)
1925	lead arsenate	310	33	
	oil emulsion	210	22	c.1900
	nicotine	168	17	
	lime-sulphur	136	14	
	nicotine-sulphate	131	14	
1930	oil emulsions	356	30	
	lead arsenate	340	29	
	nicotine	165	14	
	nicotine-sulphate	165	14	
	calcium arsenate	155	13	c.1906
1935	oil emulsions	400	28	
	lead arsenate	374	25	
	pyrethrum	238	15	
	nicotine-sulphate	227	15	
	derris	216	14	
1940	lead arsenate	371	25	
	oil emulsions	293	19	
	derris	269	18	
	pyrethrum	227	15	
	nicotine	175	12	
	(calcium arsenate)	173	12)	
1945	oil emulsions	274	28	
	lead arsenate	203	20	
	derris	183	19	
	nicotine	165	17	
	cryolite	161	17	1929

Table 5.1 (cont)

1950	DDT	1,408	39	1939
	BHC	938	26	1942
	parathion	535	15	1946
	chlordane	445	12	1945
	toxaphene	324	9	1947
1955	DDT	742	32	
	BHC	698	30	
	parathion	458	20	
	dieldrin	233	10	1948
	toxaphene	199	8	
1960	DDT	601	31	
	BHC	548	28	
	parathion	283	15	
	dieldrin	273	14	
	malathion	230	12	1950
1965	DDT	234	38	
	BHC	174	22	
	parathion	145	18	
	malathion	118	15	
	carbaryl	114	15	1956
1970	DDT	252	33	
	BHC	160	21	
	carbaryl	128	17	
	malathion	118	15	
	parathion	114	15	
1975	dimethoate	253	24	1956
	DDT	230	22	
	malathion	208	20	
	carbaryl	187	17	
	endosulphan	171	16	1956
1980	carbaryl	148	21	
	carbofuran	148	21	1965
	chlorpyrifos	145	20	1965
	malathion	138	19	
	dimethoate	134	19	
1984	permethrim	260	25	1973
	deltamethrin	206	20	1975
	fenvalerate	205	20	1975
	cypermethrin	197	19	1975
	fenitrothion	161	16	1959

In 1980 DDT at last drops out, having been there for 35 years. Here carbamate compounds, somewhat later developments than the organochlorine and organophosphorus insecticides, occupy the top two places, carbaryl and carbofuran, the latter has entered for the first time. The other new entrant is chloropyrifos, an organophosphorus broad spectrum, moderately toxic compound developed in 1965 by Dow Chemical.

I have not got 1985 data so I have used that for 1984. This shows a major, perhaps revolutionary, change in which the research emphasis has moved dramatically to synthetic pyrethroids, which occupy the first four places. As I explain later these stemmed to a large degree from research carried out at Rothamstead. Since these four compounds only appeared in the mid-1970s the rapidity of their rise to prominence rivals that of DDT et al. in 1945. The fifth place is also occupied by a newcomer, fenitrothion, a low toxicity organophosphorus compound developed in 1959.

The Major Types of Insecticides

There are, as we have already seen, a very wide range of agents with which chemical control can be brought about. In this section I shall identify the most important agents, important historically as well as in contemporary practice. I shall pay attention to the reasons why certain agents were selected rather than alternatives, what forces determined this choice?

To provide the necessary data base I examine a series of key compounds, the choice of which is based on the analysis of research trends summarised in Table 5.1 and Appendix A[35], paying special attention to:

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[35]. The appendix contains a copy of a print-out of the original data.

a. History

(i) Innovation

(ii) Use and research trends

b. Mode of action

c. Key advantages and disadvantages

The Classification of Insecticides

There are several alternative ways of structuring our discussion depending on how we agree to classify insecticides. Classificatory systems have been based on:

a. Chemical structure and origin

b. Mode of action

c. Mode of penetration

d. Mode of delivery

Thus each can be expanded to provide the following schemes of classification:

a. Chemical Structure and Origin

i. Inorganic

ii. Hydrocarbon oils

iii. Botanical insecticides

iv. Synthetic organic; chlorinated hydrocarbons, organophosphorus and carbamates

b. Mode of Action[36]

i. Physical toxicant e.g. silica gel

ii. Anti-SH-enzymes and protein coagulants e.g. arsenicals

iii. Enzyme inhibitors e.g. fluorine compounds

iv. Neuro-active interferants

1. Acetylcholinesterase inhibition e.g. carbamates,

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[36]. O'Brien (1967).

organo-phosphorus compounds

2. Axonal transmission inhibitors e.g. DDT etc., pyrethroids

3. Acetocholine receptor interferant e.g. Nicotine

4. Unknown neutral action e.g. cyclodienes.

c. Mode of Penetration

i. Stomach poison e.g. metallic compounds

ii. Contact poison e.g. pyrethroids

iii. Systemic poison e.g. systox

iv. Fumigant

v. Dipping fluids

d. Mode of Delivery

i. Spray

ii. Dust

iii. Granule

iv. Systemic

v. Fumigant

vi. Dipping fluid

Each of these classifications has points in its favour and the one which is adopted depends very much on the nature of the discussion one wishes it to structure.

Classification (a) 'chemical structure' is a compromise between chemistry, and the historical development of insecticide production. (b) 'mode of action' is perhaps the most scientifically rational, being based on our biochemical and toxicological understanding of insecticides, however, it does not relate directly either to the historical development of insecticides or current technological practice. (c) 'mode of penetration' combines "pre-science" and traditional technical practice and is rarely used in modern textbooks although it is found in older works[37].

The mode of penetration can be partially related to structural characteristics of insects; in particular the two general types of insect mouth parts. First those with biting mouth parts where the insect obtains its food by chewing a leaf. If a thin layer of insecticide is placed on a leaf, it is ingested along with the leaf substance. The toxicity of the insecticide then depends upon the amount of leaf food ingested and on the effectiveness of the insecticide (the higher the effectiveness the less food will need to be eaten). However, in the second type, those with <u>sucking</u> mouthparts, it is clear that a stomach poison would be ineffective. The insect punctures a leaf and sucks up the plant sap for food and thus only a contact, systemic (i.e. in the sap), or respiratory (fumigant) toxicant could be used to control it (although naturally the larvae of this type can be controlled by stomach poisons if they possess biting mouthparts, as for example one finds in lepidopterous insects).

A contact poison has to work in a different way to a stomach poison; some act by way of the tracheal system (as do respiratory fumigant poisons), others penetrate through the cuticle to reach the nervous system. In connection with cuticle penetration lipoid solubility is an excellent property enabling the poison to pass through the outermost 'waterproof' epi-cuticle layer of the cuticle. This positive property is, unfortunately, also responsible for some of the unwanted consequences of insecticides.

(d) 'mode of delivery' is a purely technical classification which, since most agents can be formulated to be delivered in many or all of these listed modes, tells us little of scientific importance.

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[37]. Wardle and Buckle (1923) p.84.

I have chosen classification (a) chemical structure as a framework for the discussion of available insecticide possibilities, not because it is a perfectly scientifically rational classification, but because it is a convenient compromise. It has a certain scientifical validity and yet is flexible enough to enable the historical and technical perspectives to be contained without too much 'jumping around'. The other classifications are either scientific but too rigid for our historical perspective (e.g. (b)), or whilst conforming to technical reality and practice do no have enough relationship to scientific knowledge, (e.g. (c) and (d)).

Important Insecticides

I shall discuss those compounds which appear in Table 5.1, showing the five most indexed compounds. The year in brackets refers to those years in which the compounds were in the five most indexed insecticides.

1. Inorganic Compounds. I shall examine:

   i. Arsenic group; Paris Green (1916), lead arsenate (1916, 20, 25, 30, 35, 40, 45) and calcium arsenate (1940).

   ii. Lime (1920) and Lime sulphur (1916, 25).

   iii. Carbon disulphide (1916)

   iv. Hydrogen cyanide (1916, 20)

   v. Cryolite, sodium aluminofluoride (1945).

   "Broadly speaking inorganic compounds are not soluble in fats and can be insecticidal only if digested, for which reason this group are stomach poisons..."[38]

Paris Green

Paris Green is a compound of copper acetate and copper arsenite of formula $(CH_3COO)_2Cu.3Cu(ASO_2)_2$, and was originally made from the raw

[38]. Martin (1973) p.170.

material verdigris; it possesses a most variable composition. Most of the technical improvements of the insecticide were concerned with producing a standard product[39].

History

Originally the substance was a widely used pigment for making green paint. Just how its insecticidal properties became known is not recorded. Perhaps it was a simple empirical extrapolation of human toxicology, combined with the easy availability of a cheap arsenic compound. Essig[40] relates, without supporting evidence, a "rumour that a farmer threw away some old green paint on to his potatoes which were infested with Colorado beetle, and to his surprise the nest was wiped out". Be that as it may, by 1870 Paris Green was, in the words of C.V. Riley[41] "the remedy for Colorado potato beetle ... the best yet discovered". However, by the second decade of the 20th century it had been generally ousted by lead arsenate.

Research trend

Interest in Paris Green was to steadily decline in the period of our investigation, see Figure 5.1. Paris Green, although an "excellent insecticide"[42] had certain liabilities; a tendency to ready hydrolysis to form a water-soluble arsenic, variable composition, a tendency to scorch foliage and poor adhesivity[43]

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[39]. Content of water soluble arsenic trioxide to be below 3.5%; to contain at least 55% total arsenic oxide, 30% cupric oxide, and 10% acetic acid. Martin (1973) p.171.

[40]. Quoted in Essig (1931) p.424.

[41]. Essig (1931) p.424.

[42]. Martin (1973) p.171.

[43]. Wardle and Buckle (1923) p.86.

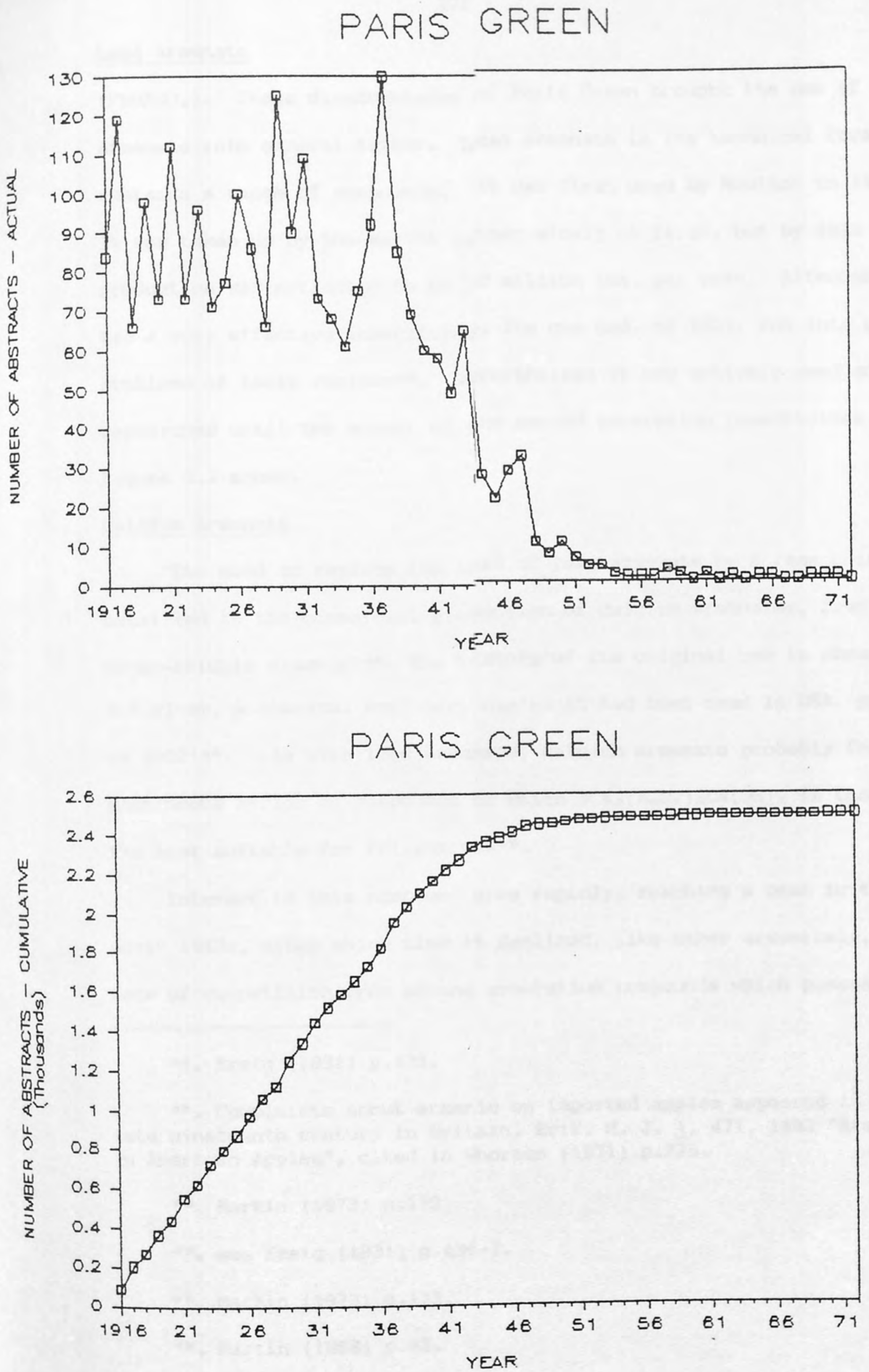
PARIS GREEN
NUMBER OF ABSTRACTS - ACTUAL
YEAR
PARIS GREEN
NUMBER OF ABSTRACTS - CUMULATIVE (Thousands)
YEAR

Fig. 5.1

Lead arsenate

($PbHAsO_4$). These disadvantages of Paris Green brought the use of lead arsenate into general favour. Lead arsenate in its technical form contains a range of compounds. It was first used by Moulton in 1892[44]. It was taken up by the market rather slowly at first, but by 1918 U.S. production was estimated to be 30 million lbs. per year. Although it was a very effective insecticide, its use had, by 1927, run into grave problems of toxic residue[45]. Nevertheless it was actively used and researched until the advent of the second generation insecticides, as Figure 5.2 shows.

Calcium Arsenate

"The need to replace the lead of lead arsenate by a less poisonous metal led to the commercial production of calcium arsenates, free from water-soluble arsenic"[46]. The history of its original use is obscure[47], W.C.Piver, a chemical engineer, claims it had been used in USA 'prior to 1907'[48]. As with lead arsenate, calcium arsenate probably forms a continuous series of compounds of which $3Ca_3(AsO_4)_2Ca(OH)_2$ is thought the most suitable for foliage use[49].

Interest in this compound grew rapidly, reaching a peak in the early 1940s, since which time it declined, like other arsenicals, in face of competition from second generation compounds which possessed a

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44. Essig (1931) p.433.

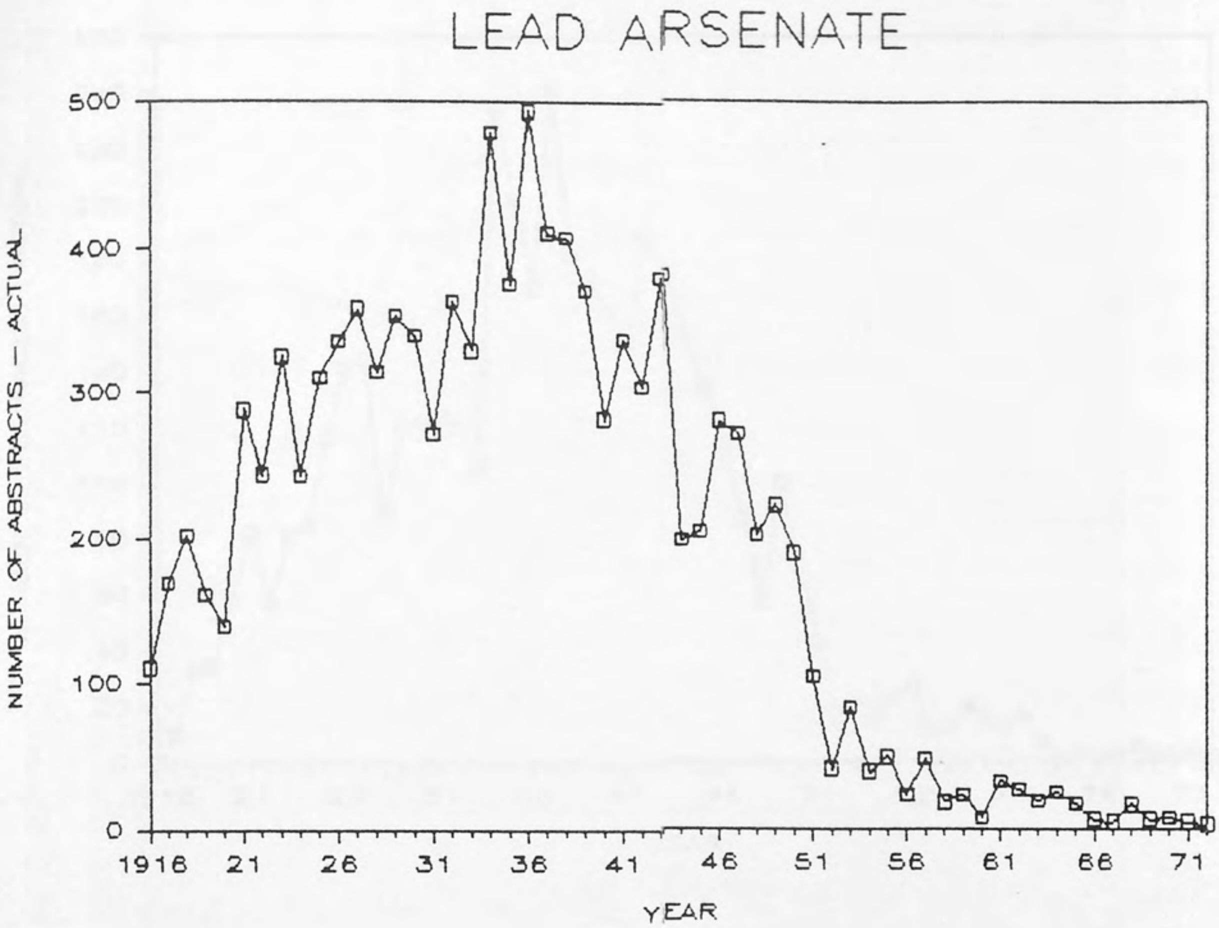
45. Complaints about arsenic on imported apples appeared in the late nineteenth century in Britain, Brit. M. J. 1, 471, 1892 "Arsenic in American Apples", cited in Whorton (1971) p.235.

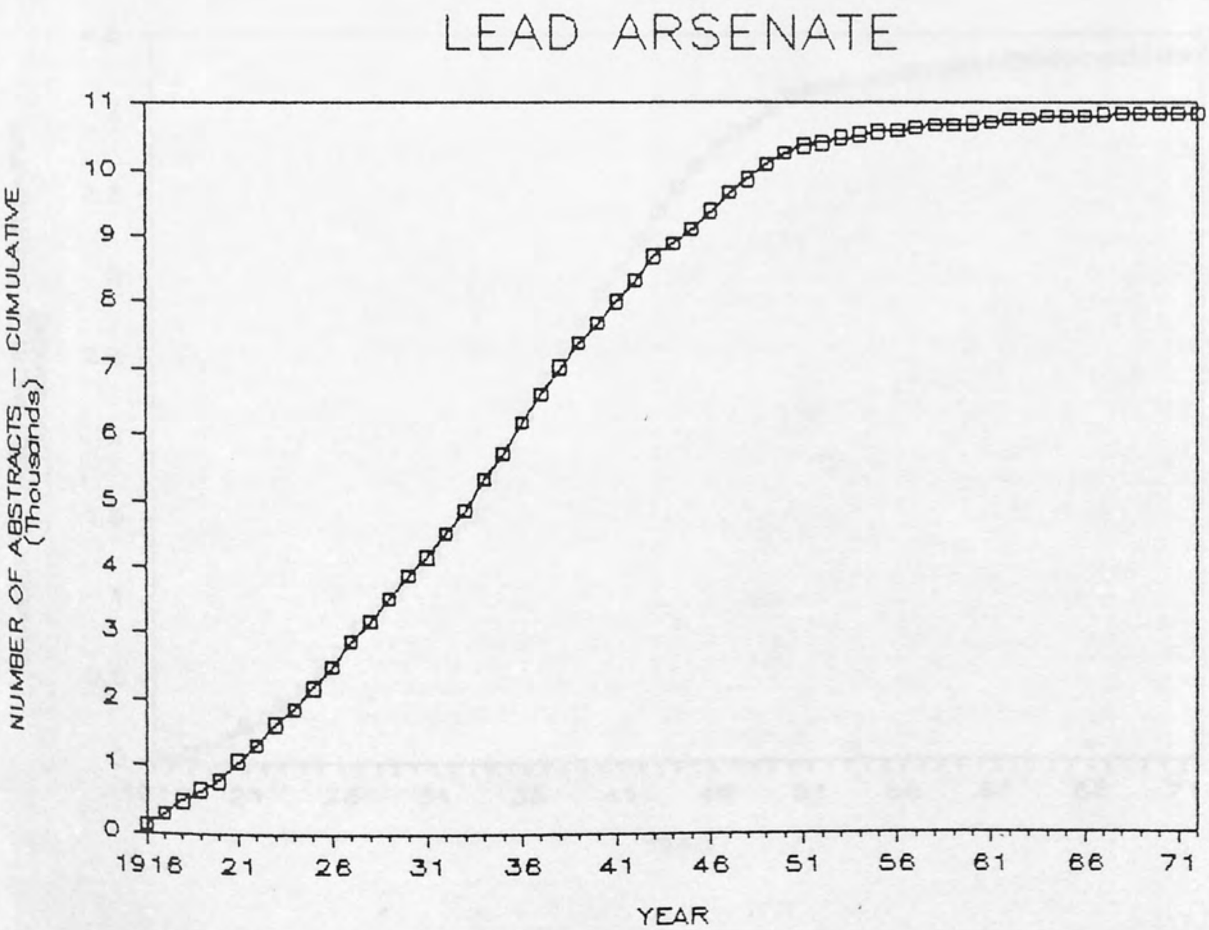
46. Martin (1973) p.172.

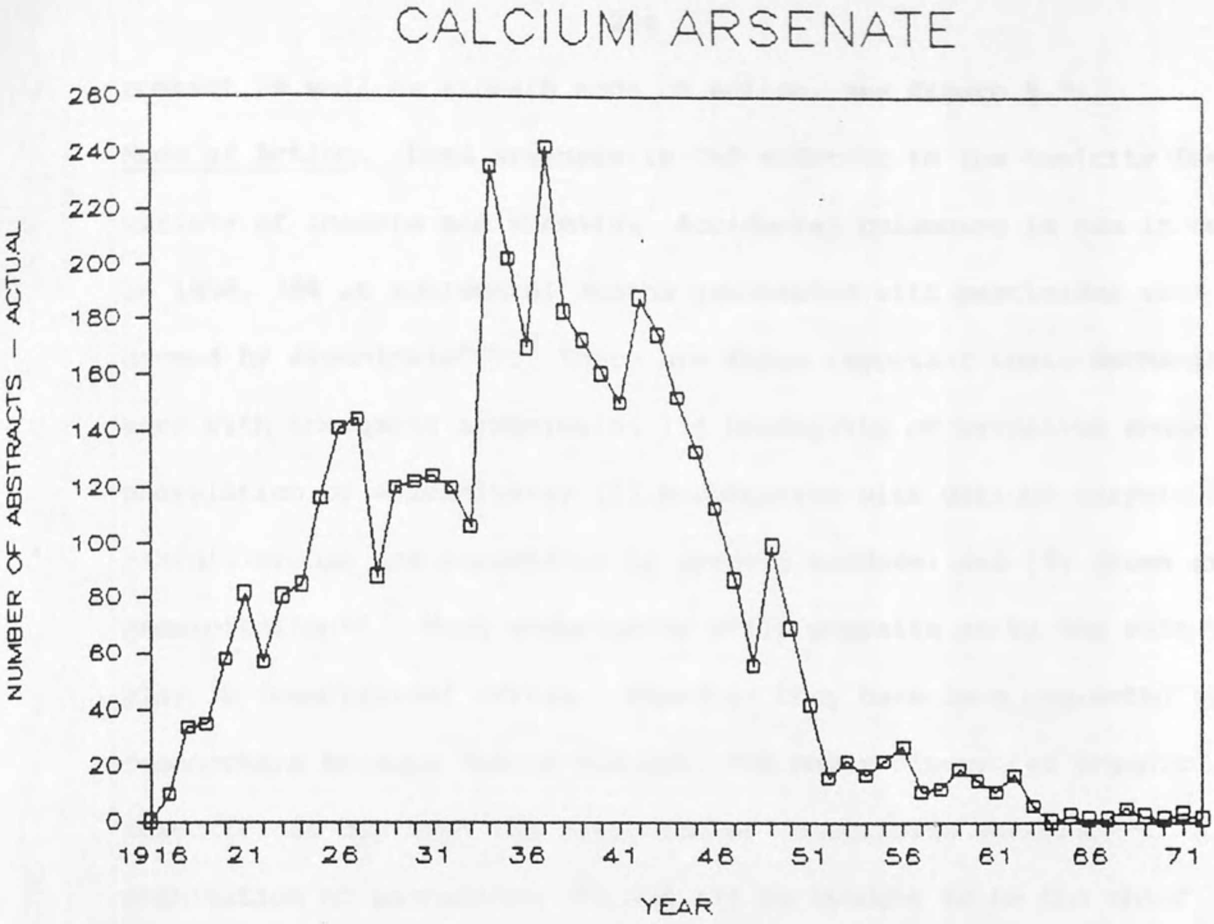
47. see Essig (1931) p.436-7.

48. Martin (1973) p.173.

49. Martin (1968) p.62.


LEAD ARSENATE
NUMBER OF ABSTRACTS — ACTUAL
500
400
300
200
100
0
1916
21
26
31
36
41
46
51
56
61
66
71
YEAR


LEAD ARSENATE
NUMBER OF ABSTRACTS — CUMULATIVE
(Thousands)
11
10
9
8
7
6
5
4
3
2
1
0
1916
21
26
31
36
41
46
51
56
61
66
71
YEAR


CALCIUM ARSENATE
NUMBER OF ABSTRACTS — ACTUAL
0
20
40
60
80
100
120
140
160
180
200
220
240
260
1916
21
26
31
36
41
46
51
56
61
66
71
YEAR

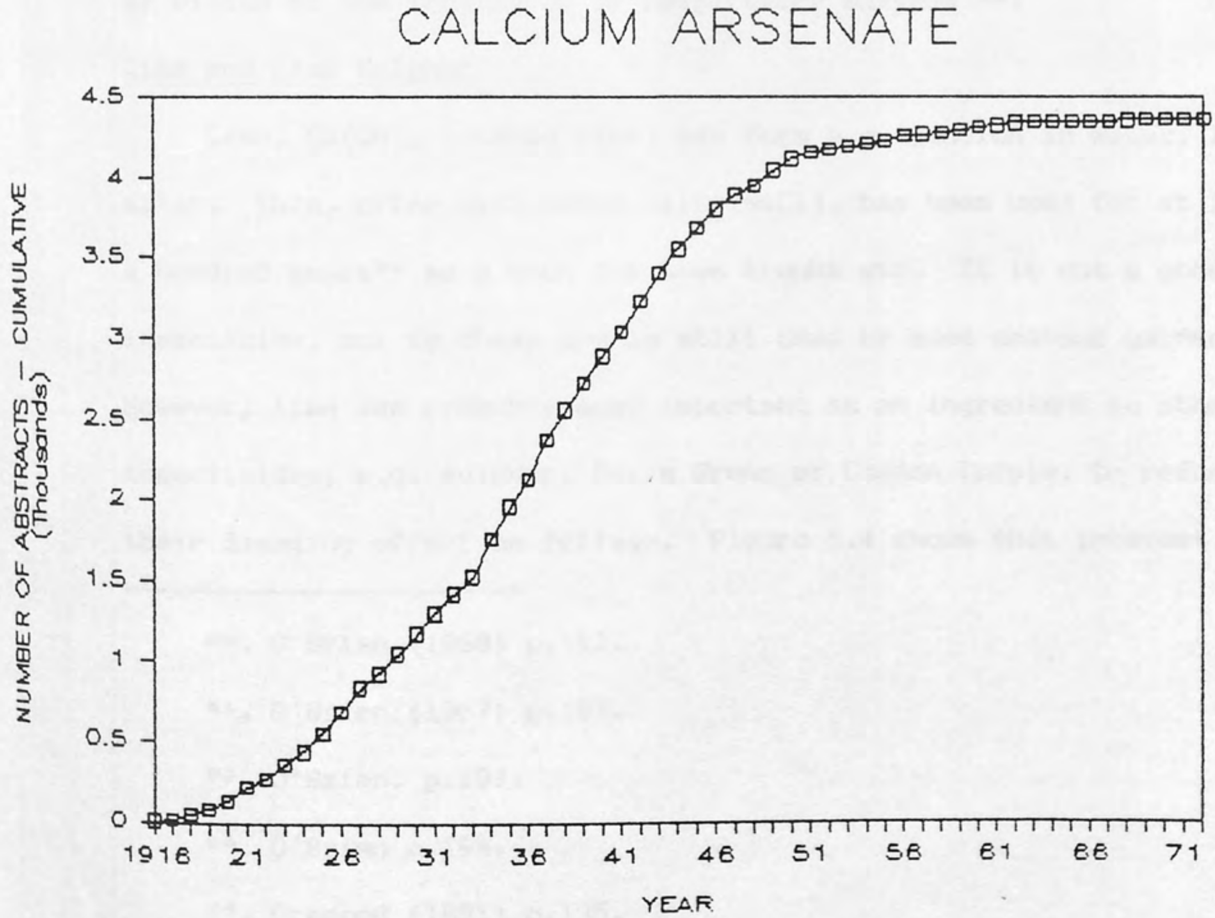

CALCIUM ARSENATE
NUMBER OF ABSTRACTS — CUMULATIVE (Thousands)
0
0.5
1
1.5
2
2.5
3
3.5
4
4.5
1916
21
26
31
36
41
46
51
56
61
66
71
YEAR

Fig. 5.3

contact as well as stomach mode of action, see figure 5.3.

Mode of Action. Lead arsenate is "of moderate to low toxicity for a variety of insects and mammals. Accidental poisoning in man is common; in 1956, 35% of accidental deaths associated with pesticides were caused by arsenicals"[50]. There are three important toxic mechanisms at work with inorganic arsenicals: (1) uncoupling of oxidative phosphorylation by arsenolysis; (2) combination with various enzymic S-H (thiol) groups and especially in pyruvic oxidase: and (3) gross protein precipitation[51]. Much uncertainty still prevails as to the role these play in insecticidal action. Possibly they have been neglected by researchers because "after the war, the newly discovered organic insecticides captured the attention of insecticide workers"[52]. A combination of mechanisms (1) and (2) is thought to be the chief insecticidal mechanism, and that "inorganic arsenicals kill primarily by virtue of the inhibition of respiratory enzymes"[53].

Lime and Lime Sulphur

Lime, $Ca(OH)_2$ (slaked lime) can form a suspension in water, lime water. This, often with added salt (NaCl), has been used for at least a hundred years[54] as a wash for tree trunks etc. It is not a good insecticide, but is cheap and is still used by some amateur gardeners. However, lime was probably most important as an ingredient to other insecticides, e.g. sulphur, Paris Green or London Purple, to reduce their damaging effect on foliage. Figure 5.4 shows that interest in it

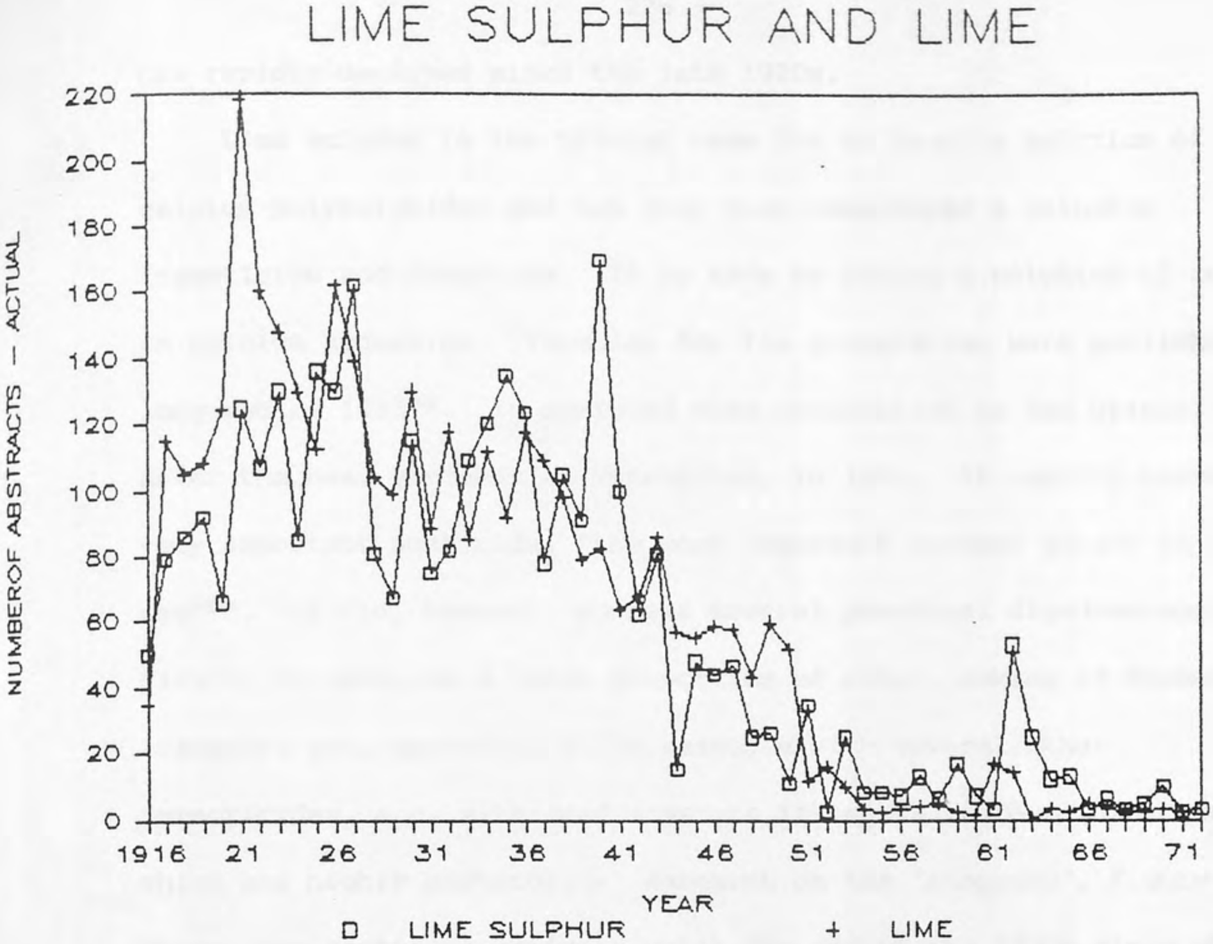
[50]. O'Brien (1968) p.192.

[51]. O'Brien (1967) p.193.

[52]. O'Brien. p.197.

[53]. O'Brien p.198.

[54]. Ormerod (1881) p.195.


LIME SULPHUR AND LIME
NUMBEROF ABSTRACTS — ACTUAL
220
200
180
160
140
120
100
80
60
40
20
0
1916
21
26
31
36
41
46
51
56
61
66
71
YEAR
□ LIME SULPHUR
+ LIME

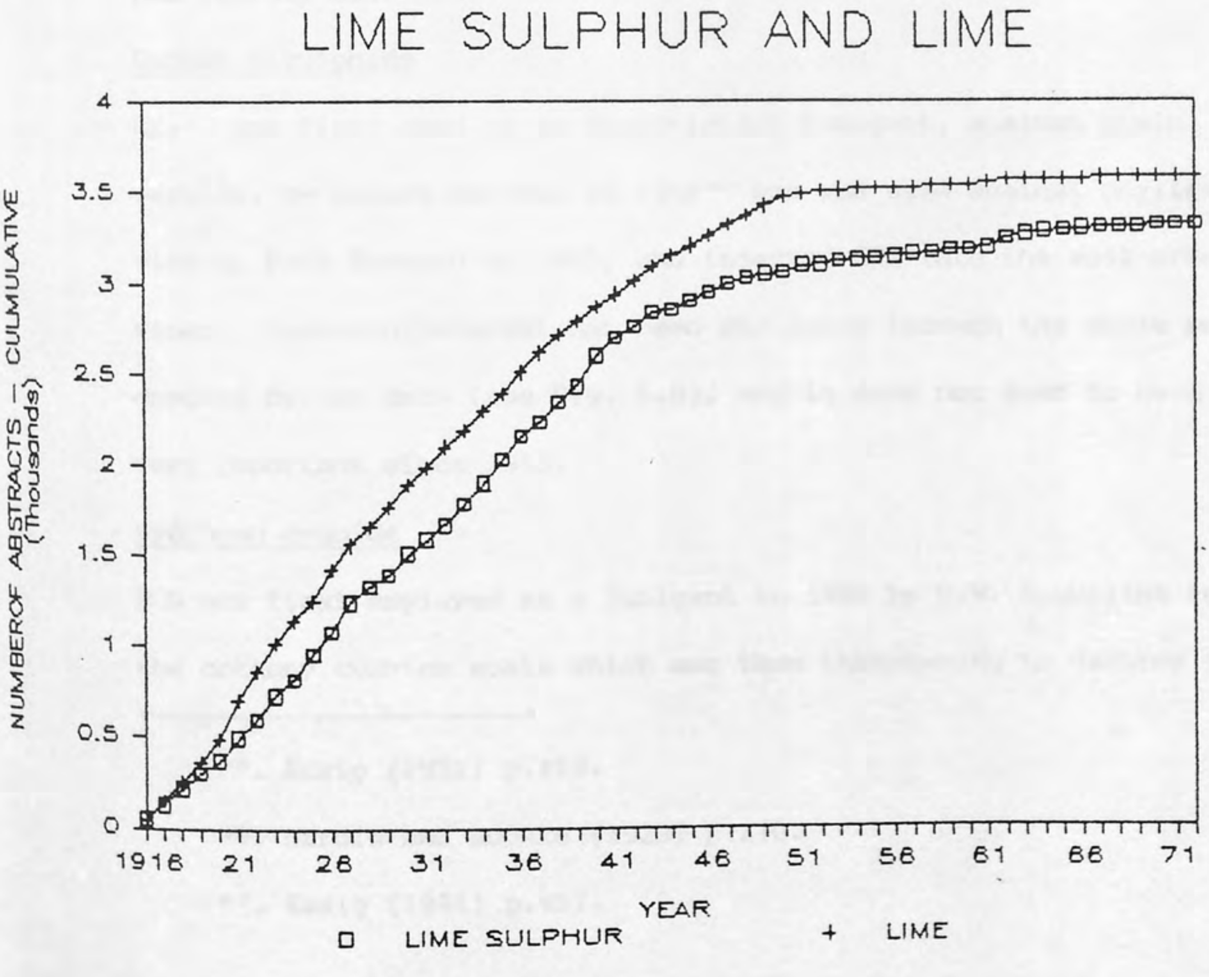

LIME SULPHUR AND LIME
NUMBEROF ABSTRACTS — CULMULATIVE (Thousands)
4
3.5
3
2.5
2
1.5
1
0.5
0
1916
21
26
31
36
41
46
51
56
61
66
71
YEAR
□ LIME SULPHUR
+ LIME

Fig. 5.4

has rapidly declined since the late 1920s.

Lime sulphur is the trivial name for an aqueous solution of calcium polysulphides and has long been considered a valuable insecticide and fungicide. It is made by mixing a solution of sulphur in calcium hydroxide. Formulae for its preparation were published as long ago as 1833[55]. It achieved wide recognition as Eau Grison, named after the head gardener at Versailles, in 1851. It rapidly became a very important pesticide, "the most important contact poison in common use"[56]. It did, however, possess several practical disadvantages. Firstly it contains a large proportion of water, making it expensive to transport and, secondly, it is reactive with several other insecticides, e.g. with lead arsenate it reacts to form thioarsenates, which are highly phytotoxic. Research on the 'compound', Figure 5.4 shows, was continued actively until the end of the 1930s since when it has rapidly declined.

Carbon disulphide

CS_2 - was first used as an insecticidal fumigant, against grain weevils, by Lazare Gerreau in 1854[57] and was used against phylloxera of vine by Paul Thenard in 1859, who injected CS_2 into the soil around the vines. Research interest has been declining through the whole period covered by our data (see Fig. 5.5), and it does not seem to have been very important since 1916.

Hydrogen cyanide

HCN was first employed as a fumigant in 1886 by D.W. Coquillet against the cottony cushion scale which was then threatening to destroy the

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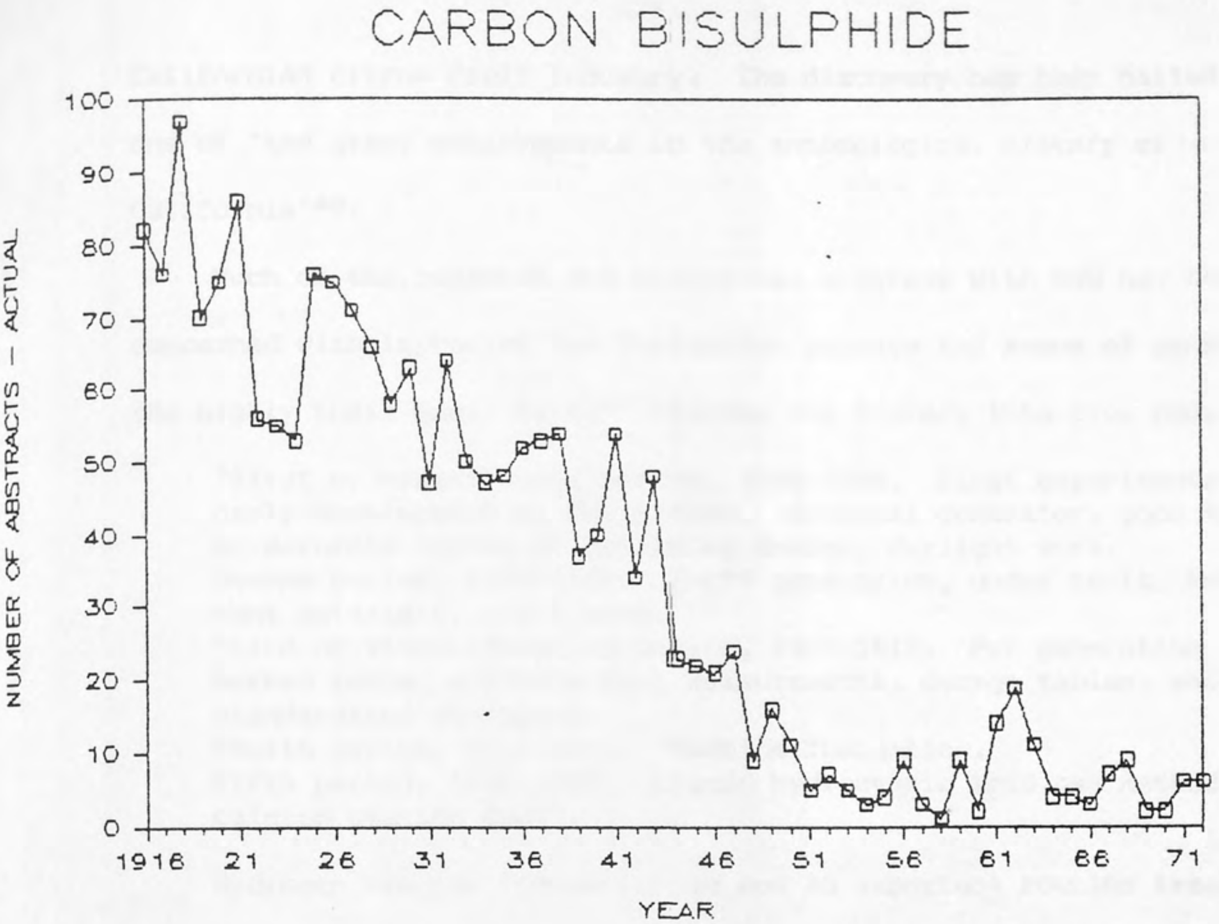
[55]. Essig (1931) p.453.

[56]. Wardle and Buckle (1923) p.110.

[57]. Essig (1931) p.457.


CARBON BISULPHIDE
NUMBER OF ABSTRACTS — ACTUAL
0
10
20
30
40
50
60
70
80
90
100
YEAR
1916
21
26
31
36
41
46
51
56
61
66
71

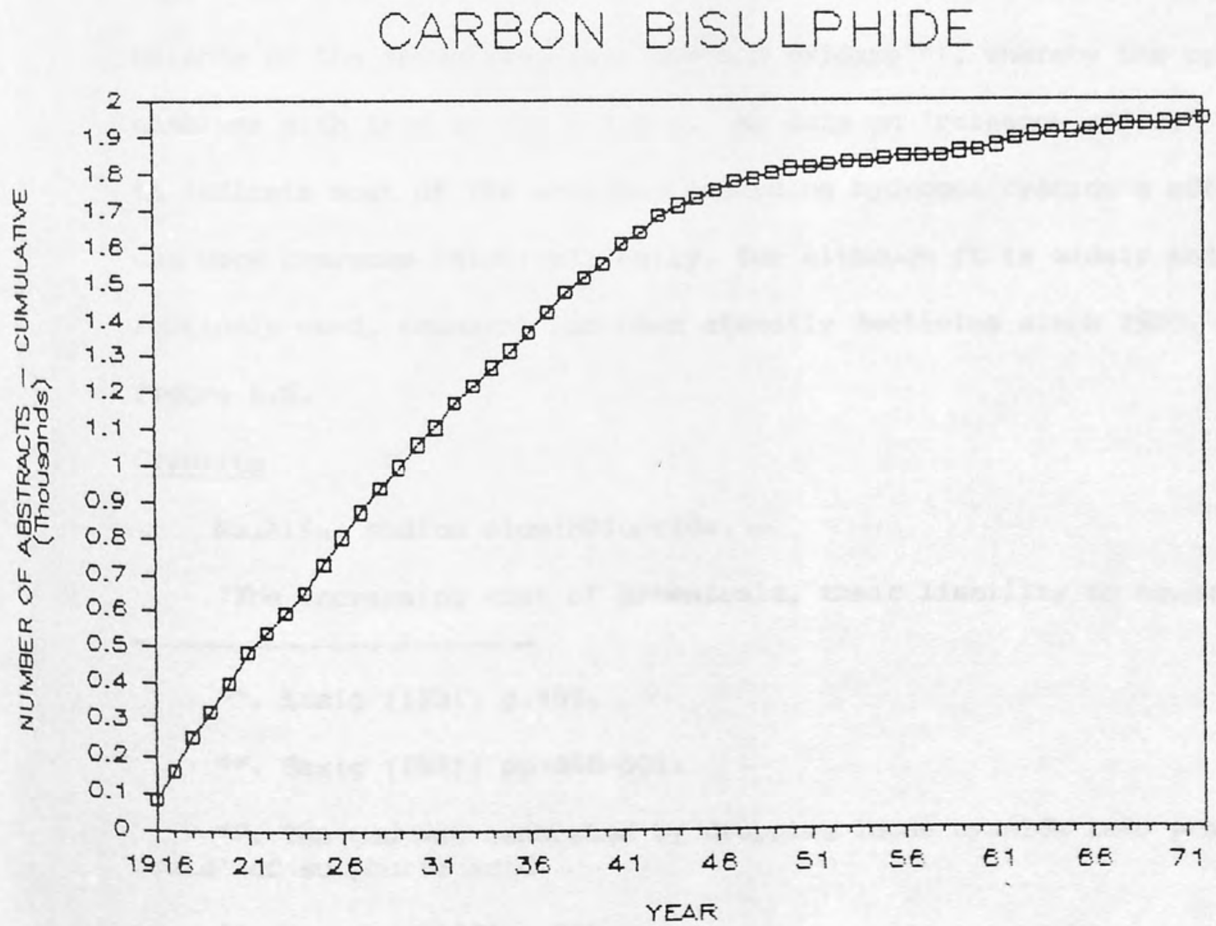

CARBON BISULPHIDE
NUMBER OF ABSTRACTS — CUMULATIVE (Thousands)
0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
0.9
1
1.1
1.2
1.3
1.4
1.5
1.6
1.7
1.8
1.9
2
YEAR
1916
21
26
31
36
41
46
51
56
61
66
71

Fig. 5.5

Californian citrus fruit industry. The discovery has been hailed as one of "the great achievements in the entomological history of California"[58].

Much of the research and historical progress with HCN has been concerned with improving the fumigation process and means of generating the highly toxic gas. Essig[59] divides its history into five periods:

> "First or experimental period, 1886-1888. First experiments and early development of fumigation. External generator, poor tents, no accurate system of obtaining dosage, daylight work.
> Second period, 1889-1906. Pot[60] generation, under tents, better tent materials, night work.
> Third or standardization period, 1907-1912. Pot generation, marked tents, accurate tent measurements, dosage tables, and standardized equipment.
> Fourth period, 1913-1916. Machine fumigation.
> Fifth period, 1916-1927. Liquid hydrocyanic acid gas method, calcium cyanide dust".

Hydrogen cyanide fumigation is now an important routine treatment in citrus fruit and general glass house pest control. It is thought that its toxic action on insects is due to "a disturbance of the normal balance of the reductase, catalase and oxidase"[61], whereby the cyanide combines with iron in the enzymes. My data on 'research effort' seems to indicate most of the problems regarding hydrogen cyanide's effective use were overcome relatively early, for although it is widely and routinely used, research has been steadily declining since 1920, see figure 5.6.

<u>Cryolite</u>

Na_3AlF_6, sodium aluminfluoride. -

"The increasing cost of arsenicals, their liability to cause

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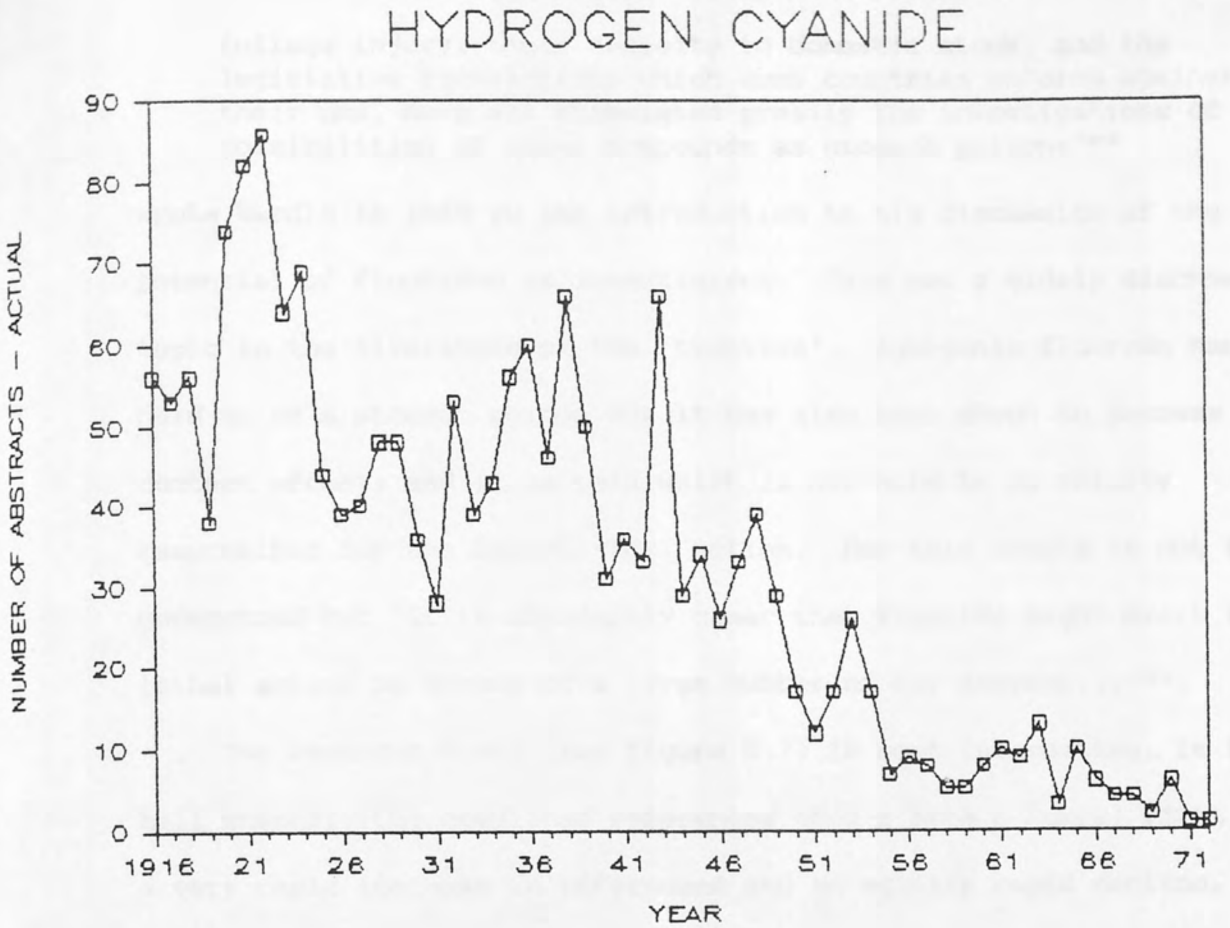
[58]. Essig (1931) p.469.

[59]. Essig (1931) pp.468-501.

[60]. The gas was generated by dropping loose cyanide into prepared 'pots' of sulphuric acid.

[61]. Martin (1973) p.296.


HYDROGEN CYANIDE
NUMBER OF ABSTRACTS - ACTUAL
YEAR
1916 21 26 31 36 41 46 51 56 61 66 71
0 10 20 30 40 50 60 70 80 90

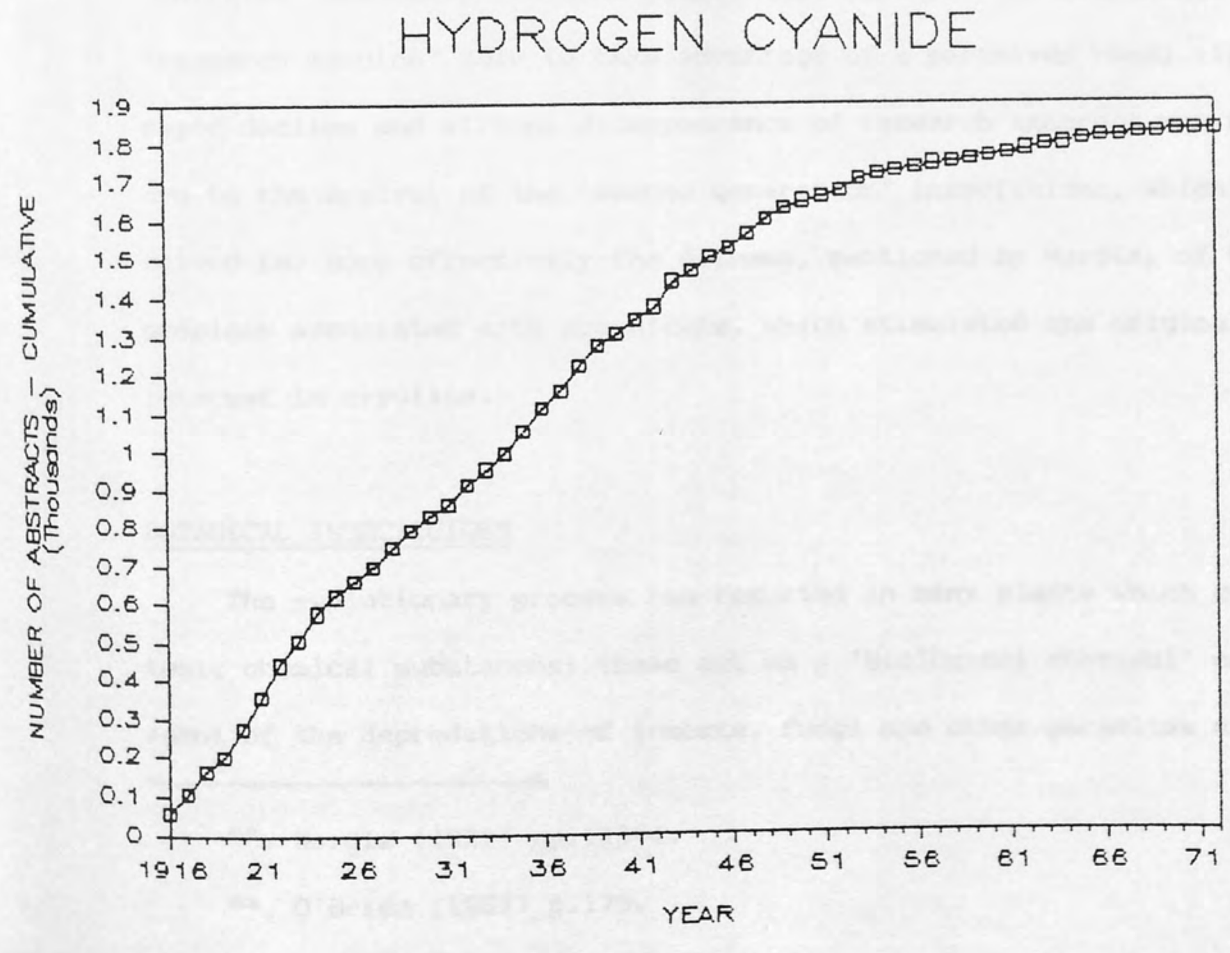

HYDROGEN CYANIDE
NUMBER OF ABSTRACTS - CUMULATIVE (Thousands)
YEAR
1916 21 26 31 36 41 46 51 56 61 66 71
0 0.1 0.2 0.3 0.4 0.5 0.6 0.7 0.8 0.9 1 1.1 1.2 1.3 1.4 1.5 1.6 1.7 1.8 1.9

Fig. 5.6

> foliage injury, their toxicity to domestic stock, and the legislative restrictions which some countries enforce against their use, have all stimulated greatly the investigations of the possibilities of other compounds as stomach poisons"[62]

wrote Wardle in 1929 in the introduction to his discussion of the potential of fluorides as insecticides. This was a widely discussed topic in the literature of the 'twenties'. Inorganic fluoride has been held to be a stomach poison but it has also been shown to possess a contact effect, and it is this which is now held to be chiefly responsible for the insecticidal action. How this occurs is not fully understood but "It is abundantly clear that fluoride might exert its lethal action on anyone of a large number of key enzymes..."[63].

The research trend (see figure 5.7) is most interesting, it is bell shaped, (the cumulated references show a fine S curve) which shows a very rapid increase in references and an equally rapid decline. This could be a result of two factors (i) the rapid increase in the 'thirties' and early 'forties' indicates, perhaps, the beginnings of a "research machine" able to take advantage of a perceived need; (ii) the rapid decline and virtual disappearance of research interest was surely due to the arrival of the 'second generation' insecticides, which solved far more effectively the dilemma, mentioned by Wardle, of the problems associated with arsenicals, which stimulated the original interest in cryolite.

BOTANICAL INSECTICIDES

The evolutionary process has resulted in many plants which contain toxic chemical substances; these act as a 'biological chemical' control agent of the depredations of insects, fungi and other parasites and

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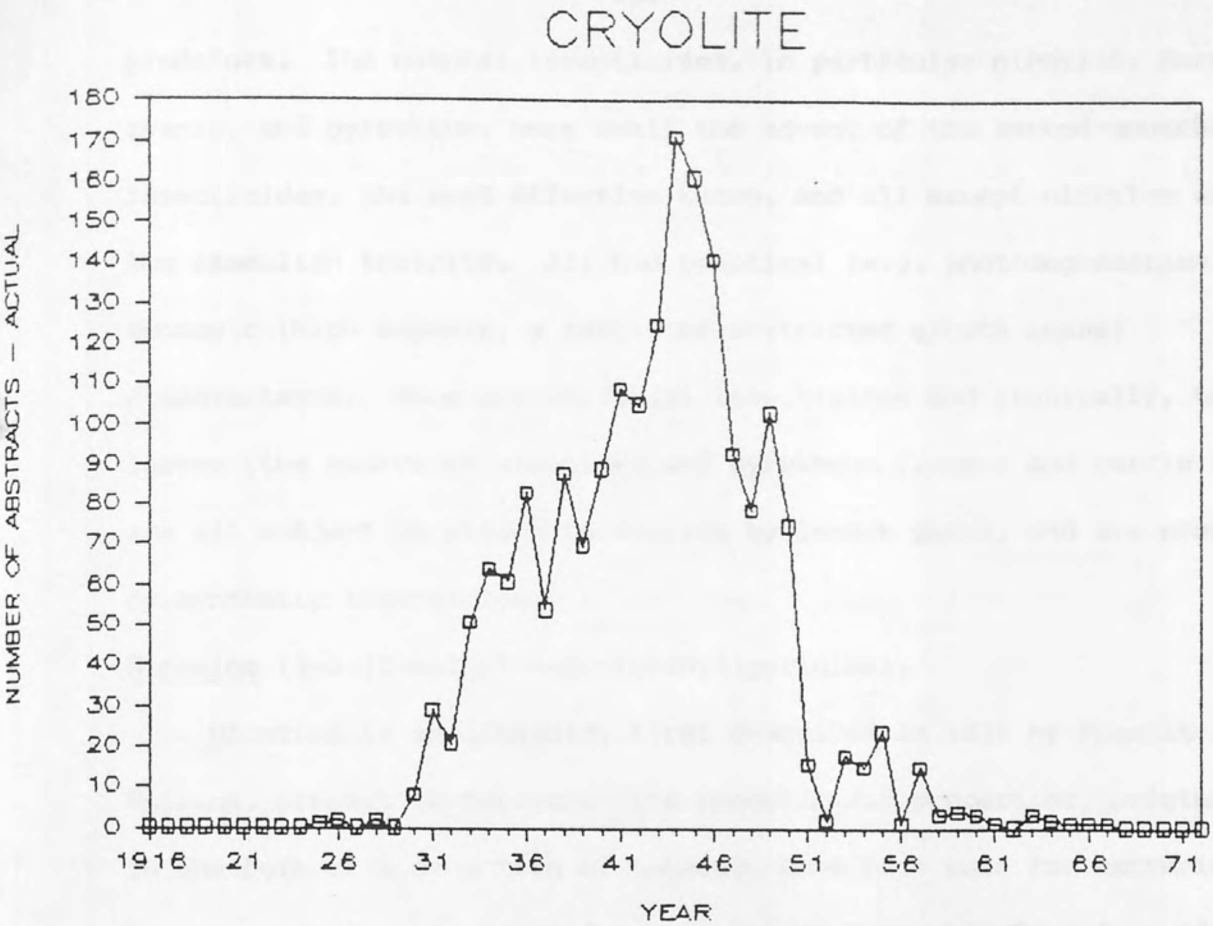
[62]. Wardle (1929) pp.173-4.

[63]. O'Brien (1967) p.179.


CRYOLITE
NUMBER OF ABSTRACTS – ACTUAL
YEAR
0
10
20
30
40
50
60
70
80
90
100
110
120
130
140
150
160
170
180
1916
21
26
31
36
41
46
51
56
61
66
71

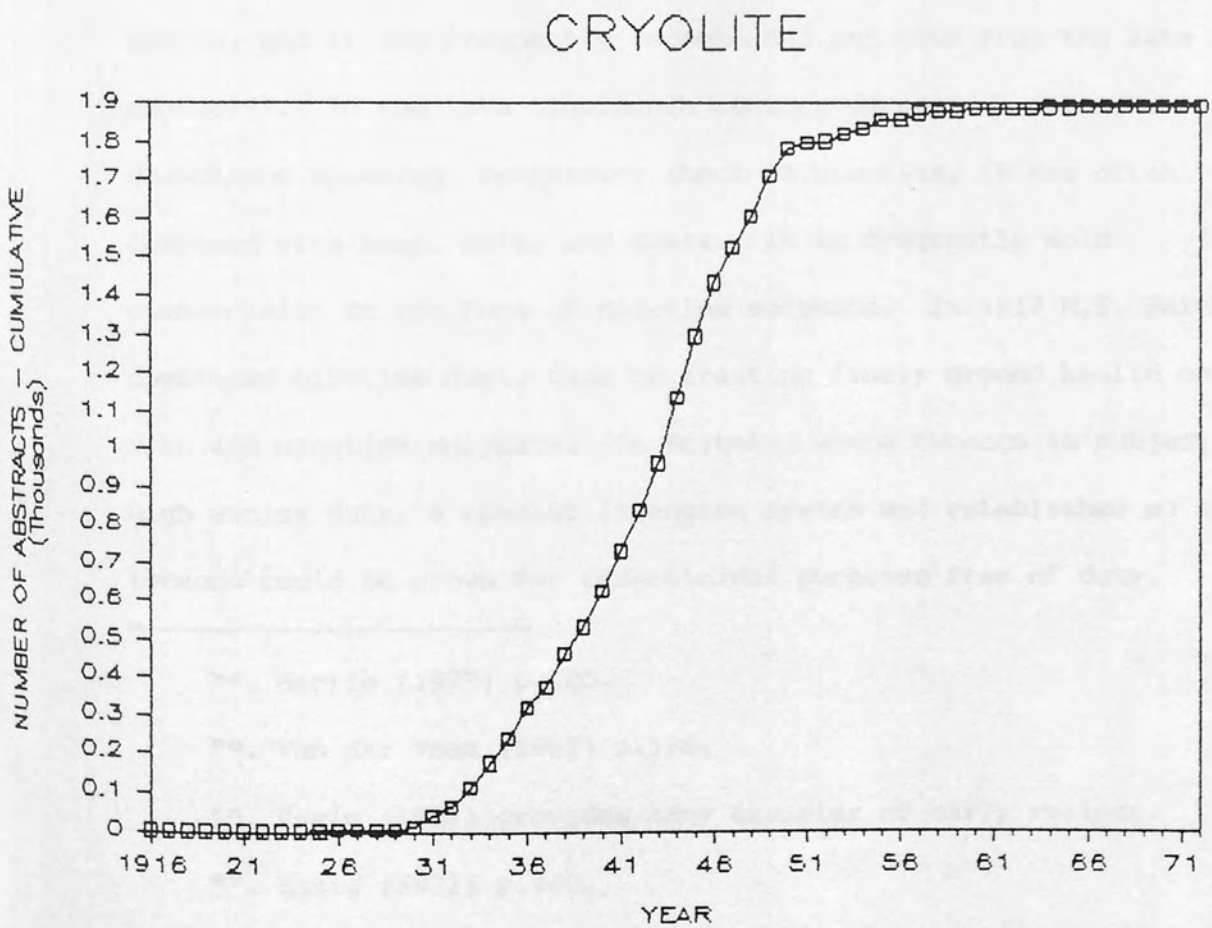

CRYOLITE
NUMBER OF ABSTRACTS – CUMULATIVE (Thousands)
YEAR
0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
0.9
1
1.1
1.2
1.3
1.4
1.5
1.6
1.7
1.8
1.9
1916
21
26
31
36
41
46
51
56
61
66
71

Fig. 5.7

predators. The natural insecticides, in particular nicotine, derris, ryania, and pyrethrum, were until the advent of the second-generation insecticides, the most effective known, and all except nicotine are of low mammalian toxicity. All had practical (e.g. photodegradation) or economic (high expense, a result of restricted growth zones) disadvantages. None are universal insecticides and ironically, tobacco leaves (the source of nicotine) and pyrethrum flowers and derris roots are all subject to attack themselves by insect pests, and are protected by synthetic insecticides.

<u>Nicotine</u> (1-3-(1-methyl-2-pyrrolidyl)pyridine).

Nicotine is an alkaloid, first described in 1828 by Posselt and Reimann, present in tobacco. Its insecticidal properties, originally in the form of a decoction of tobacco, have been used for centuries. The tobacco plant was introduced to Europe circa 1560[64] and in 1690 La Quitinye recommended[65] the utilisation of tobacco extract against aphids, and it was frequently recommended and used from the late 17th century[66]. In the late nineteenth century commercial nicotine decoctions appeared, containing about 2% nicotine, it was often combined with soap, oils, and dusts. It is frequently sold commercially in the form of nicotine sulphate. In 1917 R.E. Smith[67] developed nicotine dust, made by treating finely ground kaolin or lime with 40% nicotine sulphate. In Britain, where tobacco is subject to high excise duty, a special licensing system was established so that tobacco could be grown for insecticidal purposes free of duty.

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64. Martin (1973) p.180.

65. Van der Veen (1967) p.126.

66. Essig (1931) provides many examples of early recipes.

67. Essig (1931) p.440.

Nicotine acts as a nerve poison, probably at the ganglia rather than the neuromuscular-junctions. It has been suggested that nicotine affects ganglia "by mimicking (on an excessive scale) acetylcholine there"[68]

Research on nicotine and nicotine sulphate grew until the mid 1930s and thereafter declined i.e. the growth curve is S shaped, see Figures 5.8 and 5.9.

Derris (Rotenone)

"Tuba root" extract had long been used as a fish and arrow poison in the Malay Archipelago. Oxley[69], in 1848, suggested using it to control insect pests of nutmeg. The main source of "tuba root" is the root of Derris elliptica, the chief active ingredient being rotenone. This is also obtained from several plant species e.g. the genera Derris, Lonchocarpus and Tephrosia[70]. The crude materials are quite often used directly as "derris dust", or, from South American sources, as "cubé root"[71]. The structure of rotenone was independently elucidated by several groups in 1932. One of its major defects as an insecticide is that it breaks down in sunlight, or heat, within a few days. The mode of action of rotenoids on insects remains obscure, but appears to involve a blockage of oxygen utilisation, possibly by blocking $NADH_2$ oxidation[72].

My data suggest that there was little active research on Derris until the 1930s, when for a decade activity rose very rapidly only to

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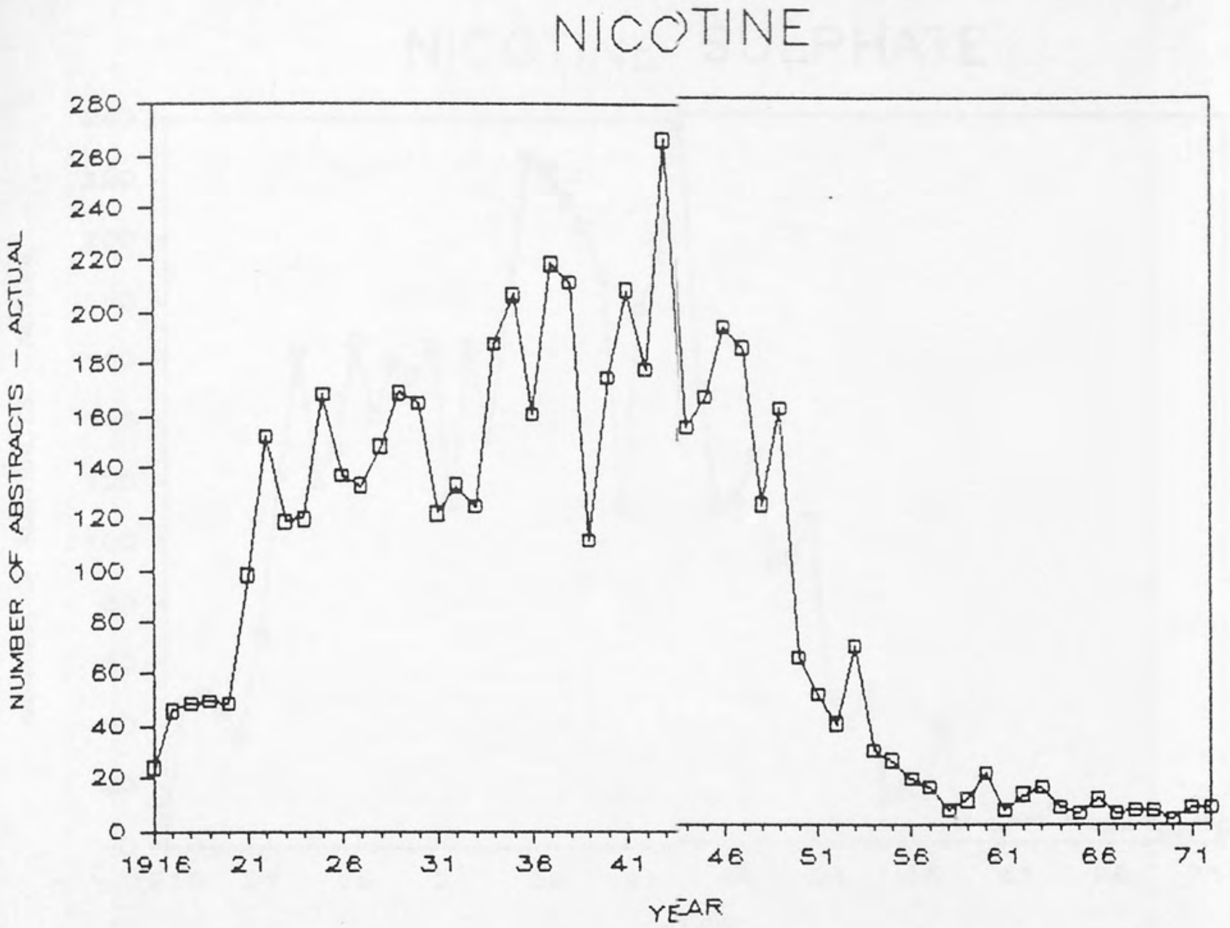
[68]. O'Brien (1967) p.181.

[69]. Martin (1973) p.195.

[70]. Martin (1973) p.196.

[71]. O'Brien (1967) p.158.

[72]. Loc. cit. p.163.


NICOTINE
NUMBER OF ABSTRACTS - ACTUAL
YEAR
0
20
40
60
80
100
120
140
160
180
200
220
240
260
280
1916
21
26
31
36
41
46
51
56
61
66
71

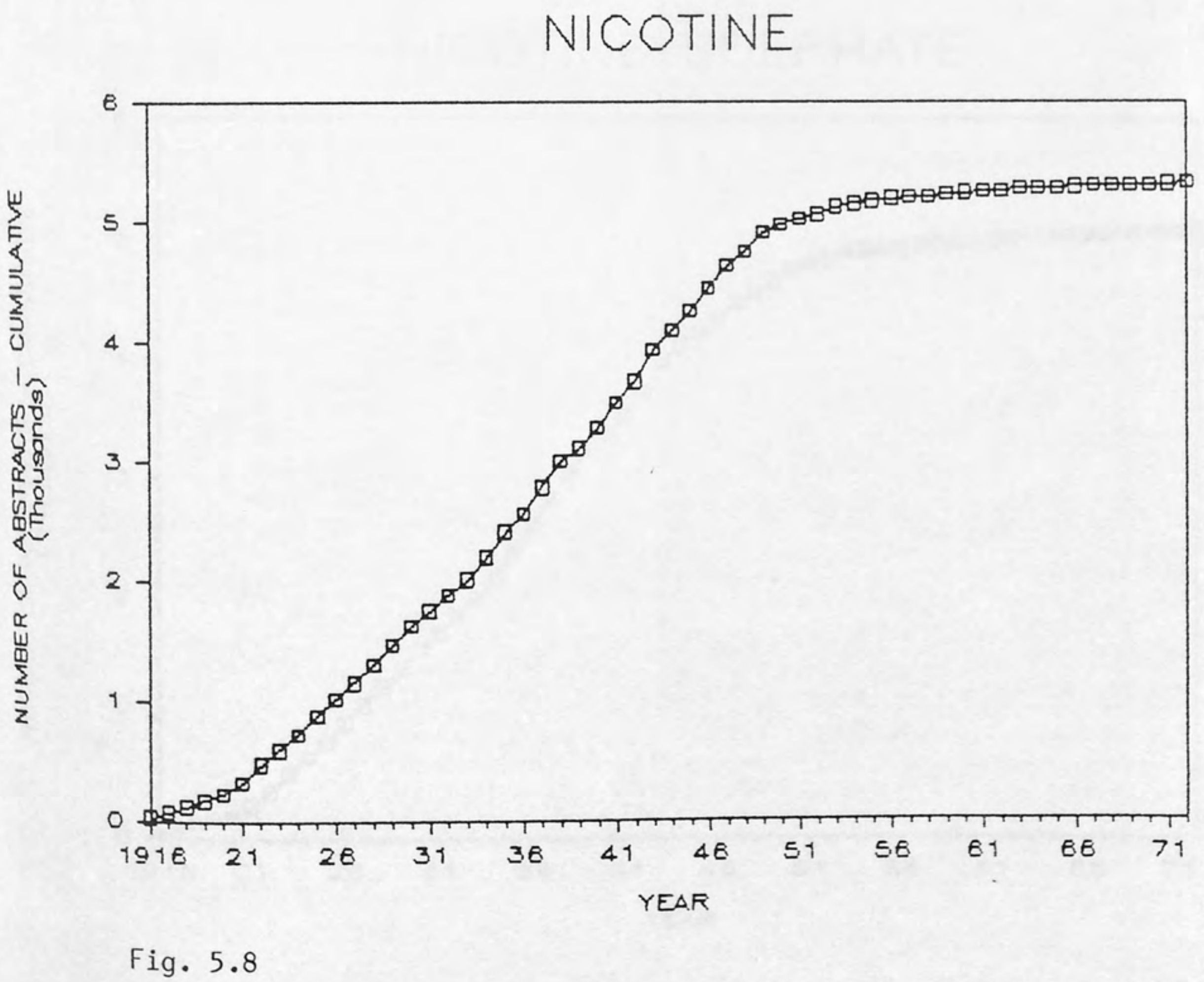
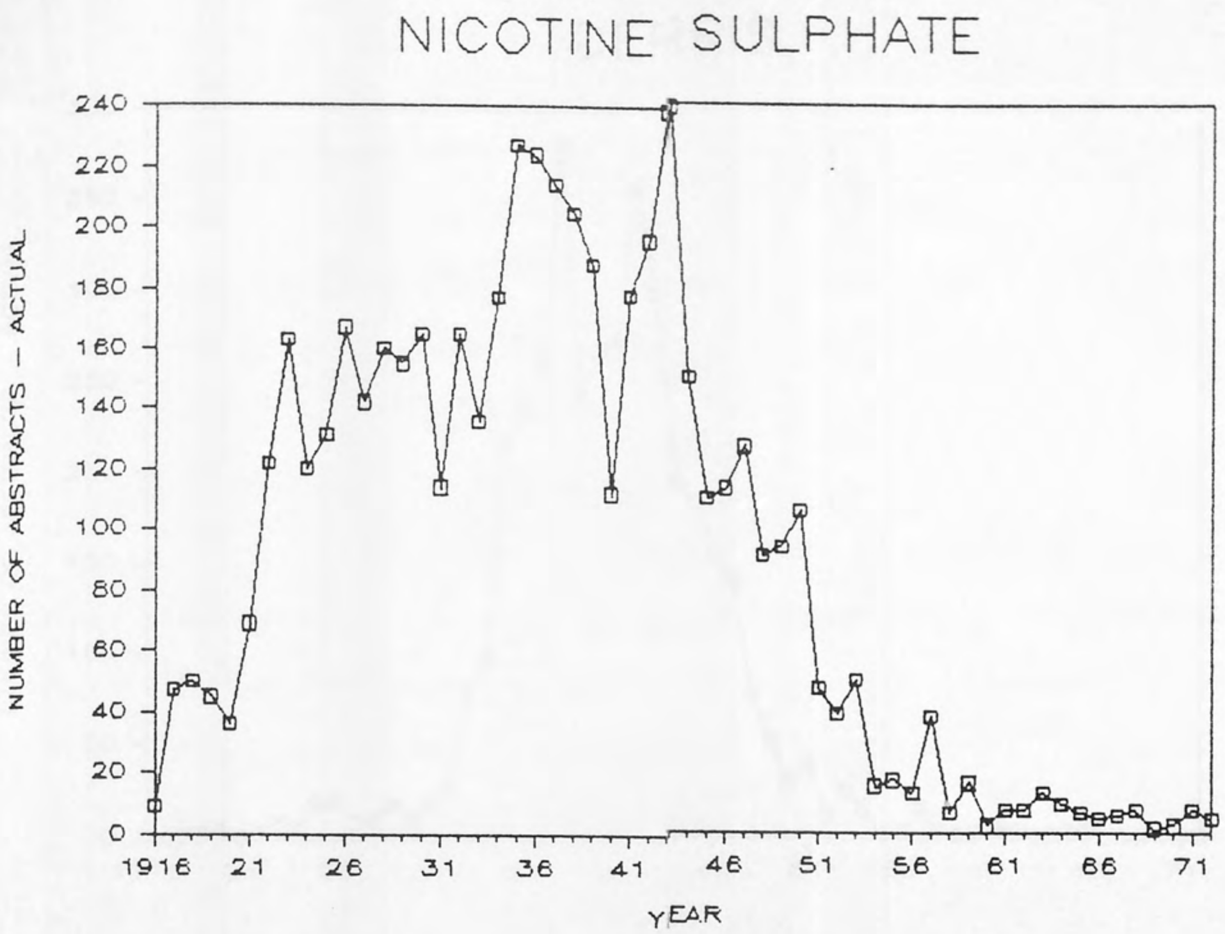

NICOTINE
NUMBER OF ABSTRACTS — CUMULATIVE (Thousands)
YEAR
0
1
2
3
4
5
6
1916
21
26
31
36
41
46
51
56
61
66
71

Fig. 5.8


NICOTINE SULPHATE
NUMBER OF ABSTRACTS – ACTUAL
0
20
40
60
80
100
120
140
160
180
200
220
240
1916
21
26
31
36
41
46
51
56
61
66
71
YEAR

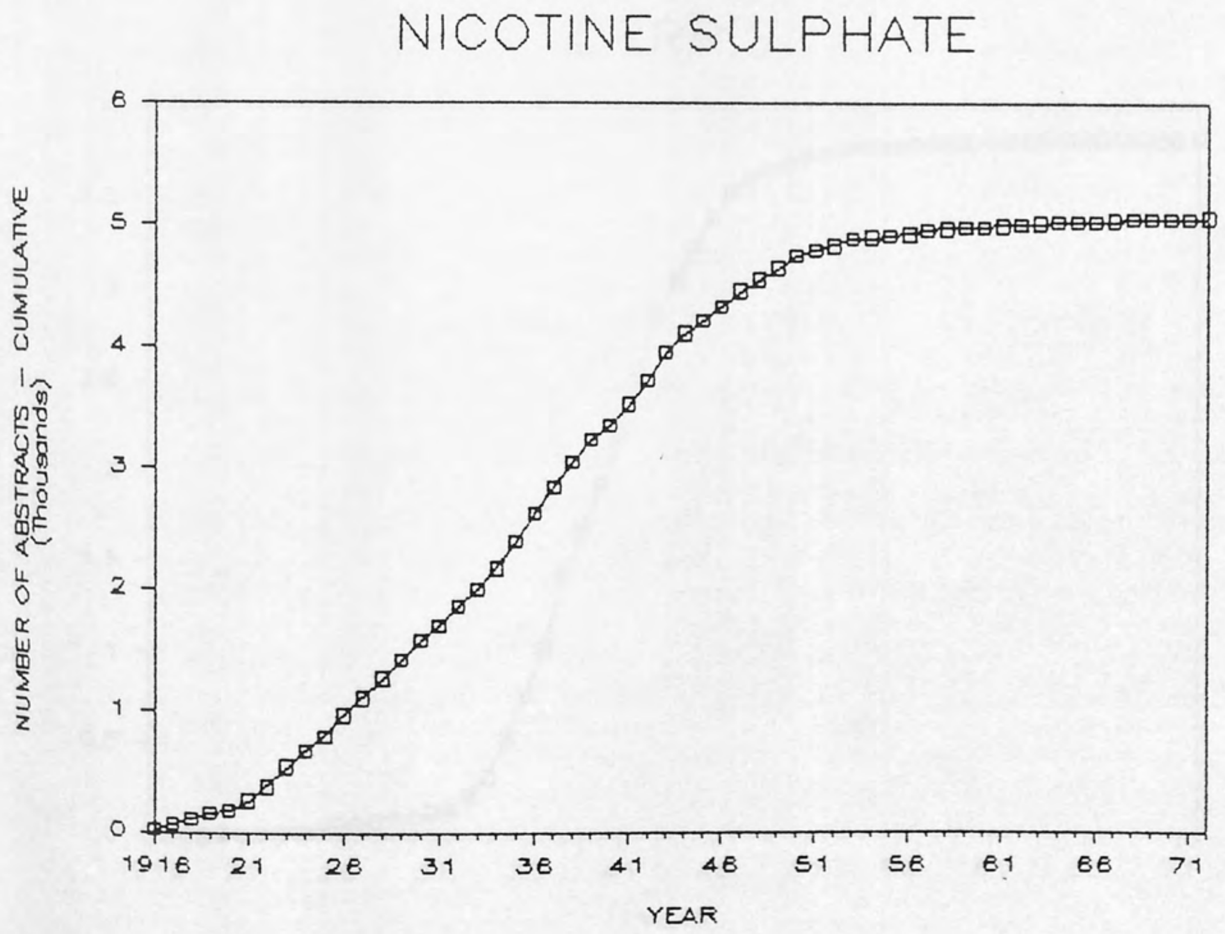
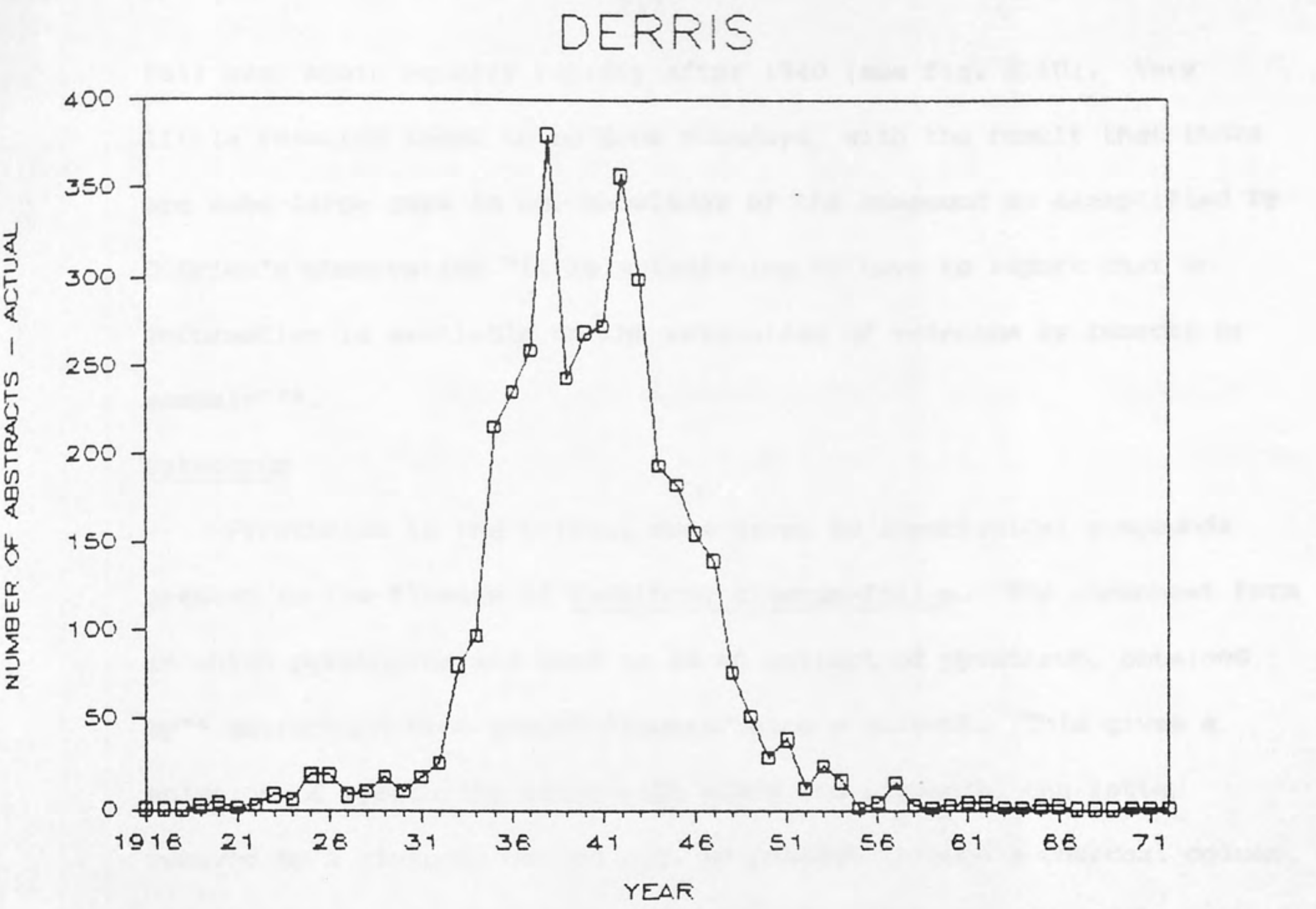

NICOTINE SULPHATE
NUMBER OF ABSTRACTS – CUMULATIVE (Thousands)
0
1
2
3
4
5
6
1916
21
26
31
36
41
46
51
56
61
66
71
YEAR

Fig. 5.9


DERRIS
NUMBER OF ABSTRACTS — ACTUAL
400
350
300
250
200
150
100
50
0
1916
21
26
31
36
41
46
51
56
61
66
71
YEAR

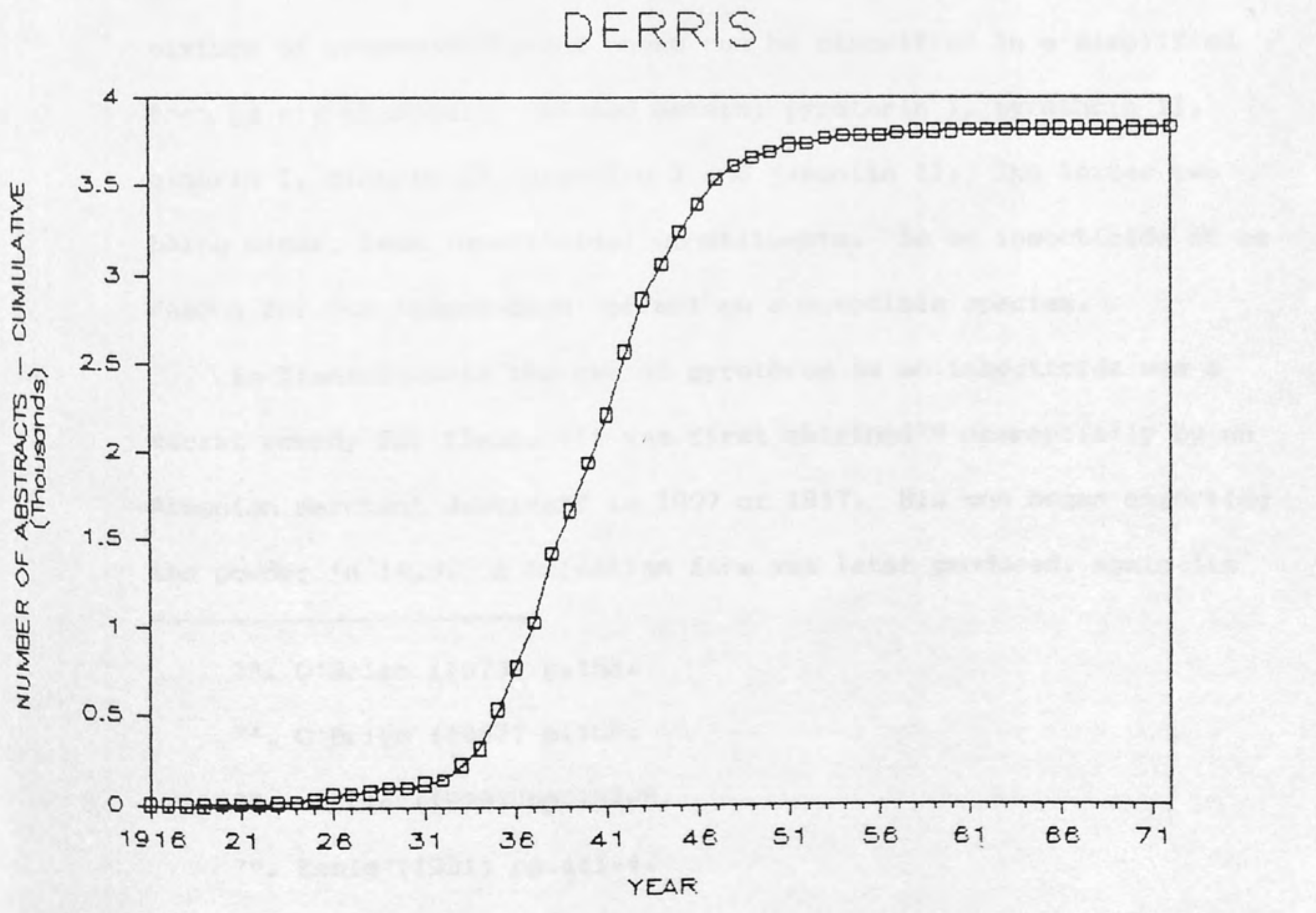

DERRIS
NUMBER OF ABSTRACTS — CUMULATIVE (Thousands)
4
3.5
3
2.5
2
1.5
1
0.5
0
1916
21
26
31
36
41
46
51
56
61
66
71
YEAR

Fig. 5.10

fall away again equally rapidly after 1940 (see fig. 5.10). Very little research seems to be done nowadays, with the result that there are some large gaps in our knowledge of the compound as exemplified by O'Brien's observation "It is astonishing to have to report that no information is available on the metabolism of rotenone by insects or mammals"[73].

Pyrethrum

Pyrethrins is the trivial name given to insecticidal compounds present in the flowers of Pyrethrum cincrae-folium. The commonest form in which pyrethrins are used is as an extract of pyrethrum, obtained by[74] extraction from ground flowers using a solvent. This gives a solution of pyrethrins along with waxes and pigments, the latter removed by a clean-up method e.g. by passage through a charcoal column, and the solvent is then distilled off. Flower heads, depending upon the variety, contain 0.7-3% pyrethrins. The pyrethrins are a complex mixture of compounds[75], and these can be classified in a simplified form as six chemically related esters; pyrethrin I, pyrethrin II, cinerin I, cinerin II, jasmolin I and jasmolin II; The latter two being minor, less insecticidal constituents. As an insecticide it is famous for its 'knock-down' effect on susceptible species.

In Transcaucasia the use of pyrethrum as an insecticide was a secret remedy for fleas. It was first obtained[76] commercially by an Armenian merchant Jumtikoff in 1807 or 1817. His son began exporting the powder in 1828. A Dalmatian form was later produced, again its

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[73]. O'Brien (1973) p.163.

[74]. O'Brien (1967) p.165.

[75]. Martin (1973) pp.187-8.

[76]. Essig (1931) pp.441-4.

seeds were guarded as a secret. In about 1850 it entered France and by 1857 a local industry was established. Despite secrecy, seeds eventually were obtained and distributed to other countries and growing began in the USA, Kenya (which became a centre of world production), Japan, etc.

Up to 1920 pyrethrum was invariably used as a powder, but by the early 1930s it was increasingly used in the form of a kerosine solution particularly as a space spray against flying insects[77], its chief contemporary use. It is a contact insecticide, suffering from the drawbacks of photodegradation, but its rapid knock-down action, coupled to very low mammalian toxicity, ensures its popularity. (In fact, unlike derris and nicotine, pyrethrum use continues to grow.) Its mode of action remains a mystery, pyrethrins cause rapid paralysis which is consistent with toxic effects on nerves (central or peripheral) or muscle. Many facts and theories are reviewed by O'Brien[78] and by Martin[79].

My bibliographic data in Fig. 5.11 show that research interest grew very rapidly between 1930 and 1940 and declined until 1970, since when it has revived somewhat, indeed it provides an interesting example of a revitalised S curve. It could be that this revival has been stimulated by the growing interest in pyrethrin synergists, and in synthetic pyrethrins, such as allethrin, and the more recent compounds such as permethrin.

Petroleum (hydrocarbon) oils

"These consist largely of aliphatic hydrocarbons both saturated

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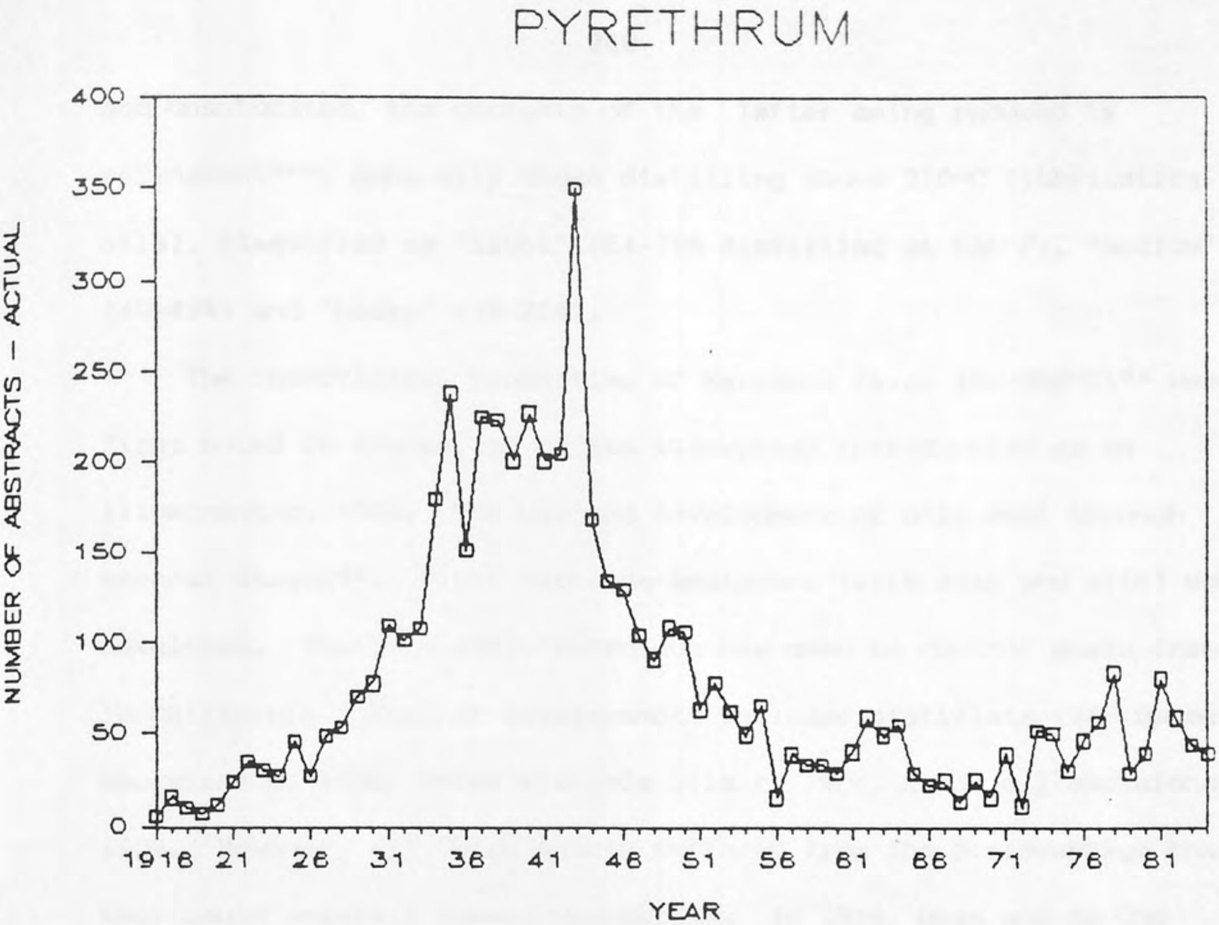
[77]. Hartley and West (1969) p.35.

[78]. O'Brien (1967) pp.168-171.

[79]. Martin (1973) pp.187-192.


PYRETHRUM
NUMBER OF ABSTRACTS – ACTUAL
YEAR
400
350
300
250
200
150
100
50
0
1916
21
26
31
36
41
46
51
56
61
66
71
76
81

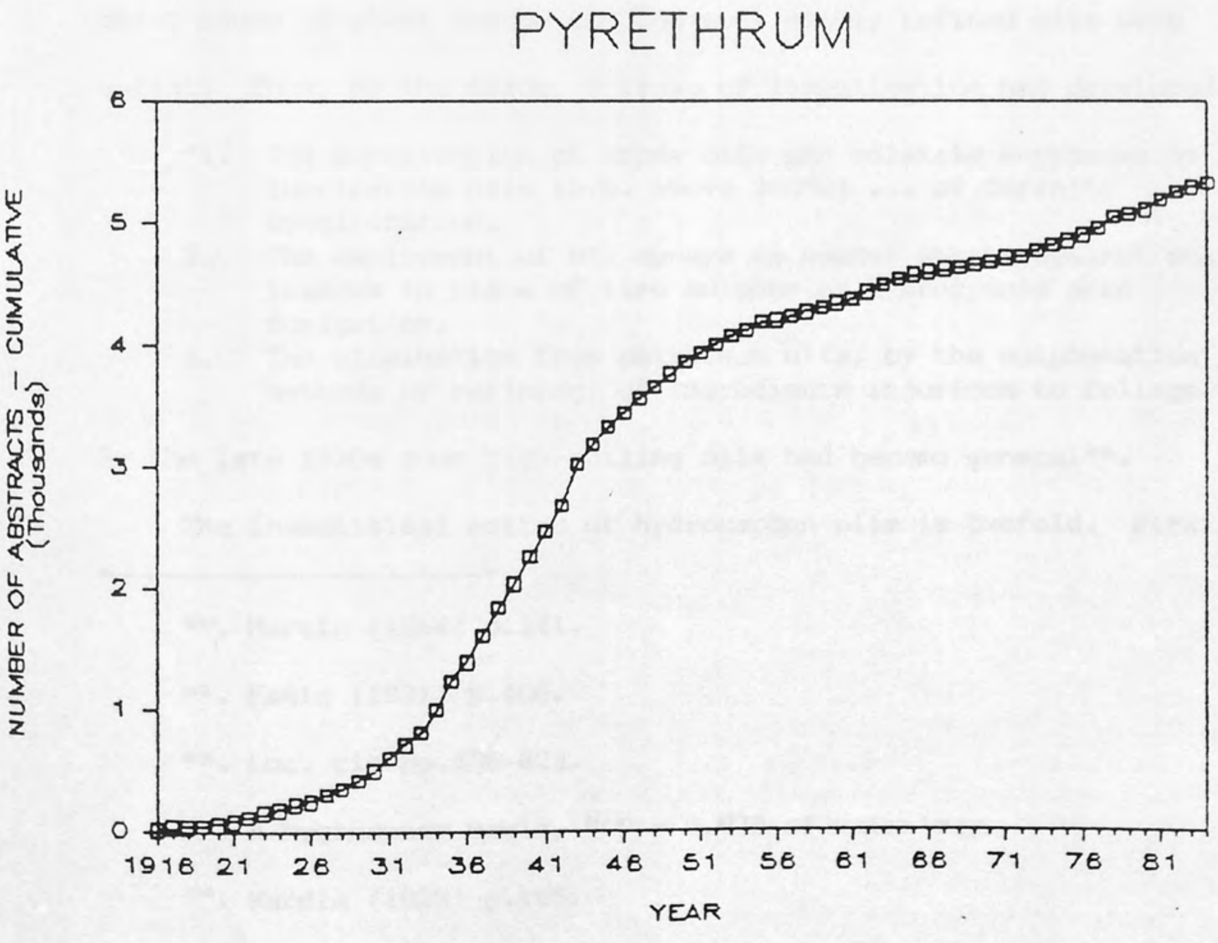

PYRETHRUM
NUMBER OF ABSTRACTS – CUMULATIVE (Thousands)
YEAR
6
5
4
3
2
1
0
1916
21
26
31
36
41
46
51
56
61
66
71
76
81

Fig. 5.11

and unsaturated, the contents of the latter being reduced by refinement"[80], generally those distilling above 310°C (lubricating oils), classified as 'light' (64-79% distilling at 636°F), 'medium' (40-49%) and 'heavy' (10-25%).

The insecticidal properties of kerosene (b.p. 150-300°C)[81] were first noted in the period of its widespread introduction as an illuminant c. 1865. The use and development of oils went through several stages[82]. First kerosene emulsions (with soap and milk) were developed. Then, in 1881, petroleum was used to control scale insects in California. Further developments included distillate (28° Baume)[83] emulsions c. 1900, water miscible oils c. 1904, crude oil emulsions c. 1909. However, all these agents suffered from the disadvantage that they could severely damage vegetation. In 1916, Gray and de Ong discovered that the unsaturated hydrocarbon compounds in oils were the chief cause of plant damage and the most highly refined oils were safest. Thus, by the 1920s, 3 lines of investigation had developed[84]:

"1. The substitution of crude oils and volatile kerosenes by lubricating oils (b.p. above 300°C) ... of definite specification.
2. The employment of oil sprays as summer sprays against scale insects in place of lime sulphur or hydrocyanic acid fumigation.
3. The elimination from petroleum oils, by the sulphonation methods of refining, of ingredients injurious to foliage."

By the late 1920s such high-boiling oils had become general[85].

The insecticidal action of hydrocarbon oils is twofold. Firstly,

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[80]. Martin (1968) p.341.

[81]. Essig (1931) p.406.

[82]. Loc. cit pp.406-423.

[83]. A hygrometer scale, 30° = 0.875 of water'sʒg.

[84]. Wardle (1929) p.186.

[85]. Martin (1973) p.206.

mechanical action whereby oil enters the insect tracheal system to cause asphyxiation, also there is a 'wetting' action on the cuticle, normally it remains unwetted by water, and this allows insect limbs and other appendages to become 'tied-up' by surface tension forces[86]. Secondly, a chemical toxication against eggs[87].

It can be seen from Figure 5.12 that there was an enormous increase in research activity on these agents from 1920-1935, thereafter the research tempo dropped, nevertheless they were, along with lead arsenate, the most referenced agent in the Review of Applied Entomology from 1925 to 1945. Since the mid 1970s there has been a slight increase in research activity. The cumulative growth, like that of pyrethrin, shows unmistakable signs of revitalisation; the apex of the S curve has a kink.

Soap

Essig claims that "soap as an insecticide so far antedates the study of economic entomology that no time limits are possible"[88]. There is documentary evidence of its use in USA as early as 1841[89]. In later years soaps played an important role in kerosene emulsions, resin washes and many other formulae, and much research revolved around this aspect of their use. In the 1920s and 1930s a series of studies were made of the dependence of soap's insecticidal properties upon molecular studies[90]. Soap was never dominant as a research topic; in my

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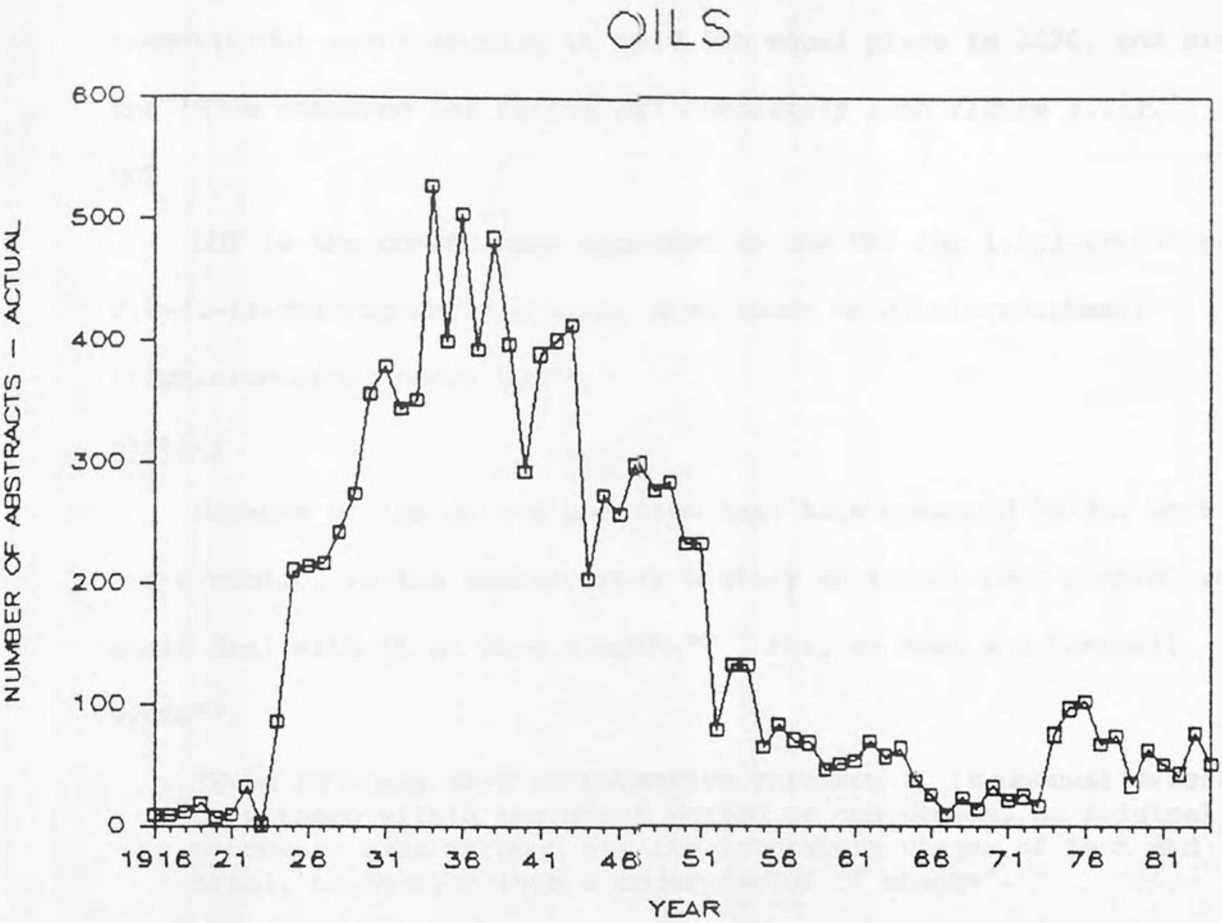
86. Hartley and West (1969) p.21.

87. Martin (1973) p.210.

88. Essig (1931) p.403.

89. Ibid.

90. Martin (1973) pp.213-4. A straight line is obtained "by plotting the logarithm of the reciprocal of the molecular concentration necessary to give 100% mortality, against the molecular weight of the acid... (a) gradual increase of toxicity with length of the carbon


OILS
NUMBER OF ABSTRACTS — ACTUAL
600
500
400
300
200
100
0
1916 21 26 31 36 41 46 51 56 61 66 71 76 81
YEAR

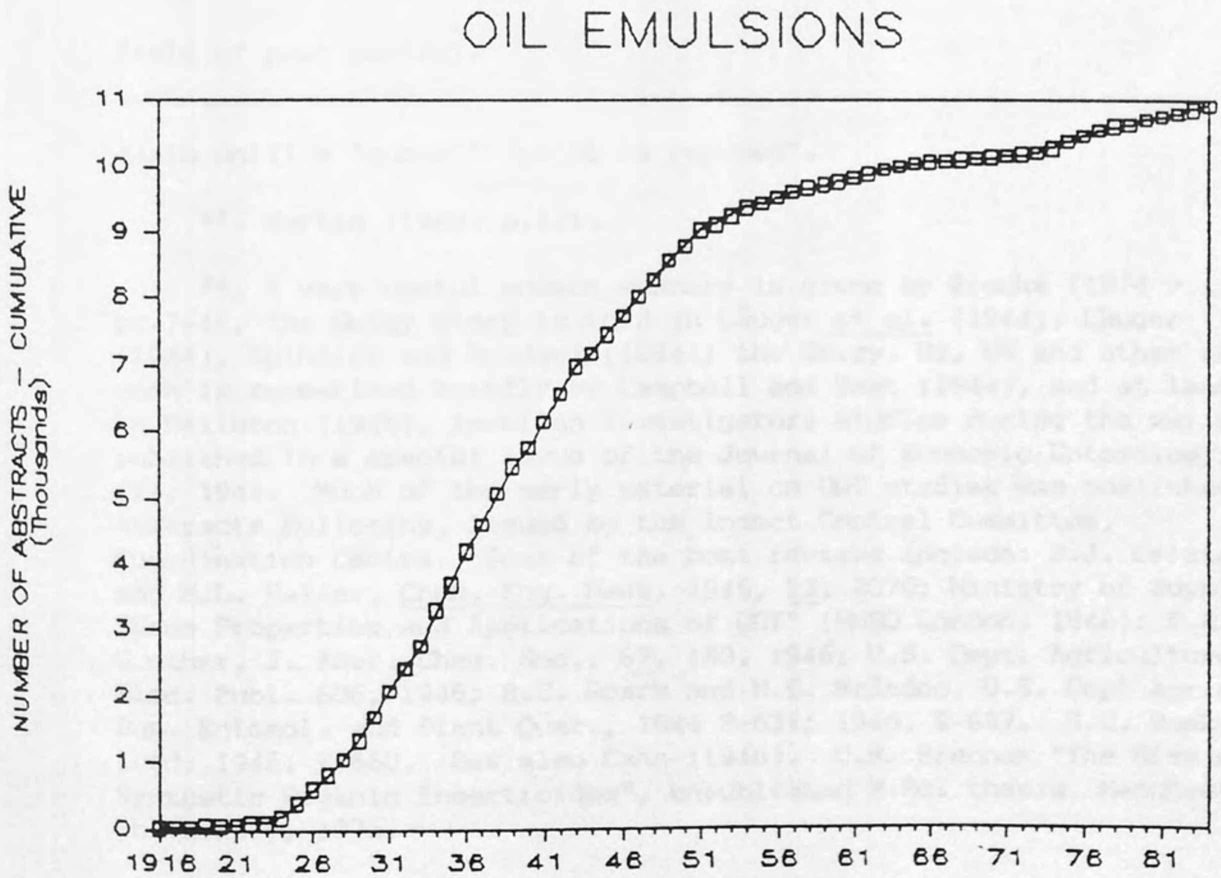

OIL EMULSIONS
NUMBER OF ABSTRACTS — CUMULATIVE
(Thousands)
11
10
9
8
7
6
5
4
3
2
1
0
1916 21 26 31 36 41 46 51 56 61 66 71 76 81
YEAR

Fig. 5.12

insecticidal agent studies it held 5th equal place in 1920, and since the 1930s research has fallen off completely (see Figure 5.13).

DDT

DDT is the common name approved by the BSI for 1,1,1-trichloro-2,2-di-(4-chlorophenyl) ethane, also known as dichlorodiphenyl-trichloroethane, hence DDT[91].

History

Because of the unique position that this compound holds, both real and symbolic, in the contemporary history of insect pest control we shall deal with it at some length.[92] For, as West and Campbell wrote[93],

> "Even in these days of intensive research it is unusual experience to witness within the short period of one decade, an original discovery pass through all its laboratory stages of test and trial, to develop into a major factor of change".

Spindler and Buxdorf (1954) have discussed how Geigy A.G. who financed the original DDT development, actually entered what was for them a new field of pest control.

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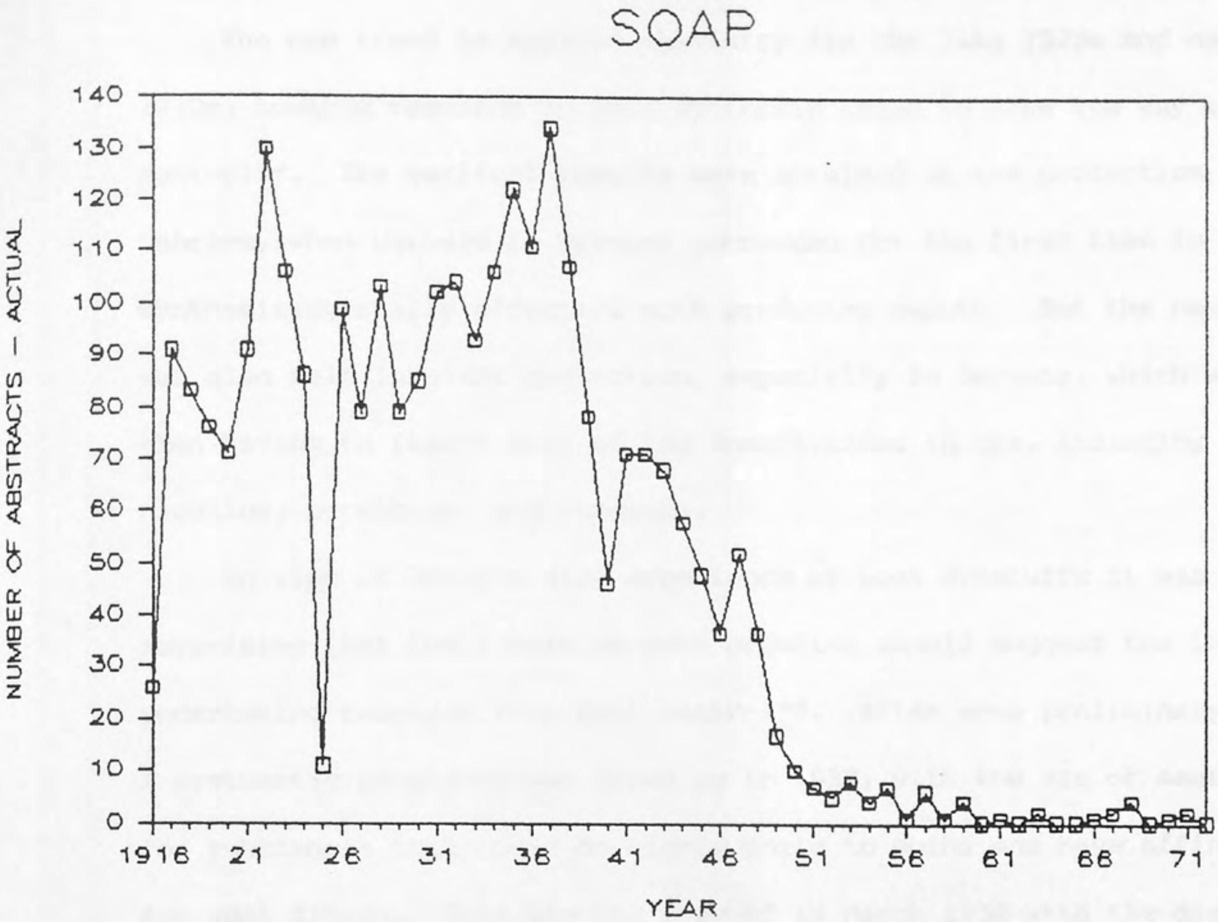
chain until a 'cut-off' point is reached".

[91]. Martin (1968) p.121.

[92]. A very useful modern summary is given by Brooks (1974 v.1) pp.7-46, the Geigy story is told in Läuger et al. (1944), Läuger (1944), Spindler and Buxdorf (1954); the Geigy, US, UK and other early work is summarised briefly by Campbell and West (1944), and at length in Heilbron (1945), American investigatory studies during the war were published in a special issue of the Journal of Economic Entomology, 37 (1), 1944. Much of the early material on DDT studies was published in Abstracts Bulletins, issued by the Insect Control Committee, Coordination Centre. Some of the best reviews include: S.J. Cristol and H.L. Haller, Chem. Eng. News, 1945, 23, 2070; Ministry of Supply, "Some Properties and Applications of DDT" (HMSO London, 1946); F.A. Gunther, J. Amer. Chem. Soc., 67, 189, 1945; U.S. Dept. Agriculture, Misc. Publ. 606, 1946; R.C. Roark and N.E. McIndoo, U.S. Dept Agric. Bur. Entomol. and Plant Quar., 1944 E-631; 1946, E-687. R.C. Roak, ibid, 1945, E-660. See also Cahn (1946). C.S. Brennan "The Rise of Synthetic Organic Insecticides", unpublished M.Sc. thesis, Manchester University, 1976.

[93]. West and Campbell (1950) p.1.


SOAP
NUMBER OF ABSTRACTS – ACTUAL
YEAR
1916
21
26
31
36
41
46
51
56
61
66
71

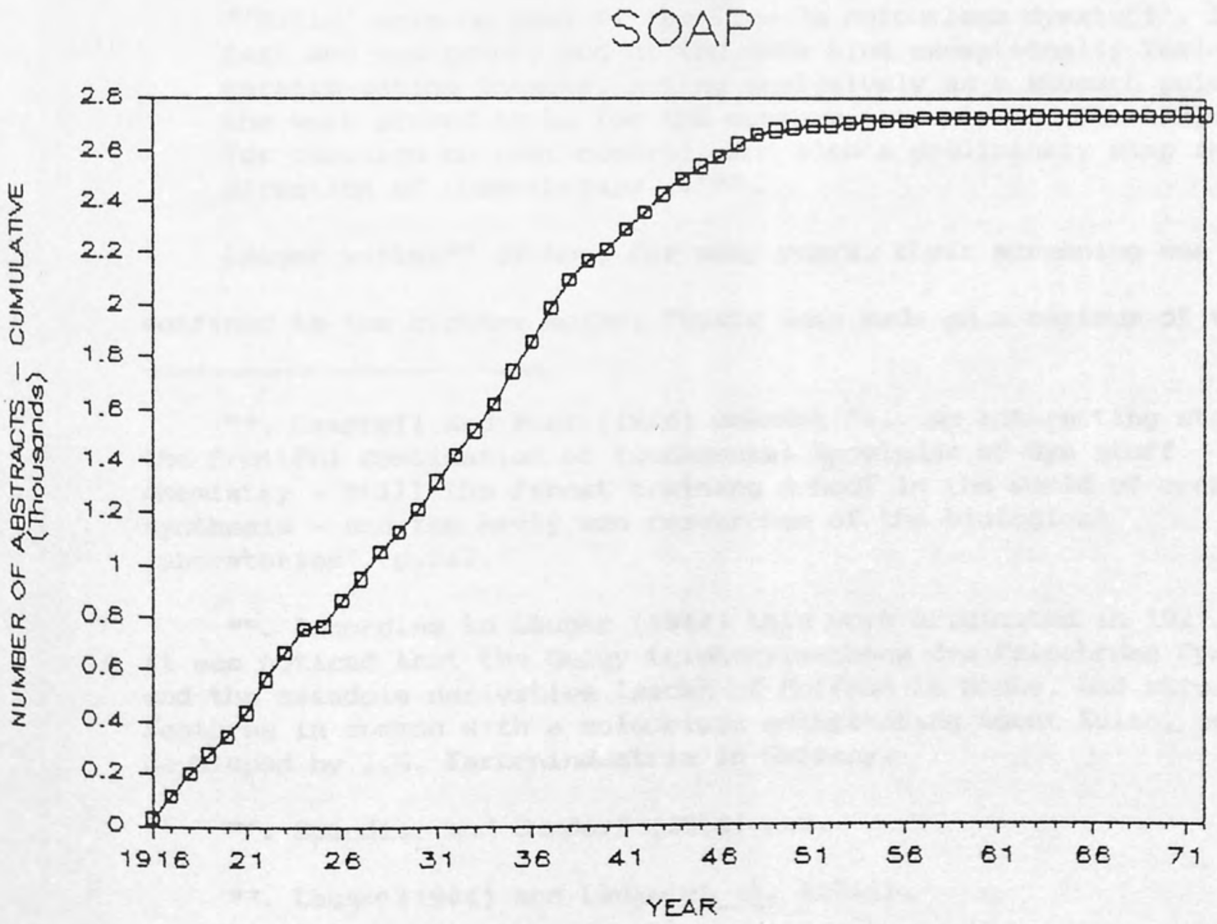

SOAP
NUMBER OF ABSTRACTS – CUMULATIVE (Thousands)
YEAR
1916
21
26
31
36
41
46
51
56
61
66
71

Fig 5.13

The new trend in applied chemistry (in the late 1920s and early 1930s) towards research in pure synthesis began to make its way in pest control[94]. The earliest results were obtained in the protection of fabrics, when workers in Germany succeeded for the first time in synthesising really effective moth producing agents. But the new trend was also felt in plant protection, especially in Germany, which was then having to import most of the insecticides in use, including nicotine, pyrethrum, and rotenone.

In view of Geigy's wide experience of wool dyestuffs it was not surprising that their work on moth proofing should suggest the idea of undertaking research into pest control[95]. After some preliminary tests a systematic programme was drawn up in 1932, with the aim of searching for substances that would be highly toxic to moths and have affinity for wool fibres. This aim was reached in March 1938 with the discovery of 'Mitin' which was put on the market in 1939 as 'Mitin FF';

> "'Mitin' acts on wool fibres like 'a colourless dyestuff', light-fast and washproof, and at the same time exceptionally toxic to keratin-eating insects, acting exclusively as a stomach poison... the work proved to be for the company not only the starting point for research on pest control, but also a preliminary step in the direction of chemotherapy..."[96].

Läuger writes[97] of how, for many years, their screening was confined to the clothes moths, "tests were made on a maximum of two to

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[94]. Campbell and West (1944) comment "... an interesting story of the fruitful combination of fundamental knowledge of dye stuff chemistry - still the finest training school in the world of organic synthesis - and the newly won researches of the biological laboratories". p.242.

[95]. According to Läuger (1944) this work originated in 1927 when it was noticed that the Geigy triphenylmethane dye Eriochrome Cyanine R and the oxindole derivative Isacen of Hoffman La Roche, had structural features in common with a colourless mothproofing agent Eulan, newly developed by I.G. Farbenindustrie in Germany.

[96]. Spindler and Buxdorf (1954) p.8.

[97]. Läuger (1944) and Läuger et al. (1944).

three keratin eating species (Tineola, Attagenus, Anthrenus)". In 1934 efforts were made to develop new ranges of chemicals for screening How were they to move from their earlier work on "condensation products of isatin-5-sulphonic acid with two miles of chlorophenols"?

> "We have learned little from the bewildering mass of literature with its completely contradictory results, and so we chose - as one so often does - Nature as our guide".

Thus studies were made of the structure of naturally occurring insecticides; vulpinic acid (found in the lichen Cetraria vulpina), rotenone and formed the conceptual starting point for what turned out to be a very long trail of syntheses leading eventually to Dichlor-diphenyl-trichlor-methyl-methane (DDT) which proved to be a contact poison of great stability.

Spindler and Buxdorf state[98] that

> "P. Müller had been working since 1935 on the production of a purely synthetic insecticide; but it was not until the autumn of 1939 that he succeeded in producing a significant group of compounds by combining chlorals with hydrocarbons and phenols. He began by synthesising diphenyltrichloroethane, which proved to have a mildly toxic action by contact. Further research on the group eventually, by the combination of chloral and chlorobenzene, yielded 4,4-dichlorodiphenyltrichloroethane... This was to prove the most effective of the compounds hitherto synthesised. It had indeed been described in 1873, in a thesis, by an Austrian student by the name Othmar Zeidler, who however did not suspect its potentialities".

Between the work of Zeidler[99] and that of Müller's group, other papers appeared from time to time describing the synthesis of various unsymmetrical DDT-analogues, so the compound had not been forgotten completely[100].

DDT proved to be not only the desired stable stomach poison, but

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98. Spindler and Buxdorf (1954) p.8.

99. Zeidler, O. (1874).

100. These are discussed by Brooks (1974) V.1.pp.45-48.

also a contact poison. Läuger[101] notes that

> "Until the discovery of Gerasol (DDT), only a very few of the many synthetically prepared organic substances (but this does not apply to natural products!) were known to be effective as contact insecticides, and, of those few, none has found any field of application".

The Geigy team produced a fascinating rationalisation of what their decade of development had achieved[102].

> "Chlorbenzene is a very good respiratory poison: O-dichlorbenzene and p-dichlorbenzene, used under the name of Chlorocamphor, are still better (both are also contact poisons). The excellent stomach poison, 4,4,1-dichlordiphenylsulphone... is to be regarded as a non-volatile condensed chlorbenzene (with a negative $-SO_2-$ group inserted). The dichlordiphenyltrichlormethyl-methane contains the same condensed chlorbenzene system acting as the toxic component. To this system is attached the residual group of chloroform. Chloroform, as has long been known, is very soluble in the nerve lipoids..." "...A highly effective substance must fulfill the following conditions: it must possess a toxic component and have attached to this groups ... which guarantee a quite outstanding lipoid-solubility. If the compound which produces lipoid-solubility is absent then the most excellent toxic component is of no use, for it is scarcely possible for it to penetrate into the insect's body..."[103]

This exciting and brilliant paper was concluded with a paragraph which, in the light of historical hindsight, has an ironically prophetic ring.

> "Just a short remark in conclusion: pyrethrin and rotenone, as well as all natural insect poisons are, in contrast to the much more stable synthetic contact insecticides described, destroyed in a short time by light and by oxidation. Nature will and must do this, **for what catastrophes would occur, if the natural insect poisons were stable. Nature is on the side of life and not death!** (my emphasis, H.R.). But the monstrous whims which she could

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[101]. Läuger et al. (1944) p.31.

[102]. Läuger et al (1944) p.35. The biochemist V.B. Wigglesworth commented (1976) "I do not pretend to know whether these were the logical steps which were actually followed or whether... the logic was inserted afterwards to give coherence to the story. What is quite certain is that few would now accept the toxicological basis of their argument..." p.38.

[103]. Läuger et al. (1944) p.44. (This refers to the NCL TR126 translation) actual page in original is 927-8. This is now considered to be an oversimplified view of the real situation, and that attempts to practically relate structure and function in this group have so far failed. However, it represented at the time a significant advance in strategic thinking, about how to discover insecticidal compounds.

> indulge in and the means at her disposal to attain some definite purpose always makes the deepest impression".[104]

Müller's discovery was made in autumn 1939, and the first patent application was made May 8th 1941, and DDT was introduced in 1942 under the trade names, 'Gerasol', 'Gnesarol' and 'Neocid'. It was protected by Swiss patent 226,180; and BP 547,871[105]. The new compound quickly showed its effectiveness by checking, in 1941, a plague of Colorado beetle which threatened the Swiss potato crop.

The early history of DDT has two phases: the first the period 1927-1942 of fundamental R & D work by the Swiss, which I have just described; and second the phase from 1942-1945 when DDT was harnessed to the British and American war effort.

The Swiss, of course, were quick to make use of DDT, the control of Colorado beetle has been mentioned. But its public hygiene potential was also realised and Neocid (a 5% DDT dust) was being used to combat fleas and lice in schools and refugee camps; and its field trials were organised, in collaboration with the Red Cross, in the Balkans. Thus one assumes the Swiss sold, or offered DDT to the Germans, however, this is not documented in any of the sources I have used. Certainly it is known that I.G. Farbenindustrie produced DDD (1,1-dichloro-2, 2-bis (p-chlorophenyl) ethane) under the code name ME 1700 during the war; this was later introduced, in 1945, by Rohm and Haas Co. under the trade name Rhothane.

Geigy informed their American subsidiary of DDT's agricultural pest control potential in September, 1941, and again in June 1942. In August 1942 the lice controlling properties were brought to the attention of the American military attache in Berne, and its military

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104. Läuger <u>et al.</u> p.49.

105. Martin (1968) p.121.

significance was not lost on the Americans. Brook[106] says that

> "The active ingredients in samples of Gerasol had been extracted, analysed and synthesised in the Beltsville laboratory of the U.S. Department of Agriculture (U.S.D.A.) by the time the structure of DDT has been received from Switzerland..."

The Second World War gave DDT a very special boost, perhaps it would never have made such an extraordinary impact in peace-time[107]. However, in war time it is a fact that insect borne disease probably carry off more people that do bullets. Thus the British government reported that[108] "In Sicily the 7th and 8th Armies suffered more casualties from malaria than from battle". When Japan entered the war Britain and America were cut off from important sources of Derris and Pyrethrum, then important control agents for typhus and malaria. Synthetic substitutes were urgently being sought by an official UK government Insecticide Development Panel of Experts. Therefore, when DDT was demonstrated, by Geigy's British subsidiary, to the Government in 1942, its development became a top priority and a military secret! Much of the story and excitement of the period is described in a book by West and Campbell[109]. Sir Ian M. Heilbron, DSO, FRS, then chemical advisor to the Ministry of Production (he had also set up the above mentioned Panel of Experts)

> "put the whole force of the Ministry of Production to initiate and expedite the manufacture of this new synthetic insecticide for which the name DDT was coined by an official of the Ministry of Supply".[110]

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[106]. Brook (1974) V.1.

[107]. This has been discussed by J.H. Perkins ("Re-shaping technology in war time: The effect of military goals on entomological research and insect control practices"). Technology and Culture, 19 (2) pp.169-186, 1978.

[108]. Brook V.1. (1974) p.11

[109]. West and Campbell (1950) p.1-11.

[110]. West and Campbell (1950) p.4.

British research concentrated on louse and mosquito control and its human and mammalian toxicity i.e. the military requirements, deferring horticultural and agricultural research. It is said that "DDT at that time became a war priority of the highest order, ranking with penicillin and radar, and nothing was allowed to stand in its way".[111] [112] Work proceeded rapidly, the first laboratory production was in January 1943, pilot plant production April 1943, and bulk plant production began in November 1943, the first large scale production outside Switzerland. This was at the Geigy works in Trafford Park, Manchester. Similar efforts were made in the United States[113], where, because of their far greater resources and different range of problems, great headway was also made on the agricultural applications of DDT. The American Geigy subsidiary Cincinnati Chemical plant, Norwood, Ohio was first American production centre, their pilot plant went on stream in May 1943, one month after the British in Manchester. By the summer of 1944, U.S. production reached 300,000 lb. per month, with a target of 1.7 million lbs. per month by 1945[114]. By 1943, despite attempts to keep it secret[115], the existence of DDT and some of its properties

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[111]. West and Campbell (1950) p.4. and Heilbron (1945).

[112]. Churchill said "The excellent DDT powder which has been fully experimented with and found to yield astonishing results will henceforth be used on a great scale by the British forces in Burma and by the American and Australian forces in the Pacifica and India in all theatres..." Broadcast, 28 Sept. 1944.

[113]. These have been recorded in an article by V. Froelicher (1944), Soap 20 (7), 117., and are summarised in West and Campbell (1950).

[114]. Brook V.1 (1974) p.11.

[115]. British workers have bitterly felt that the American researchers had upstaged them. "It is hard to think that the credit has gone into America and will stay with America because of our policy of secrecy. It is important to put on record here and now that the work started in this country and has gone on to a large extent here. There has been cordial cooperation with America and, of course, their

leaked out to the American public, and in August 1944 the British Government officially released the news to the British. "The full story can not be told of what has been described as one of the greatest scientific discoveries of the last decade ... etc". It told of the first big war-time success with DDT, the controlling of the Naples typhus epidemic, December 1943-January 1944, by de-lousing over 1,300,000 civilians with DDT powder. Without the military needs, development would doubtless have been far slower and less intensive, for as E.F. Armstrong said[116], whilst chairing a meeting at which Heilbron described the British DDT development programme, "We all deplore war, but war does accelerate the working out of some of those problems which cost a good deal to bring to completion". Rohwer called the Second World War "a bright chapter in the history of our science" (Entomology)[117] [118]

When the military service needs had been met the development work turned to agricultural and public health problems[119], means of efficiently formulating DDT preparations. By 1961 over 334 uses for DDT had been registered in USA, and up to 1970 about 100 million lbs had been used in USA[120]. Initially, there was no headlong rush to pour DDT on to crops etc.; indeed, early warnings were issued about possible

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opportunity and capacity for production is greater than ours. Nevertheless, a great deal of credit belongs to Professor Heilbron and his team". E.F. Armstrong, J. Rays. Dev. Stdy. XCIII, 71, 1956.

116. Ibid. p.69.

117. Rohwer (1949).

118. This has been discussed at length, from the American viewpoint by Cushing (1957), and Perkins (1978).

119. The success of DDT in this area resulted in P. Muller being awarded the Nobel Prize for Physiology and Medicine, 1948.

120. Brook, V.1 (1974) p.34.

hazards. Heilbron said in 1945,

> "The U.S. Department of Agriculture has, however, rightly sounded a note of warning against extensive use of the insecticide until their big programme of toxicological study and insecticidal investigation is complete".[121]

That DDT exerts its primary toxic effect on the nervous system is well known. It has been pointed out[122] that

> "studies of modes of action attempt to answer the closely related questions 'what do the toxicants do? and 'How do they do it?' For the organochlorine insecticides a great deal has been written in answer to the first question but much less that really provides any answer to the second".

O'Brien in his review said[123] "It is painful to have to admit that, after decades of intensive research, we are far from understanding the mechanism of DDT". It is thought that the lethal effect is on sensory nerves, by altering the potassium ion permeability of the nerve (axonic) membrane. There are several competing theories as to how DDT causes such a physiological disruption[124].

From the early 1960s on DDT came under a great deal of criticism; and many of its applications were banned in many countries, this process led to great controversy[125]. Nevertheless, it is still of great importance and our bibliographic data show that it held first place in R & D references in the Review of Applied Entomology from 1946 to 1970. The initial growth curve is explosive, giving a great kick

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121. Heilbron (1945) p.69.

122. Brook, V.2 (1974) p.130.

123. O'Brien (1967) p.111.

124. see O'Brien (1967) pp.113-125 and Brook, V.2. (1974) pp. 130-136. Also Corbett (1974).

125. The public debate stimulated by Carson (1962) has been reviewed at length by Dunlap (1975, 1981), and a collection of papers providing the industry's case has been edited by Sobelman (1970). The "Ribicoff Hearings", in 11 volumes, provide a rich source of material (United States Congress, 1964-1966).

for the first five years, followed by a fall after which it remained fairly steady (see Fig. 5.14) until 1975 (when it ranked 2nd) after which it declined extremely rapidly, and its growth curve took on an S shape; it appears now to be a compound in terminal decline.

BHC $C_6H_6Cl_6$

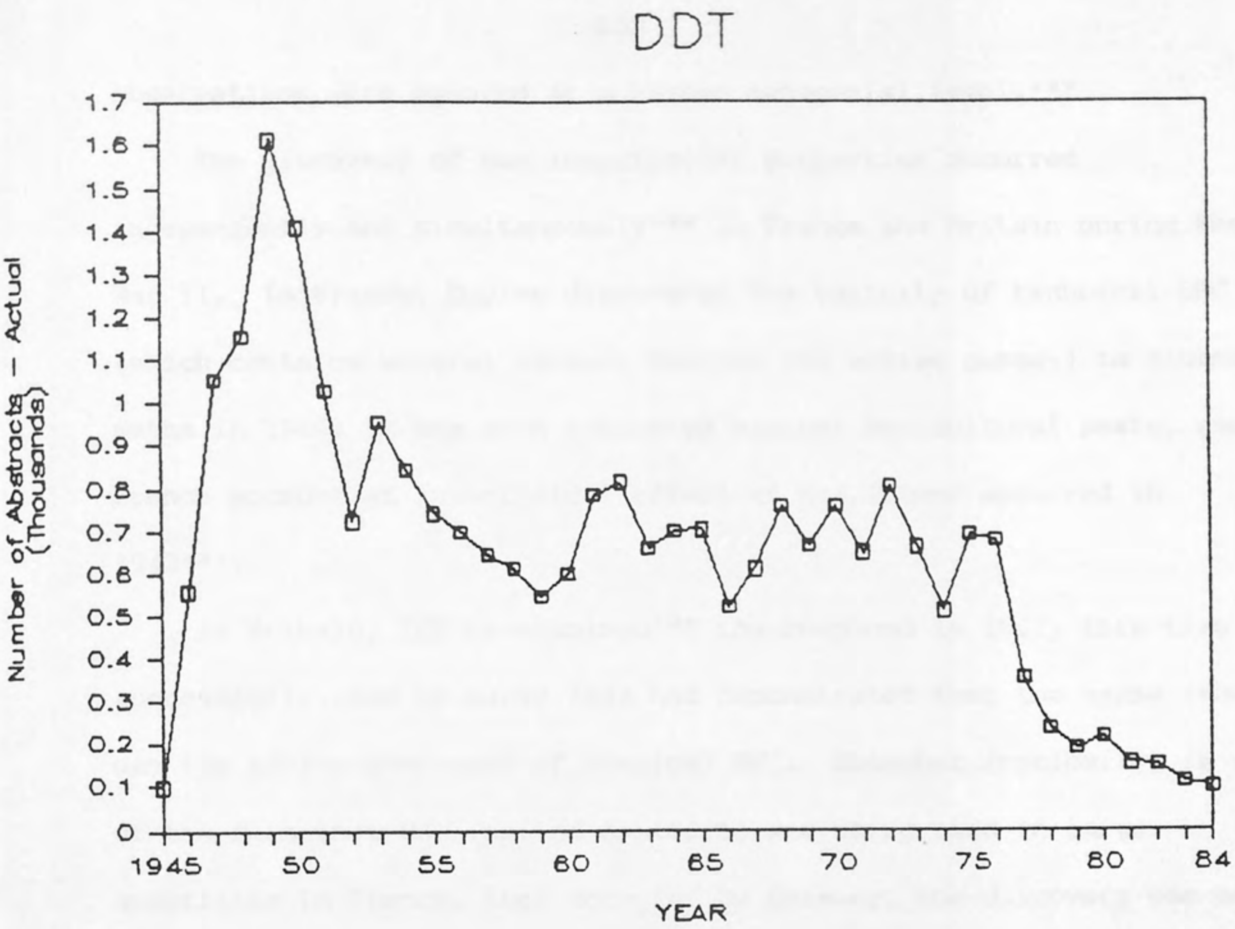
gamma-1,2,3,4,5,6-hexachlorocyclohexane (HCH) also termed gamma-benzene hexachloride; also referred to as Jacutin, Gammexane, lindane. Throughout I shall refer to it as BHC. This is the only highly insecticidal member of its chemical group, unlike DDT or the cyclodienes, and only the gamma isomer is strongly insecticidal.

Brook[126] says that "in a strictly historical sense, hexachlorocyclohexane (HCH) is the oldest of the organochlorine insecticides, since its purely chemical origins can be traced to the earliest ventures in organic chemistry". Faraday described its preparation in 1825. Having been known as a chemical for so long it is perhaps surprising that its insecticidal properties remained undiscovered for over 100 years. Several times they came close to being found. Lambermont[127] says it was considered as a possible fumigant during the First World War, but was never taken up. A patent in 1935[128] describing a production process for BHC mentioned that it and other chlorides appeared to be good insecticides, but once more the observation was not followed up. ICI tested BHC in 1937 as an ovicide for clothes moths. These proved negative, although the bench worker noticed insecticidal properties on the larvae and imago these

[126]. Brook V.1. (1974) p.185.

[127]. Cited by Brook, V.1. (1974) p.185.

[128]. H. Bender, U.S.P. 2,010,841 (the account in Chem. Abs., 1935, 6607 is inaccurate).


DDT
Number of Abstracts — Actual (Thousands)
YEAR
1945
50
55
60
65
70
75
80
84

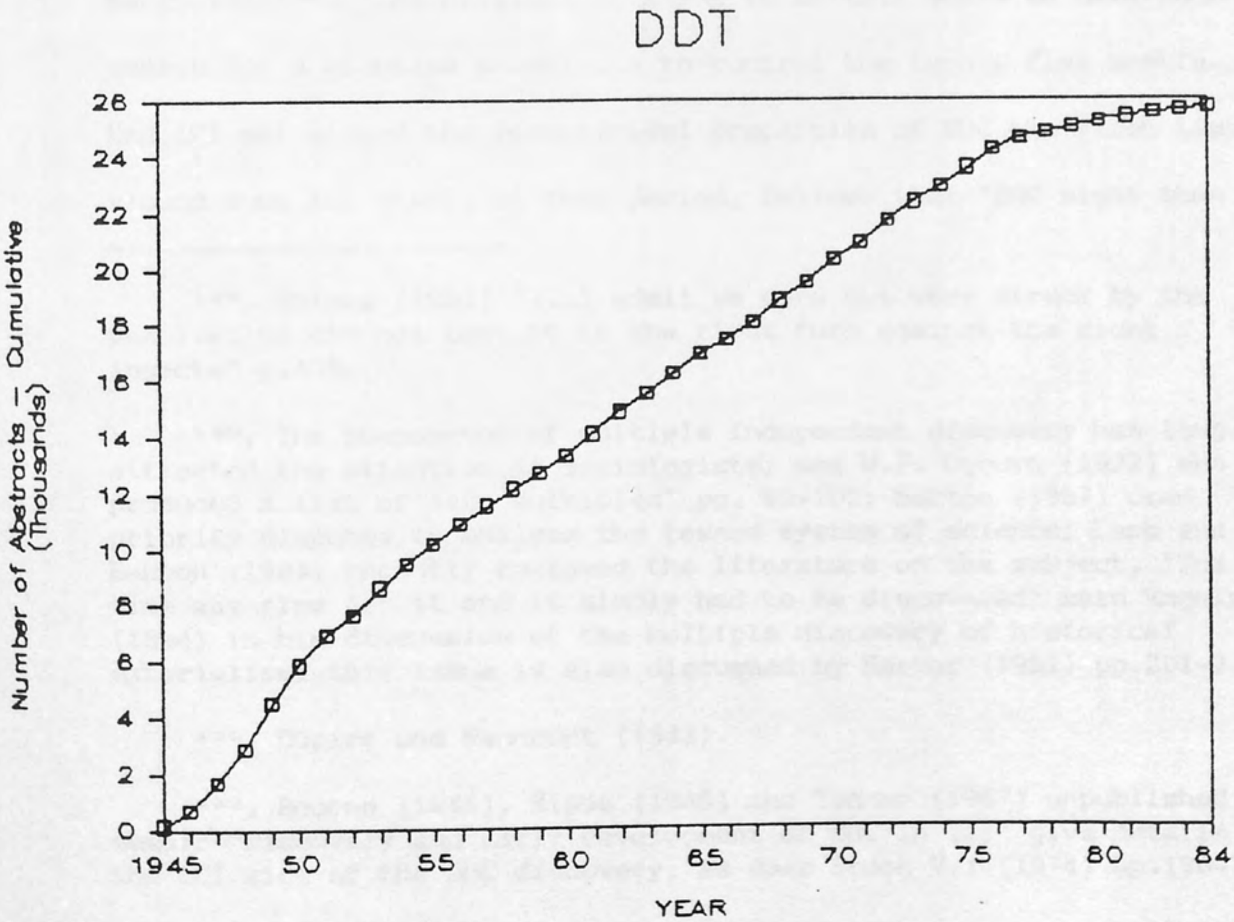

DDT
Number of Abstracts — Cumulative (Thousands)
YEAR
1945
50
55
60
65
70
75
80
84

Fig. 5.14

observations were ignored at a higher managerial level.[129]

The discovery of the insecticidal properties occurred independently and simultaneously[130] in France and Britain during World War II. In France, Dupine discovered the toxicity of technical BHC (which contains several isomers besides the active gamma-) to clothes moths in 1940; it was soon evaluated against agricultural pests, and a French account of insecticidal effect of the isomer appeared in 1943[131].

In Britain, ICI re-examined[132] the compound in 1942, this time successfully, and by early 1943 had demonstrated that the gamma isomer was the active component of chemical BHC. Somewhat ironically, in view of the fact that BHC (called Aphitira) was being used in large quantities in France, then occupied by Germany, the discovery was made a state secret! The first British public announcement was made in early 1945[133]. The original stimulus in Britain seems to have been a search for a nicotine substitute to control the turnip flea beetle. Had ICI not missed the insecticidal properties of BHC the first time around some ICI staff, of that period, believe that "BHC might then

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[129]. Holmes (1951) "...I admit we were not very struck by the results: we did not test it in the right form against the right insects" p.405.

[130]. The phenomenon of multiple independent discovery has long attracted the attention of sociologists; see W.F. Ogburn (1922) who produced a list of 148 'multiples' pp. 90-102; Merton (1957) used priority disputes to analyse the reward system of science; Lamb and Easton (1984) recently reviewed the literature on the subject. "The time was ripe for it and it simply had to be discovered" said Engels (1894) in his discussion of the multiple discovery of historical materialism; this issue is also discussed by Barber (1952) pp.201-2.

[131]. Dupire and Raucourt (1943).

[132]. Bourne (1945), Slade (1945) and Tanner (1967) unpublished memoir "Discovery and Early Development of BHC in ICI" give details of the ICI side of the BHC discovery, as does Brook V.1 (1974) pp.186-7.

[133]. Tanner (1967).

have had the edge over DDT for mosquito control in the Services".

BHC has a wide range of applications in both agriculture and public health[134]. It has certain disadvantages, a strong smell, and it taints certain crops. It can be used as a stomach, contact and fumigant insecticide, and is probably the most insecticidal of all the organochlorines in terms of concentration of compound required at the site of action[135].

As with DDT "we know painfully little about Lindane's (gamma BHC) action. Probably it ia a neuroactive agent that acts in a way not unlike DDT".[136]

The general pattern with regard to HCH production appears to have been one of continuous decline, particularly in USA where the decline appears to have begun in 1954, when its use on forage crops was banned. However, production in Japan rose by almost 300% between 1960 and 1968 to 4,000 tons, although it has since begun to decline. In Britain in the mid-1960s about 100 tons a year was used. Our bibliographic data shows a similar pattern to that of DDT, a very rapid growth to a peak followed by a long slow decline (see figure 5.15). Nevertheless it was still, after twenty years, number two in our league table in 1970, after that date its decline became as dramatic as its initial growth, and the growth curve takes on the characteristic S shape.

The Cyclodiene Group of Insecticides

Many potent insecticidal compounds were found in this group and in this section I shall deal at length with two, chlordane and dieldrin, which at one time or another appeared in the 'top five' of the

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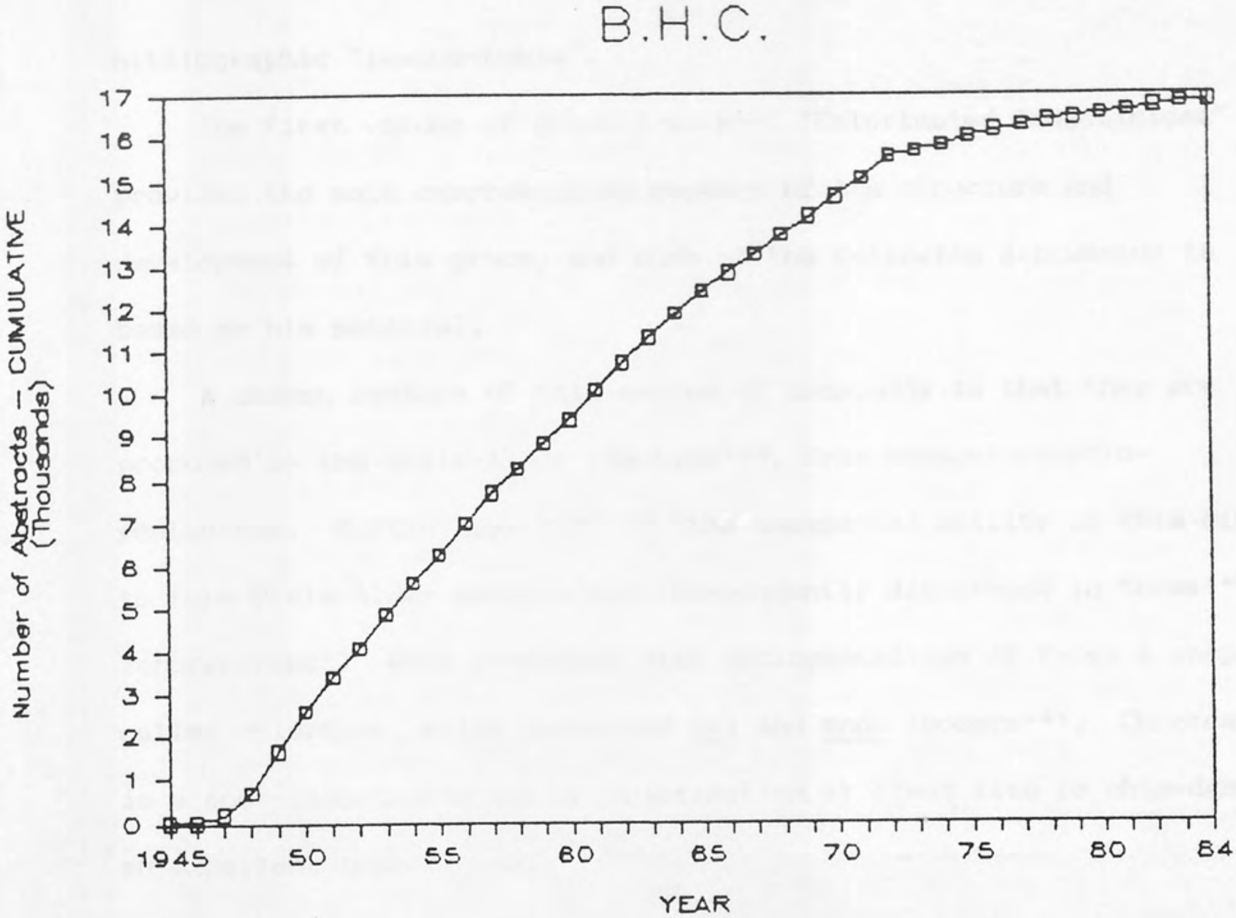
[134]. Ulmann (1972).

[135]. Martin (1961) p.19.

[136]. O'Brien (1967) p.184.


B.H.C.
Number of Abstracts – CUMULATIVE (Thousands)
YEAR
1945 50 55 60 65 70 75 80 84
0 1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17

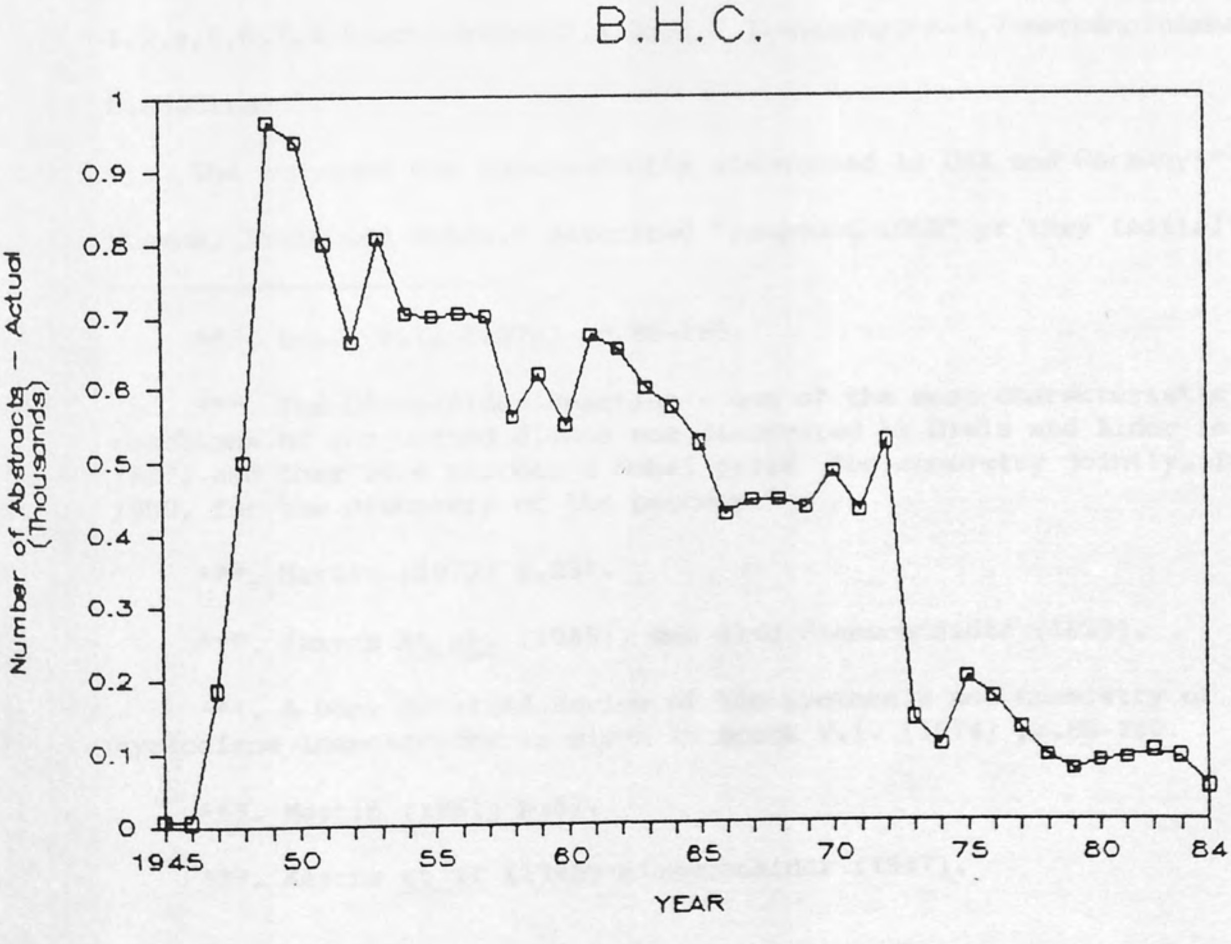

B.H.C.
Number of Abstracts – Actual (Thousands)
YEAR
1945 50 55 60 65 70 75 80 84
0 0.1 0.2 0.3 0.4 0.5 0.6 0.7 0.8 0.9 1

Fig. 5.15

bibliographic "league-table".

The first volume of Brook's work[137] "Chlorinated Insecticides" provides the most comprehensive summary of the structure and development of this group, and much of the following discussion is based on his material.

A common feature of this series of compounds is that they are produced by the Diels-Alder reaction[138], from hexachlorocyclopentadiene. Martin says that[139] "the unexpected ability of this diene to form Diels-Alder adducts was independently discovered in three[140] laboratories". When condensed with cyclopentadiene it forms a compound called chlordene, which possessed exo and endo isomers[141]. Chlordene is a poor insecticide but on chlorination it gives rise to chlordane, an excellent insecticide.

Chlordane

This is the common name approved by the ISO and BSI for 1,2,4,5,6,7,8,8-octachloro-2,3,3a,4,7,7a-hexahydro-4,7-methanoindene, $C_{10}H_6Cl_{10}$[142].

The compound was independently discovered in USA and Germany[143]. Kearns, Ingle and Metcalf described "compound 1068" as they initially

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137. Brook V.1. (1974) pp.85-183.

138. The Diels-Alder Reaction - one of the most characteristic reactions of conjugated dienes was discovered by Diels and Alder in 1927, and they were awarded a Nobel prize for chemistry jointly, in 1950, for the discovery of the process.

139. Martin (1973) p.231.

140. Kearns et al. (1945), see also Riemschneider (1963).

141. A very detailed review of the synthesis and chemistry of cyclodiene insecticides is given in Brook V.1. (1974) pp.85-140.

142. Martin (1961) p.67.

143. Kearns et al (1945) Riemschneider (1947).

called it, as "more toxic than DDT and to compare favourably with in toxicity to the pure gamma-isomer of benzene hexachloride to a number of species of insects".

The American group obtained compound 1068 from the Velsicol Chemical Corporation. Brook has related[144] Julius Hyman's (of the Velsicol Corp.) recollections of its origins. Large amounts of cyclopentadiene were produced in the USA during World War II as a by-product of synthetic rubber production; its uses were limited and Velsicol employed it in the production of petroleum resins for varnishes etc. One of the by products of the resin production was

> "an oily solvent, rich in methylated naphthalenes, which was used as a solvent for DDT. Such solvents were found by Kearns and others to have insecticidal properties themselves. Further, Hyman had initiated a literature survey on cyclopentadiene reactions as part of a search for possible alternative uses for it. He also had a special interest in the Diels-Alder reaction which caused his attention to be attracted to the preparation of hexachlorocyclopentadiene from cyclopentadiene. A series of related reactions were carefully examined and experimented with and one of the derived compounds (called compound 237 by Velsicol) was found to be insecticidal. It was four and five times lower than DDT's, but cheaper at a quarter of the price. However, it was more volatile, thus less persistent. In an attempt to reduce this volatility it was chlorinated and thus chlordane was discovered."

This was in the latter half of 1944, and this product, then called Velsicol - a patent describing the synthesis was taken out in December 1948. "It was the discovery that hexachlorocyclopentadiene participates in the Diels-Alder reaction (that) offered prospects for the development of a whole new range of insecticides".[145]

Chlordane quickly gained acceptance as a broad spectrum insecticide in agriculture and public health[146]. It was a successful

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144. Brook V.1.(1974) pp.141-143.

145. Brook (1974) V.1. pp.141-143.

146. B.P. 614, 931, 1948 (see C.A. 43, 4693, 1949).

soil insecticide. It later (1950s) ran into resistance and toxicological problems, partially due to manufacturing impurities in technical chlordane[147].

A great deal of research has been done on the mode of action of cyclodiene insecticides, but

> "In spite of fairly copious data, there is still not much to be said about the action of cyclodienes except that they probably interfere with nerves. It is the author's guess that these compounds are not anti-enzymes, but that they complex with a neural membrane in such a way to modify its properties".[148]

The usage of chlordane and heptachlor (a closely related material, in fact one of the several constituents of technical chlordane)[149] has begun to fall off since the mid 1960s.[150] The bibliographic data show that research interest in both compounds has declined, although the curves exhibit different characteristics (see Fig. 5.16). Chlordane, like DDT and BHC, shows a very sharp rapid rise to a peak followed by a long decline, since the early 1950s. Whereas with heptachlor (see Fig. 5.17) the rise to its peak (which has been only half that of chlordane), was far more gradual, and it showed signs of decline after the early 60s. By the late 1970s the growth curves for both had become S shaped.

Endosulphan

Originated from work by Farbwerke-Hoechst A.G. In open chain analogue of chlordane[151]. Its insecticidal properties were described in 1956 and it was given the trade mark Thiodan. It is relatively

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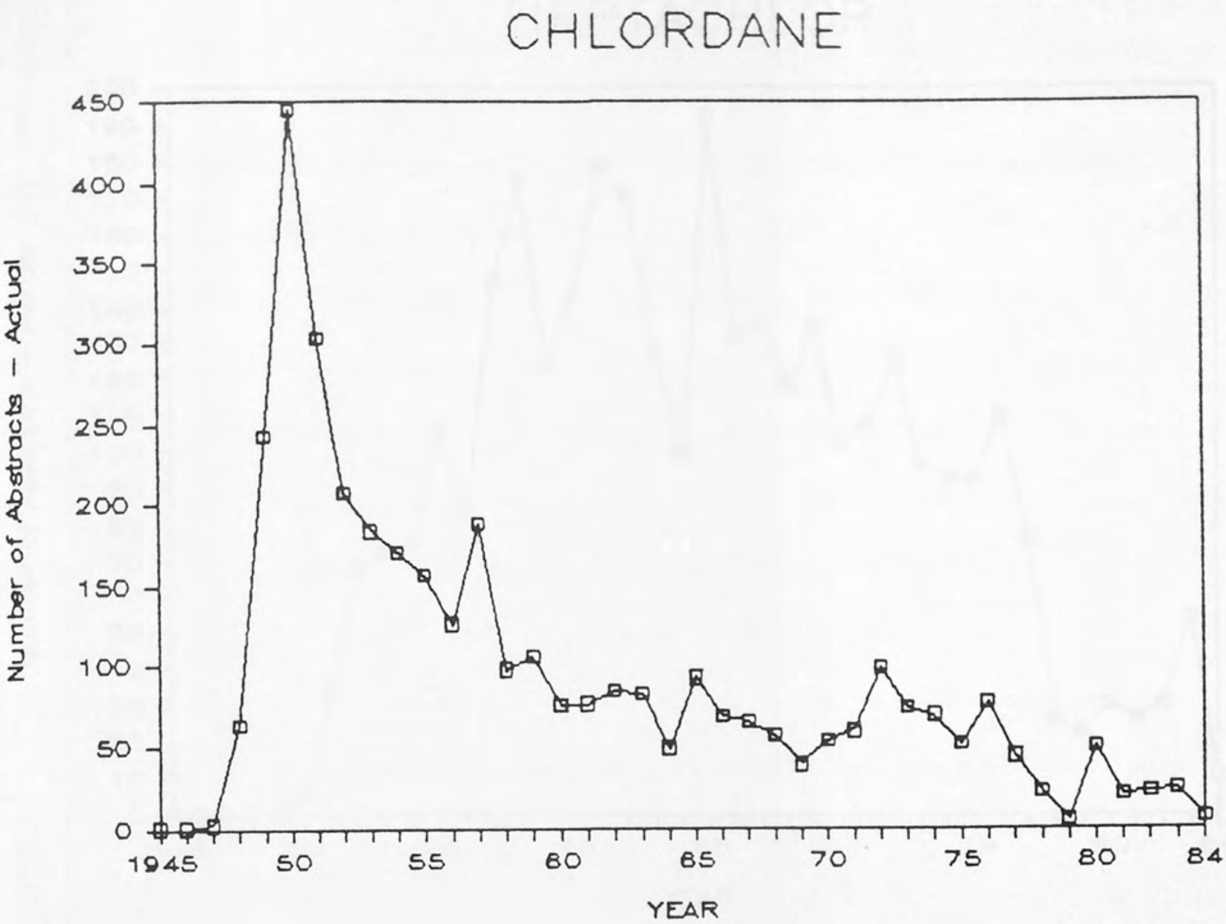
147. For a detailed discussion of this problem see Brook V.1. (1974).

148. O'Brien (1967) p.140.

149. Brook V.1. (1974) p.154.

150. Brook (1974) V.1. p.155.

151. Brook V.1 (1974) p.158.


CHLORDANE
Number of Abstracts – Actual
450
400
350
300
250
200
150
100
50
0
1945
50
55
60
65
70
75
80
84
YEAR

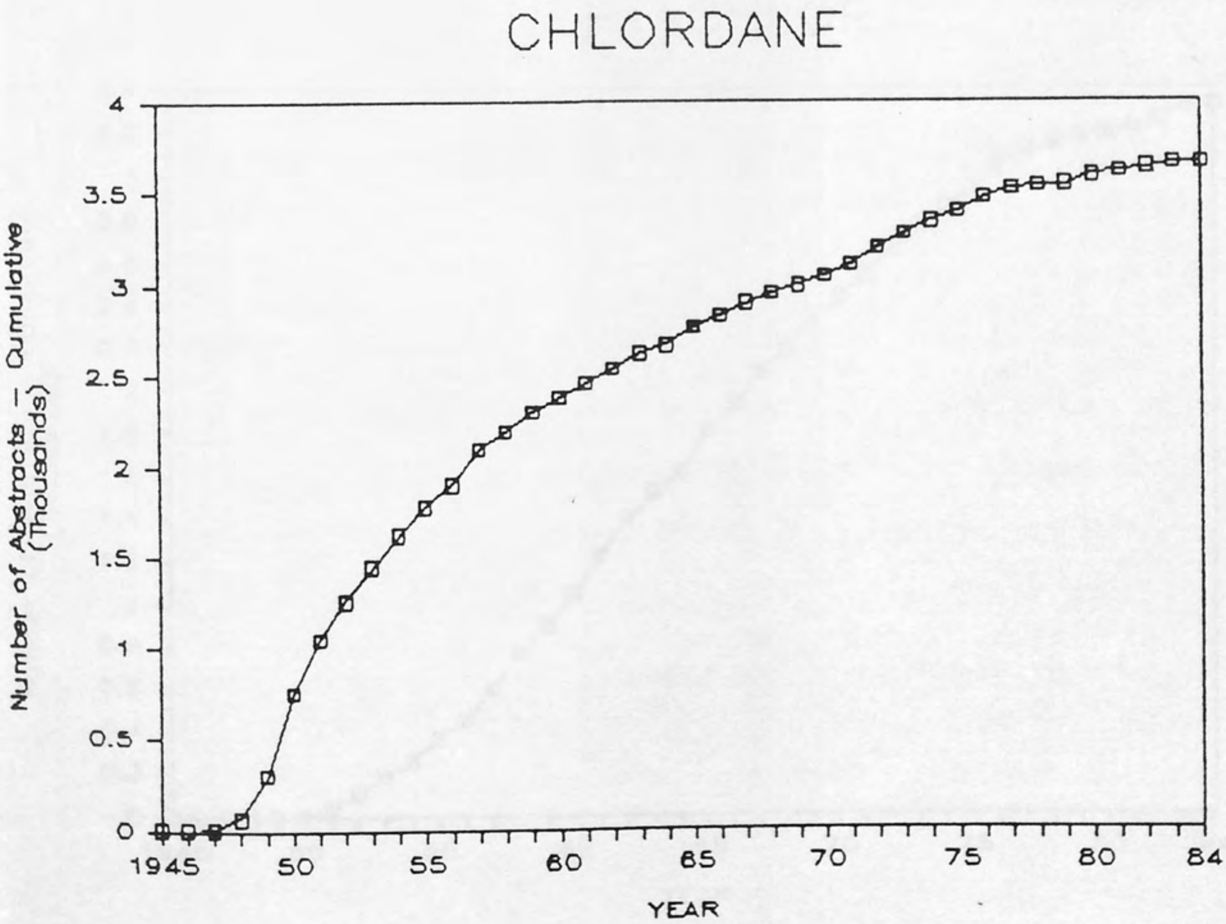
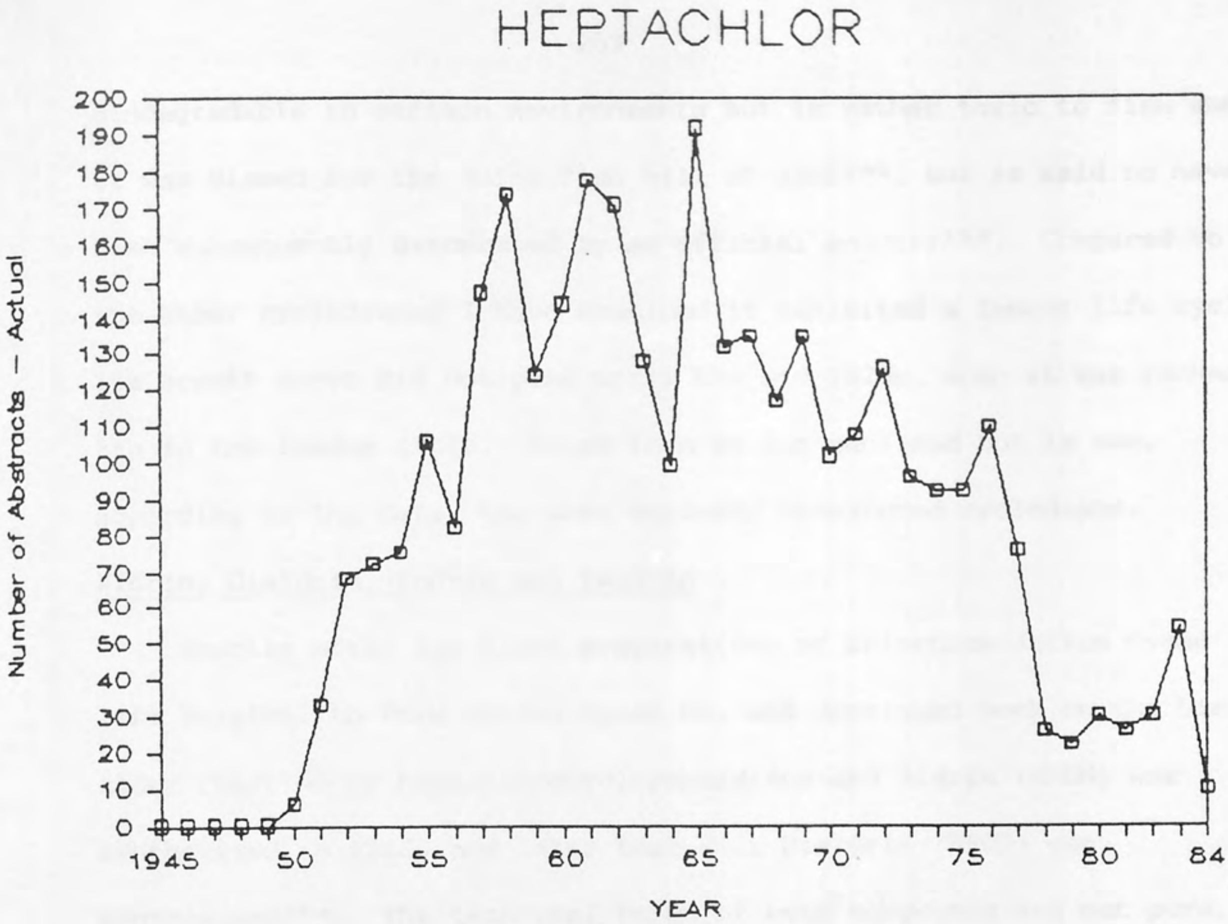

CHLORDANE
Number of Abstracts – Cumulative
(Thousands)
4
3.5
3
2.5
2
1.5
1
0.5
0
1945
50
55
60
65
70
75
80
84
YEAR

Fig. 5.16


HEPTACHLOR
Number of Abstracts — Actual
YEAR
1945
50
55
60
65
70
75
80
84

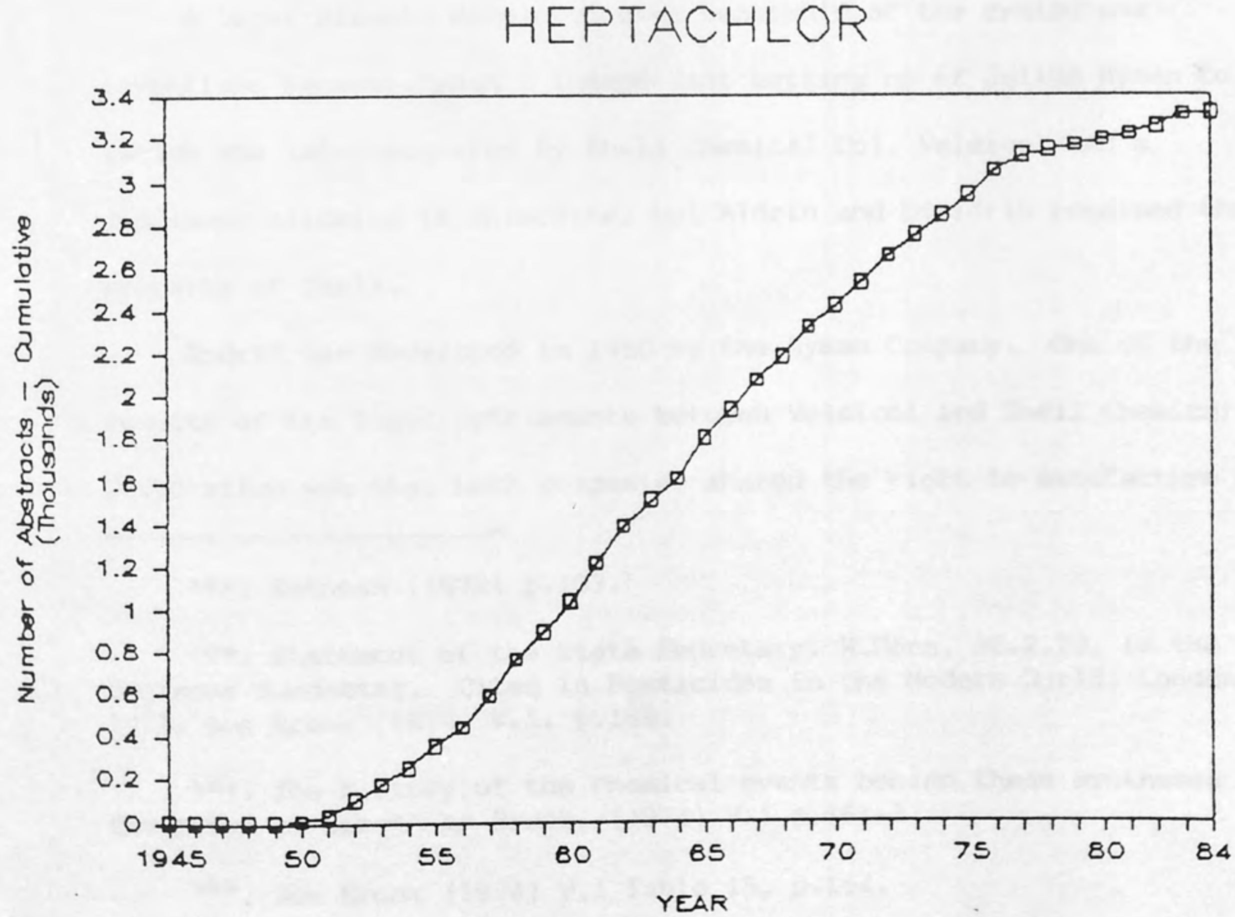

HEPTACHLOR
Number of Abstracts — Cumulative (Thousands)
YEAR
1945
50
55
60
65
70
75
80
84

Fig. 5.17

biodegradable in certain environments but is rather toxic to fish and it was blamed for the Rhine fish kill of 1969[152], but is said to have been subsequently exonerated by an official enquiry[153]. Compared to the other cyclodienes I have examined it exhibited a longer life cycle, its growth curve did not peak until the mid 1970s, when it was ranked 5th in the league table. Since then it has declined but is now, according to the data, the most actively researched cyclodiene.

Aldrin, Dieldrin, Endrin and Isodrin

Shortly after the first preparations of Chlordane Julius Hyman left Velsicol to form Julius Hyman Co. and continued work on the Diels-Alder reaction of hexachlorocyclopentadiene and Aldrin (HHDN) was synthesised in 1948, and later that year Dieldrin (HEOD) was synthesised[154]. The technical forms of both compounds are not pure, and contain a mixture of several other compounds.[155]

A legal dispute developed over ownership of the cyclodiene inventions because Hyman's independent setting up of Julius Hyman Co (which was later acquired by Shell Chemical Co), Velsicol had a judgement allowing it chlordane, but Aldrin and Dieldrin remained the property of Shell.

Endrin was developed in 1950 by the Hyman Company. One of the results of the legal settlements between Velsicol and Shell Chemical Corporation was that both companies shared the right to manufacture and

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152. Rothman (1972) p.103.

153. Statement of the State Secretary, W.Dorn, 20.2.70, in the Deutsche Bundestag. Cited in Pesticides in the Modern World, London, 1972, see Brook (1974) V.1. p.159.

154. The history of the chemical events behind these syntheses are described at length by Brook, (1974) V.1 p.161-3.

155. See Brook (1974) V.1 Table 15, p.164.

market Endrin.[156]

Aldrin, Dieldrin and Endrin are nonsystematic and persistent contact and stomach insecticides active on many insects, the former two being highly regarded soil insecticides. These compounds reached a production peak in the mid-1960s,[157] and have declined since as a result of resistance problems, and environmental toxicity considerations.[158] In the USA the sales peak was reached in 1956, and there was a 70% reduction from 1956-1968, and in 1974 most uses were banned.[159]

The bibliographic data show that Dieldrin reached the top five in 1955, replacing chlordane, remaining there in 1960, but being in turn replaced in 1965. Dieldrin, Endrin and Aldrin show similar growth curves (see figures 5.18, 5.19, 5.20), the latter compound perhaps reaching its peak four or five years later in 1962, but the trend is the same, a decline after reaching peaks in the late 1950s or early 1960s, with a dramatic fall-off after the early 1970s. All three growth curves are now mature S curves.

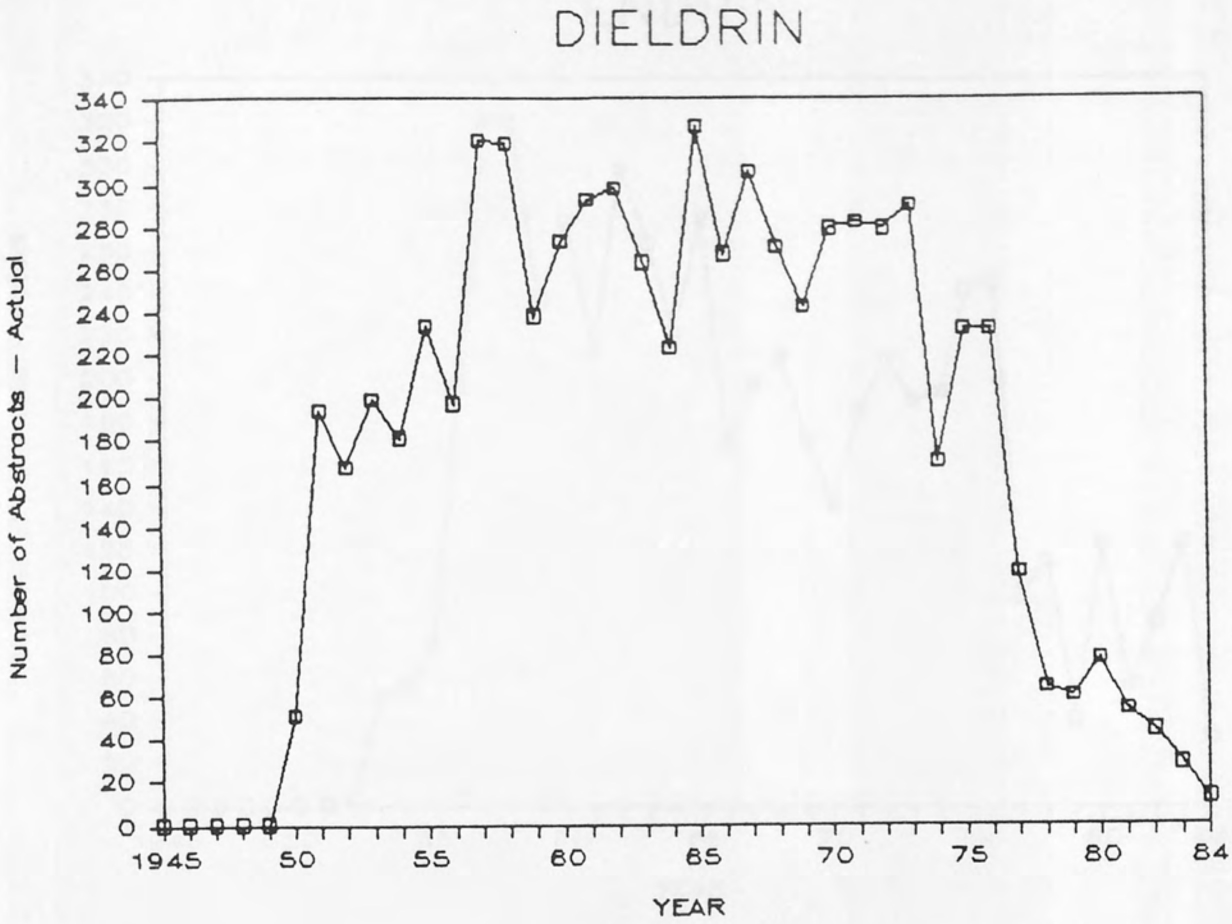
---

[156]. Aldrin is the BSI common name for a material containing not less than 95% by weight of the compound 1,2,3,4,10,10-hexachloro-1,4,4a,5,8,8a-hexahydro-1,4-endo, exo-5, 8-dimenthanonaphthalene (using the American system of nomenclature) this abbreviated to HHDN.
Dieldrin is the BSI trivial name for a material containing not less that 85% by weight of the chemical 1,2,3,4,10,10-hexachloro-6,7-epoxy - 1,4,4a,5,6,7,8a-octahydro-1,4,endo, exo-5,8, dimethanonaphthalene (American nomenclature = HEOD)
Endrin, trivial BSI name for material containing at least 92% weight of the chemical 1,2,3,4,10,10-hexachloro-6,7-epoxy-1,4,4a,5,6,7,8,8a-octahydro-1,4-endo, endo-5, 8-dimethanonaphthalene.

[157]. Brook (1974) V.1. pp.170, 182.

[158]. For a discussion of this see Gillespie <u>et al.</u> (1979).

[159]. Carter (1974) p.239.


DIELDRIN
Number of Abstracts – Actual
0
20
40
60
80
100
120
140
160
180
200
220
240
260
280
300
320
340
1945
50
55
60
65
70
75
80
84
YEAR

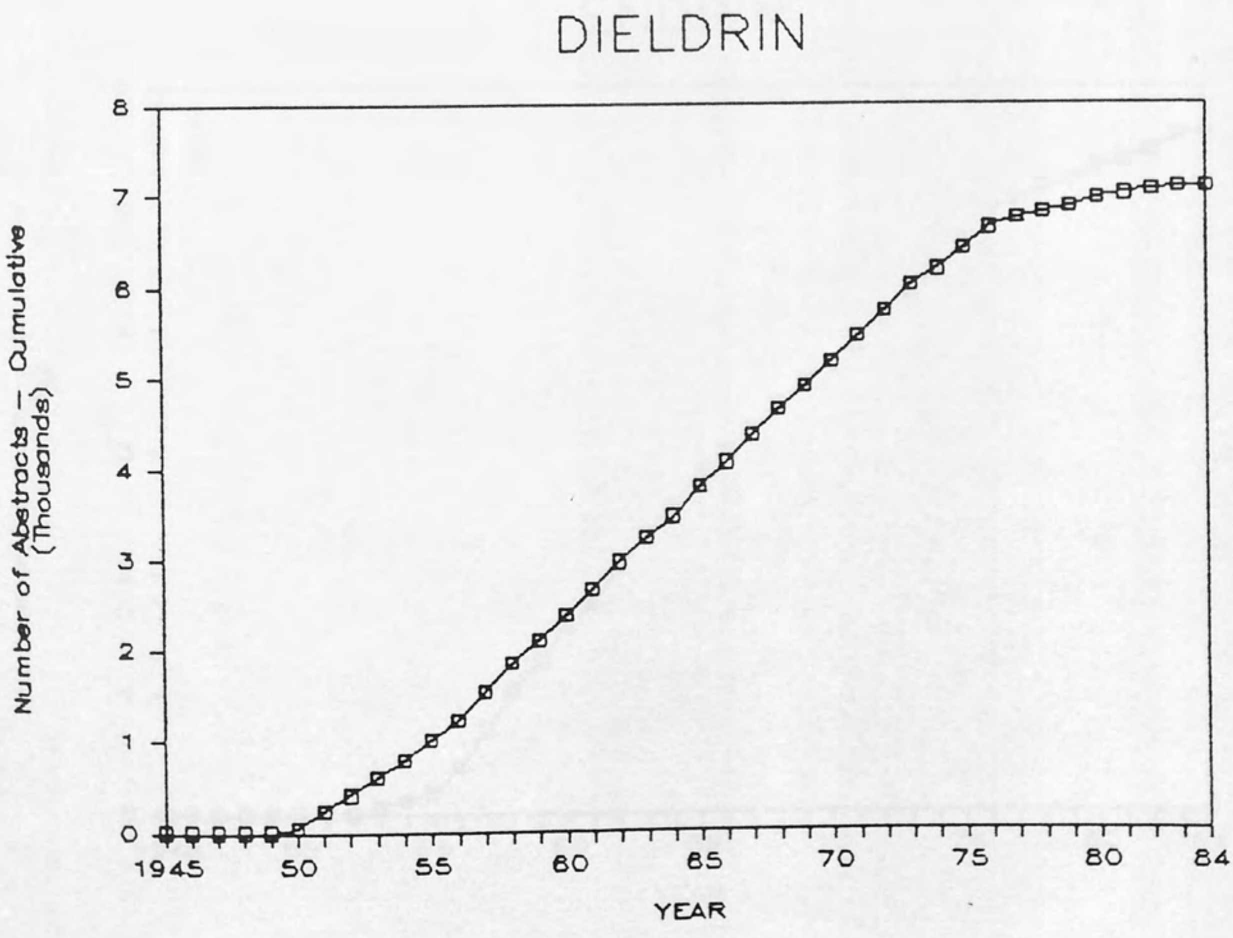
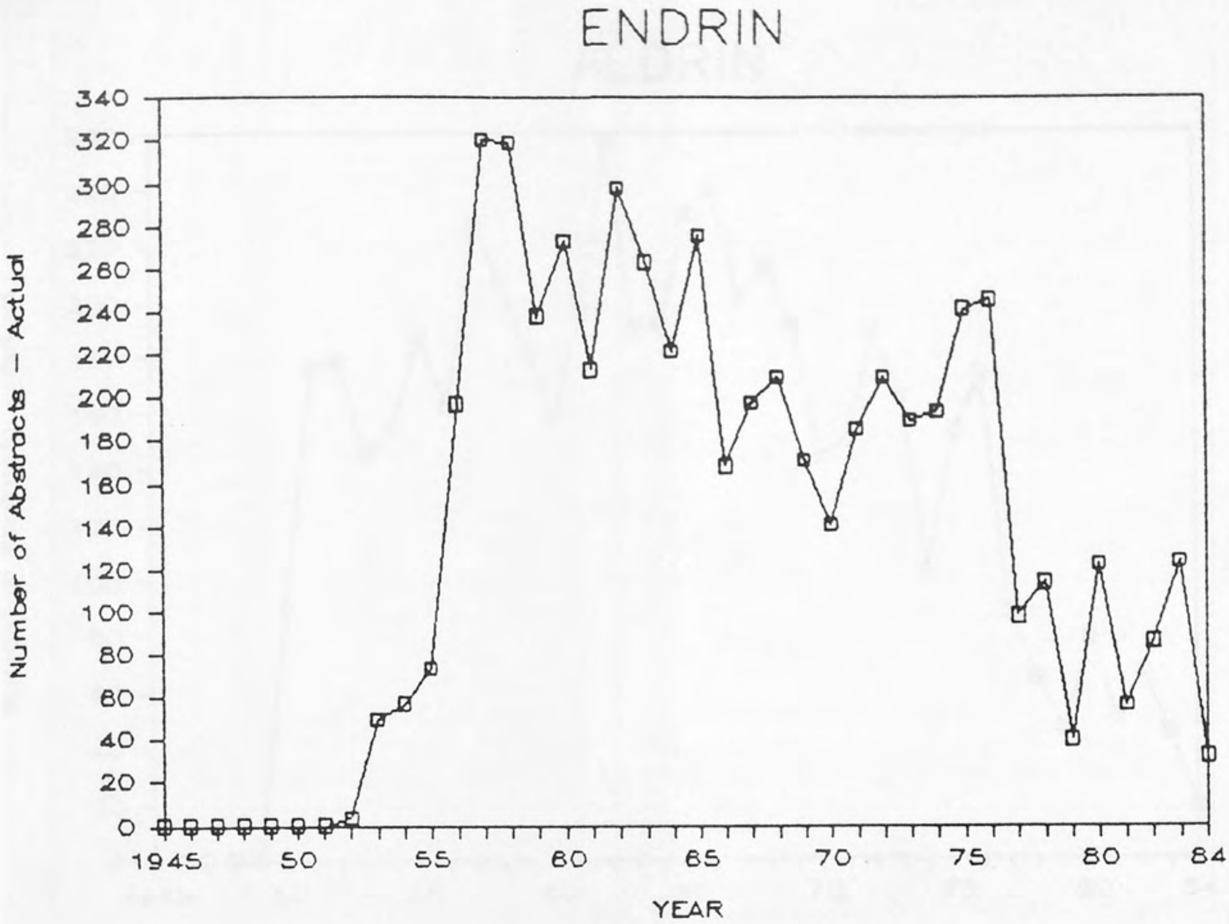

DIELDRIN
Number of Abstracts – Cumulative
(Thousands)
0
1
2
3
4
5
6
7
8
1945
50
55
60
65
70
75
80
84
YEAR

Fig. 5.18


ENDRIN
Number of Abstracts – Actual
340
320
300
280
260
240
220
200
180
160
140
120
100
80
60
40
20
0
1945
50
55
60
65
70
75
80
84
YEAR

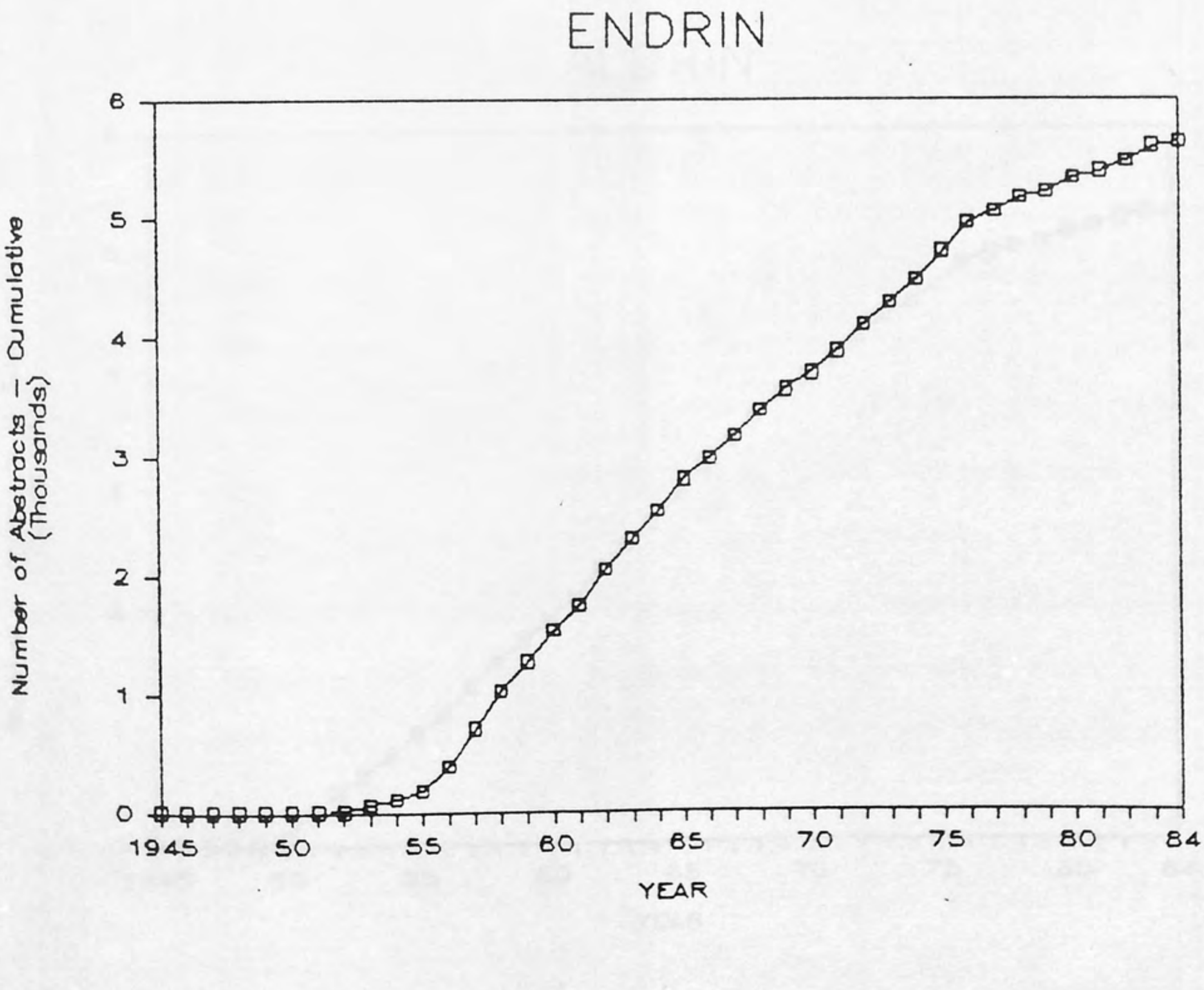
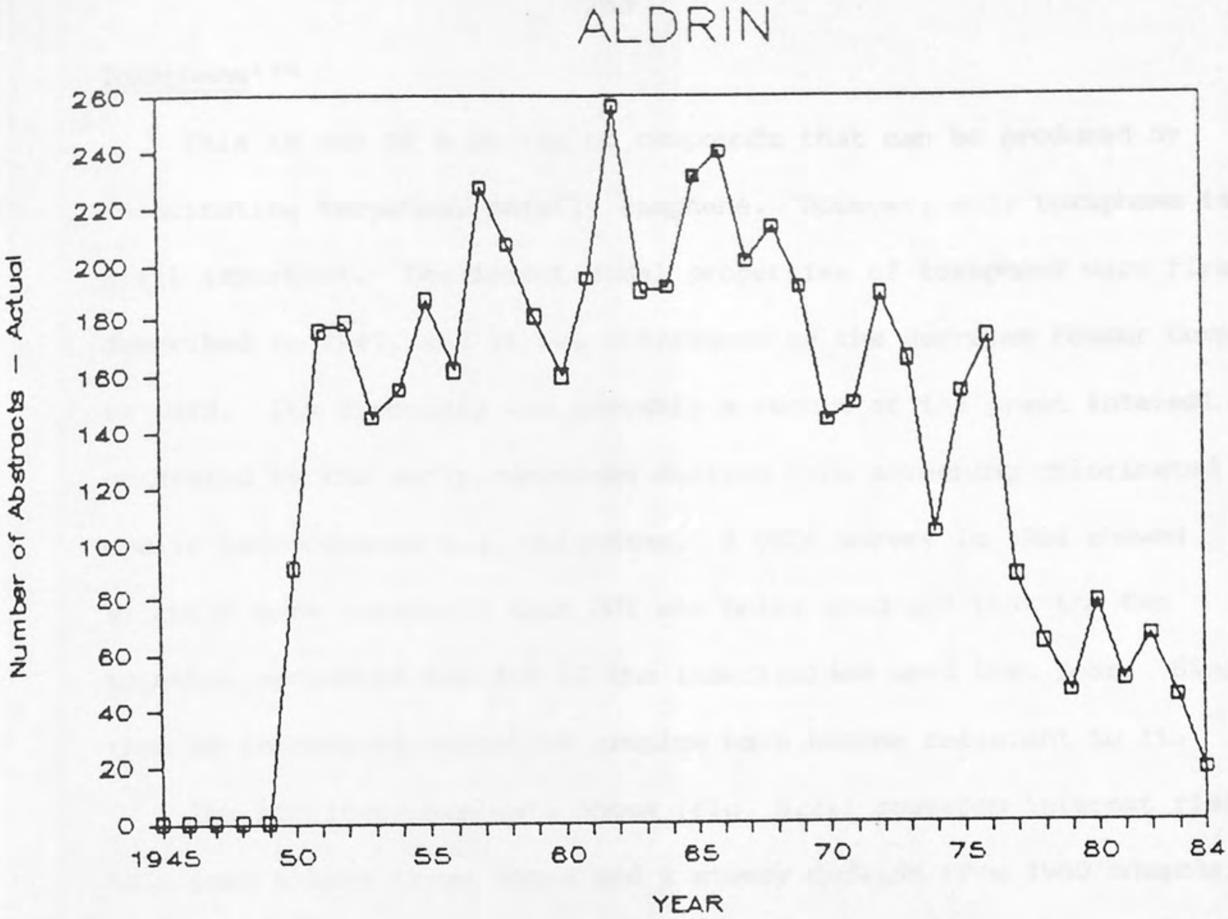

ENDRIN
Number of Abstracts – Cumulative (Thousands)
6
5
4
3
2
1
0
1945
50
55
60
65
70
75
80
84
YEAR

Fig. 5.19


ALDRIN
Number of Abstracts – Actual
260
240
220
200
180
160
140
120
100
80
60
40
20
0
1945
50
55
60
65
70
75
80
84
YEAR

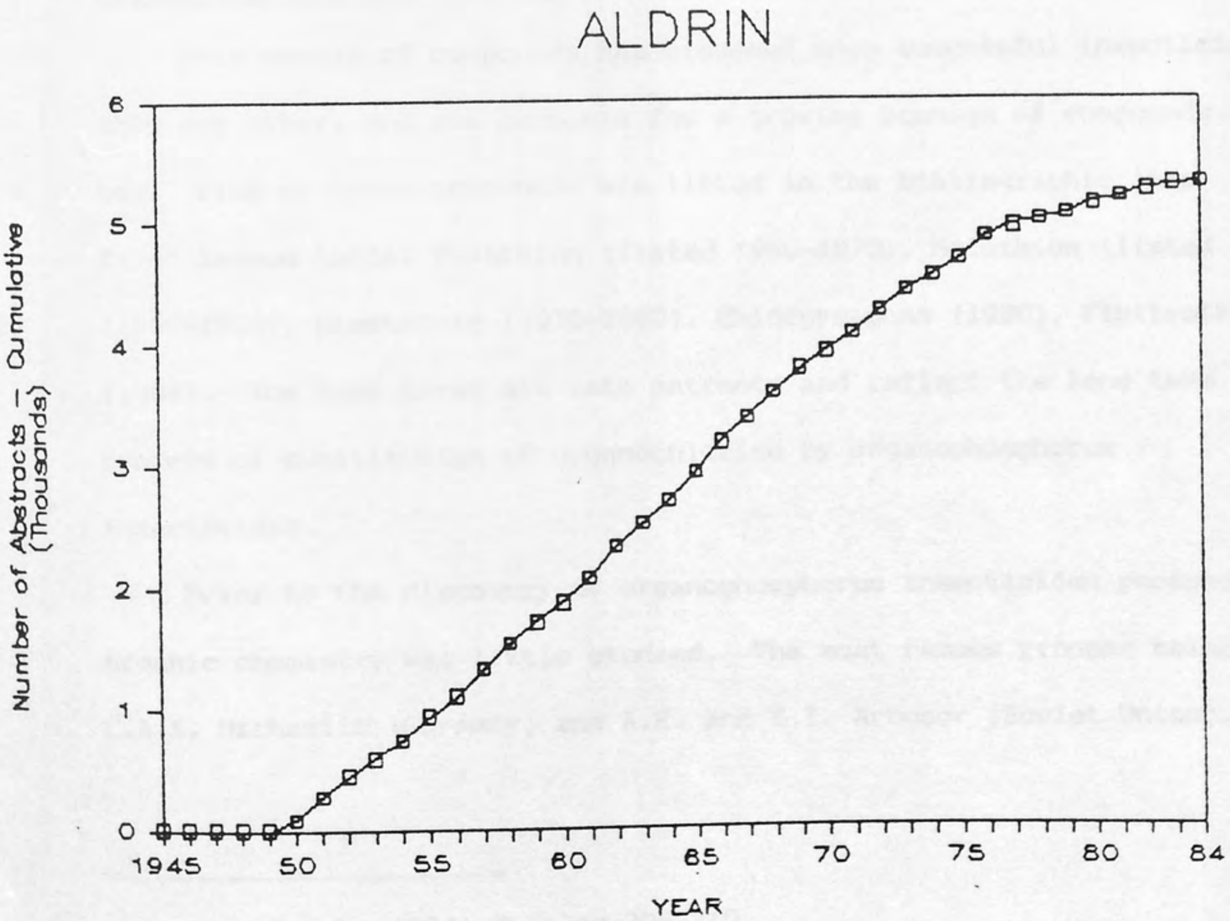

ALDRIN
Number of Abstracts – Cumulative (Thousands)
6
5
4
3
2
1
0
1945
50
55
60
65
70
75
80
84
YEAR

Fig. 5.20

Toxaphene[160]

This is one of a series of compounds that can be produced by chlorinating terpenes, chiefly camphene. However, only toxaphene is still important. The insecticidal properties of toxaphene were first described in 1947, and it was introduced by the Hercules Powder Company in 1948. Its discovery was probably a result of the great interest generated by the early successes derived from screening chlorinated cyclic hydrocarbons e.g. chlordane. A USDA survey in 1964 showed slightly more toxaphene than DDT was being used and that the two together accounted for 46% of the insecticides used that year. Since then an increasing number of species have become resistant to it.

The bibliographic data shows (Fig. 5.21) research interest rising to a peak within three years and a steady decline from 1950 onwards; it was in 5th position in the research interest league in 1950 and 1955.

Organophosphate Insecticides

This series of compounds has produced more successful insecticides than any other, and now accounts for a growing tonnage of compounds in use. Five of these compounds are listed in the bibliographic 'top five' league table: **Parathion** (listed 1950-1970), **Malathion** (listed (1960-1980), **Dimethoate** (1975-1980), **Chlorpyriphos** (1980), **Finitrothion** (1984). The last three are late entrants and reflect the long term process of substitution of organochlorine by organophosphorus insecticides.

Prior to the discovery of organophosphorus insecticides phosphorus organic chemistry was little studied. The most famous pioneer being C.A.A. Michaelis (Germany) and A.E. and E.I. Arbusor (Soviet Union).

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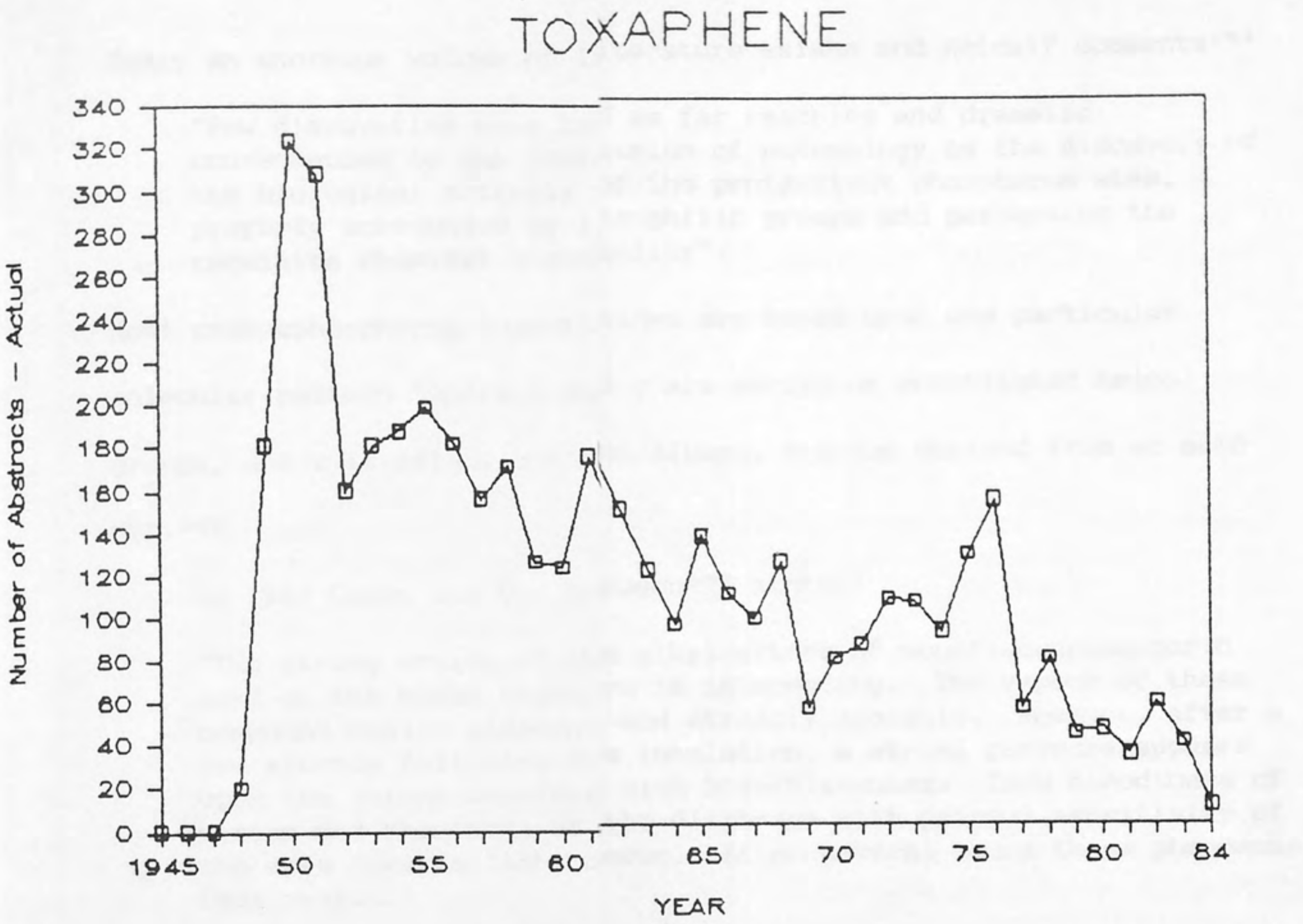
160. Brook (1974) V.1. pp.205-210.


TOXAPHENE
Number of Abstracts — Actual
YEAR
1945
50
55
60
65
70
75
80
84

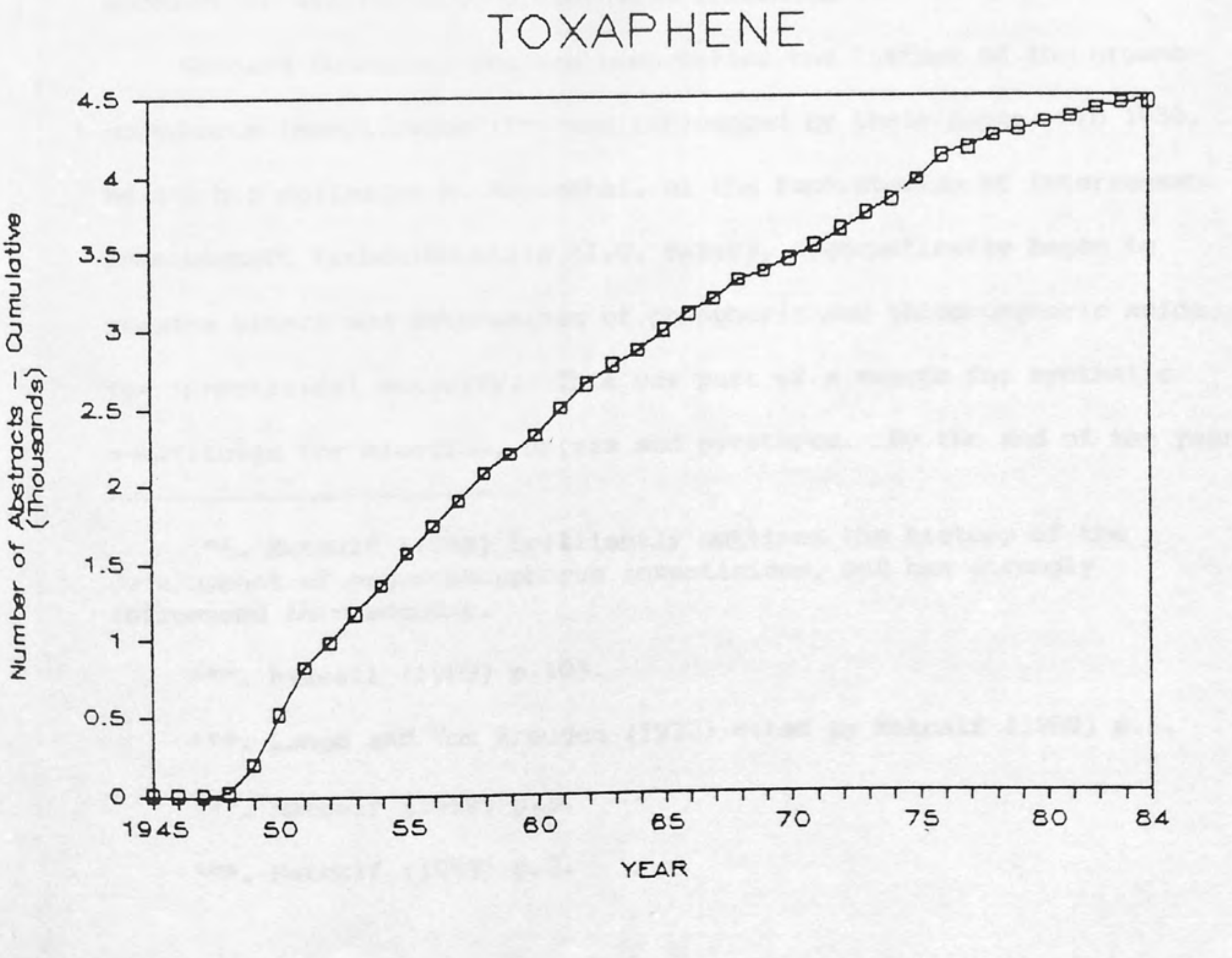

TOXAPHENE
Number of Abstracts — Cumulative (Thousands)
YEAR
1945
50
55
60
65
70
75
80
84

Fig. 5.21

Today an enormous volume of literature exists and Metcalf comments[161]

"Few discoveries have had as far reaching and dramatic consequences to our profession of entomology as the discovery of the biological activity of the pentavalent phosphorus atom, properly surrounded by lipophilic groups and possessing the requisite chemical instability".

Most organophosphorus insecticides are based upon one particular molecular pattern "where x and y are alkoxy or substituted amino groups, and z is often, but not always, a group derived from an acid HZ".[162]

In 1932 Lange and Von Kreugen[163] stated:

"The strong action of the alkyl esters of monofluorophosphoric acid on the human organism is interesting. The vapour of these compound smells pleasant and strongly aromatic. However, after a few minutes following the inhalation, a strong pressure appears upon the larynx combined with breathlessness. Then cloudiness of vision and phenomena of the diaphragm with painful sensitivity of the eyes towards light occur. After several hours these phenomena fade away..."

The compound was diethyl phosphorofluridate - it is "the common ancestor of all the organophosphorus toxicants".[164]

Gerhard Schräder, who has been called the "father of the organophosphorus insecticides"[165] was influenced by their paper. In 1936, he and his colleague H. Kukenthal, at the laboratories of Interressen Gemeinschaft Farbenindustrie (I.G. Faber), systematically began to examine esters and esteramines of phosphoric and thiophosphoric acids for insecticidal activity. This was part of a search for synthetic substitutes for nicotine, derris and pyrethrum. By the end of the year

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[161]. Metcalf (1959) brilliantly outlines the history of the development of organophosphorus insecticides, and has strongly influenced this account.

[162]. Hassall (1969) p.103.

[163]. Lange and Von Kreugen (1932) cited by Metcalf (1959) p.3.

[164]. Metcalf (1959) p.3.

[165]. Metcalf (1959) p.3.

they had hit upon insecticidal compounds. These were patented secretly.[166]

It is frequently stated that this line of research was an offshoot of German poison gas research.[167] However, it has been claimed that, on the contrary, it was the insecticide work which led to the military research. In view of the confusion surrounding this matter it is worth quoting Metcalf at length on this matter.[168]

> "Schräder (1952) states that in 1938 the work on organophosphorus insecticides was declared to be 'secret' by the German government and that no more publications or patents were issued until the end of the war ... (their) researches had shown the high mammalian toxicity of [certain organophosphorus] substances ... Extensive efforts were, therefore, directed towards the development of chemical warfare agents of the organophosphorus type both in Germany and England ... It is however, of interest to note that in Germany these highly effective anti-personnel agents, or 'nerve gases' were developed. Tabun or O-ethyl N,N-dimethylphosphoramido cyanide was patented by Schräder and Kukenthal in February, 1937 as German Patent 767,723 but not issued until September, 1952 and was being manufactured at the rate of 100 tons per month by the end of the war. The more toxic sarin... and soman... were also prepared for use.
>
> In England, of necessity working entirely independently, Saunders and McCombie reinvestigated the dialkyl phosphorfluoridates [which were also discovered and patented by the Germans in 1940 - HR] as an insecticide in 1944 as British Patent 602,446 ... This grim offshoot of the insecticide business has continued to flourish..."

Later Schräder sought an effective insecticide for use against the Colorado beetle, and by August 1945 three had been found, these included **Parathion**. All were broad spectrum insecticides. Allied intelligence teams interrogated Schräder at the end of the war and much of the German insecticidal studies were published in British Intelligence Objectives Sub-Committee (BIOS) Reports 714, 1808, and

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166. Metcalf (1959) lists all the earlier workers and the compounds they produced. Dimefox (1940) resulted from this line of research; and also, a pioneering systematic insecticide - Schradan (1942).

167. I, too, am guilty of this, see Rothman (1972) p.98.

168. Metcalf (1959) p.4.

1905 (1946).

Since that time a very large number of organophosphorus insecticides have been put onto the market, some are general purpose compounds, others are highly specialised selective insecticides, often with special uses as plant and animal systematics[169] etc. Malathion, a wide spectrum general insecticide was introduced by American Cyanamid in 1950. It has a far lower mammalian toxicity (high mammalian toxicity was one of the chief drawbacks of the early organophosphorus insecticides) than parathion and is now probably the most widely used of the organophosphorus compounds.

It is widely accepted that organophosphates kill both mammals and insects by inhibiting cholinesterase. This results in an accumulation of acetylcholine at nerve endings which interferes with their proper functioning.[170] Some organophosphorus insecticides can cause acute poisoning of people and disasters have occurred.[171] However, there appears to have been a trend toward the production of compounds with lower mammalian toxicity in recent years.[172] Organophosphorus compounds are now seen as the source of the main replacements for the organochlorine compounds,

> "...while organochlorine compounds have fallen under an ever increasing cloud of disapproval, the reputation of the organophosphorus insecticides has risen as their variety and their uses have multiplied. In terms of tonnage they are now in some

[169]. G. Schräder pioneered the development of systemic organophosphorus insecticides and describes his early work in Schräder (1952), see also Unterstenhofen (1961).

[170]. O'Brien (1967) p.55 and Corbett (1974) pp.107-163.

[171]. Bull (1982) "A growing problem: pesticides and the third world poor". Oxfam, Oxford.

[172]. This statement is somewhat oversimplified in view of Metcalf's analysis (Metcalf 1972).

countries the most commonly used insecticides".[173]

The bibliographic data shows (see Fig. 5.22) that parathion research peaked very quickly by 1950 and thereafter declined, although it maintained a higher level than almost any other individual compound until the mid 1970s; thereafter it rapidly declined. Malathion showed a more steady growth from the 1950s reaching its peak by the mid 1970s and has remained steady since then, with a slight decline (see. Fig. 5. 23). The rise of four other organophosphorus compounds since 1975, into the top five 'R & D' category would appear to add substance to the statement in the previous paragraph, about their substitution for organochlorine insecticides.

Malathion was regarded as a step forward since it was one of the first organophosphorus insecticides with low mammalian toxicity, the excellent insecticidal properties of earlier compounds being accompanied by extreme toxicity to man and wild life. Selectivity, i.e. toxicity to a good range of insects and low toxicity to warm blooded creatures, became a research goal. It was not an easy task because, apart from the intrinsic problems of synthesis etc., there was always a tension between selectivity and the need to sell the product as widely as possible. Thus, acethion had even greater selectivity than malathion but never became commercially successful because it did not kill a wide spectrum of insects.[174] Dimethoate (o,o-dimethyl S-methylcarbamoyl-methyl phosphorodithioate(X)), is another selective compound, though in a different fashion than malathion since it exhibits a spectrum of toxicity to both insects and vertebrates[175].

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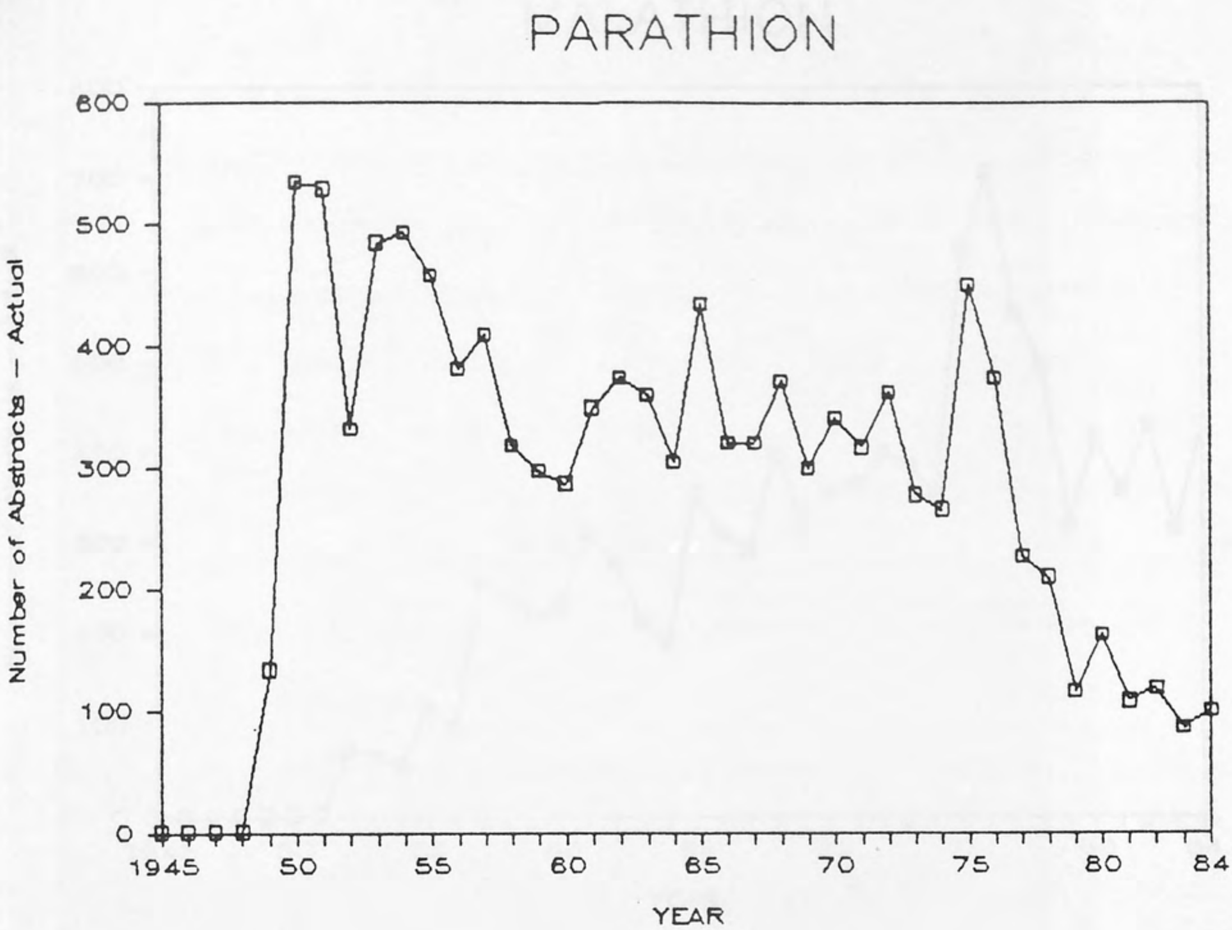
173. Hassall (1969) pp.102-103.

174. Brooks (1976) p.117.

175. O'Brien (1967) p.265.


PARATHION
Number of Abstracts — Actual
YEAR
0
100
200
300
400
500
600
1945
50
55
60
65
70
75
80
84

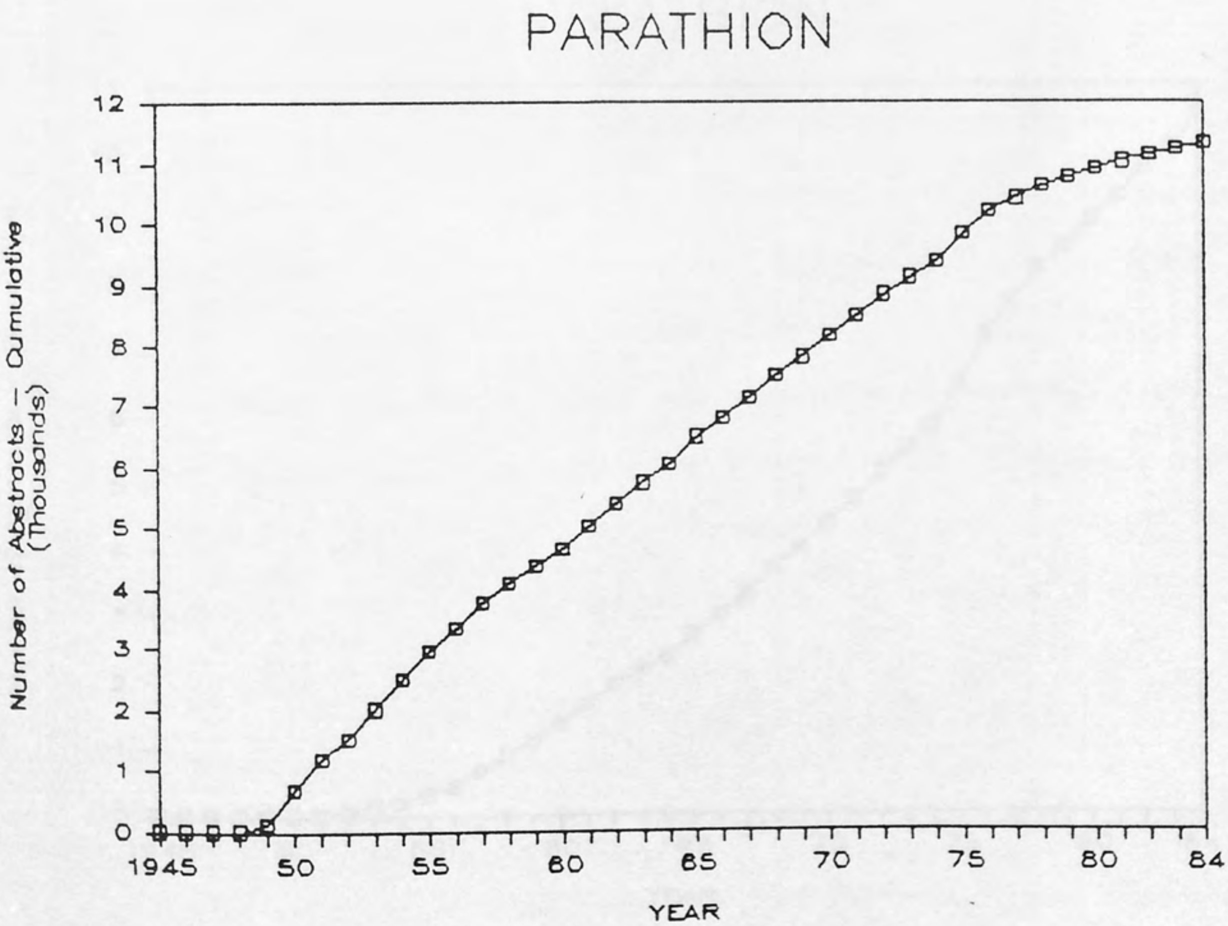
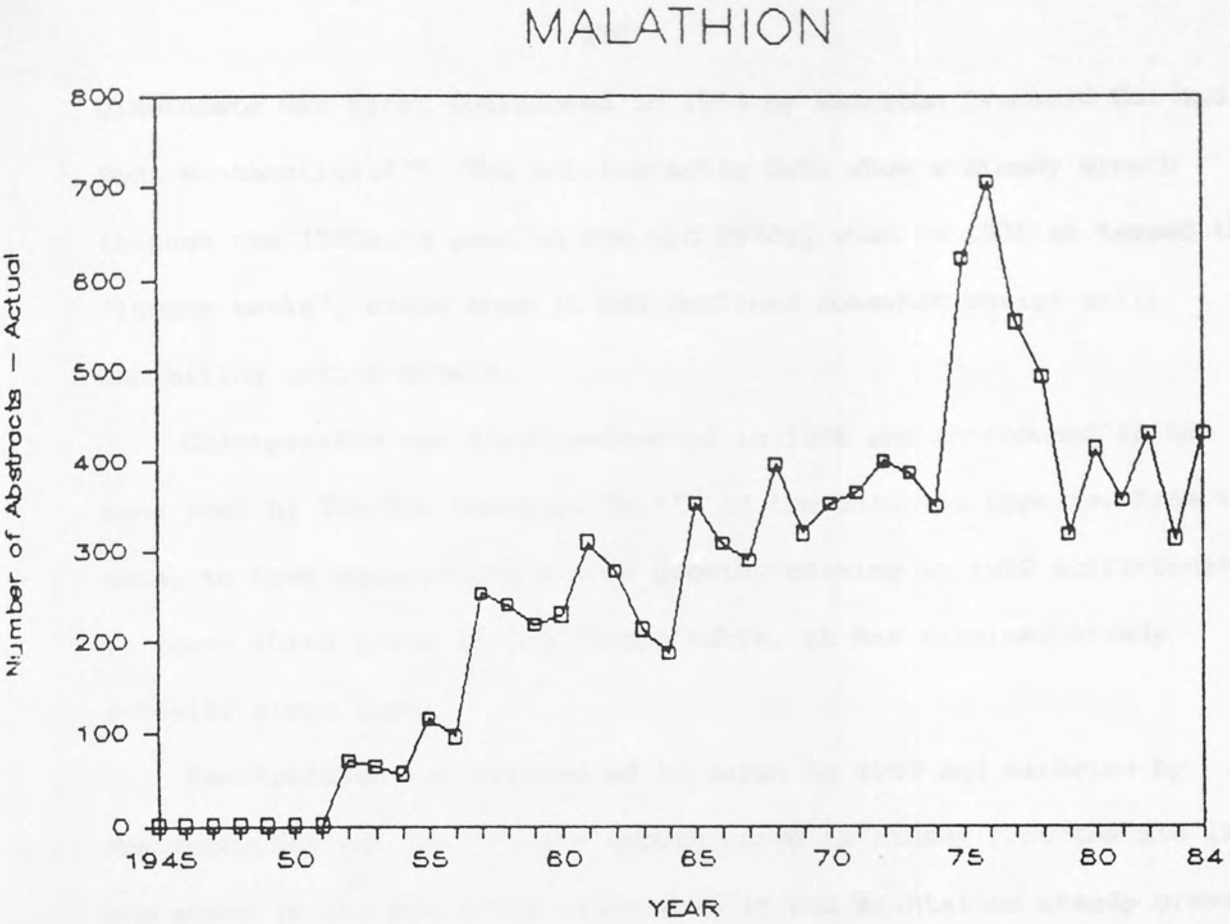

PARATHION
Number of Abstracts — Cumulative (Thousands)
YEAR
0
1
2
3
4
5
6
7
8
9
10
11
12
1945
50
55
60
65
70
75
80
84

Fig. 5.22


MALATHION
Number of Abstracts — Actual
800
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600
500
400
300
200
100
0
1945
50
55
60
65
70
75
80
84
YEAR

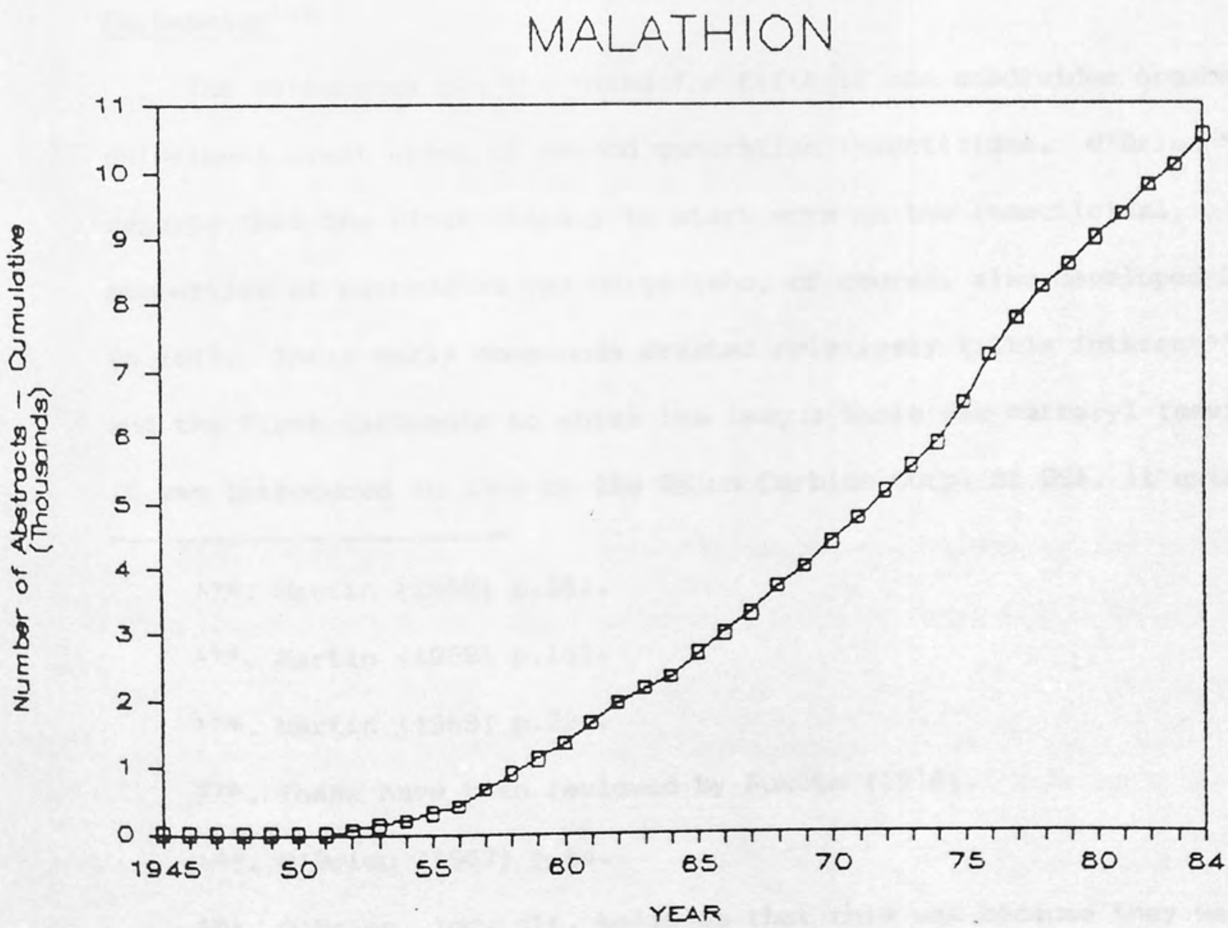
MALATHION
Number of Abstracts — Cumulative (Thousands)
11
10
9
8
7
6
5
4
3
2
1
0
1945
50
55
60
65
70
75
80
84
YEAR

Fig. 5.23

Dimethoate was first introduced in 1956 by American Cyanamid Co. and Soc. Montecatini.[176] The bibliographic data show a steady growth through the 1960s, a peak in the mid 1970s, when in 1975 it topped the 'league table', since then it has declined somewhat whilst still exhibiting active growth.

Chlorpyrifos was first announced in 1965 and introduced in the same year by The Dow Chemical Co.[177] in the USA. It appears, from the data, to have experienced a slow growth, peaking in 1980 sufficiently to reach third place in the league table, it has retained steady activity since then.

Fenitrothion was discovered in Japan in 1960 and marketed by Sumitomo Chemical Co.[178], its growth curve is steady from the mid 1960s and peaks in the mid 1970s since when it has maintained steady growth, entering the league table in fifth place in 1984.

Carbamates[179]

The carbamates are the third (or fifth if one subdivides organochlorines) great group of second generation insecticides. O'Brien[180] reports that the first company to start work on the insecticidal properties of carbamates was Geigy (who, of course, also developed DDT) in 1947. Their early compounds created relatively little interest[181], and the first carbamate to enter the league table was carbaryl (sevin). It was introduced in 1956 by the Union Carbide Corp. of USA, it entered

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176. Martin (1968) p.163.

177. Martin (1968) p.161.

178. Martin (1968) p.224.

179. These have been reviewed by Fukuto (1976).

180. O'Brien (1967) p.84.

181. O'Brien, loc. cit. believes that this was because they were heterocyclic whereas carbaryl was a naphthyl carbamate. p.85.

the league table in 1965 and remained until 1980. Examination of its growth curve (Fig. 5.24). shows that it still has not reached maturity; it is a broad spectrum insecticide registered in USA for use on over 100 crops. Carbamates are cholinergic agents, inhibiting acetylcholine. The world's greatest chemical disaster, at Bophal, India, resulted from a malfunction in a plant manufacturing carbaryl.

Another carbamate, carbofuran, joined the league table in 1980. It was introduced in the mid 1960s by Niagra Chemical Co. of Canada. Its early growth was slow until the mid 1970s, when its growth spurted and a high research interest over the last decade is indicated by the data. This compound is a broad spectrum insecticide, and since it is highly toxic to mammals and birds its prominence is hard to understand,[182] perhaps it might have something to do with its efficiency as a soil insecticide.

Synthetic Pyrethroids

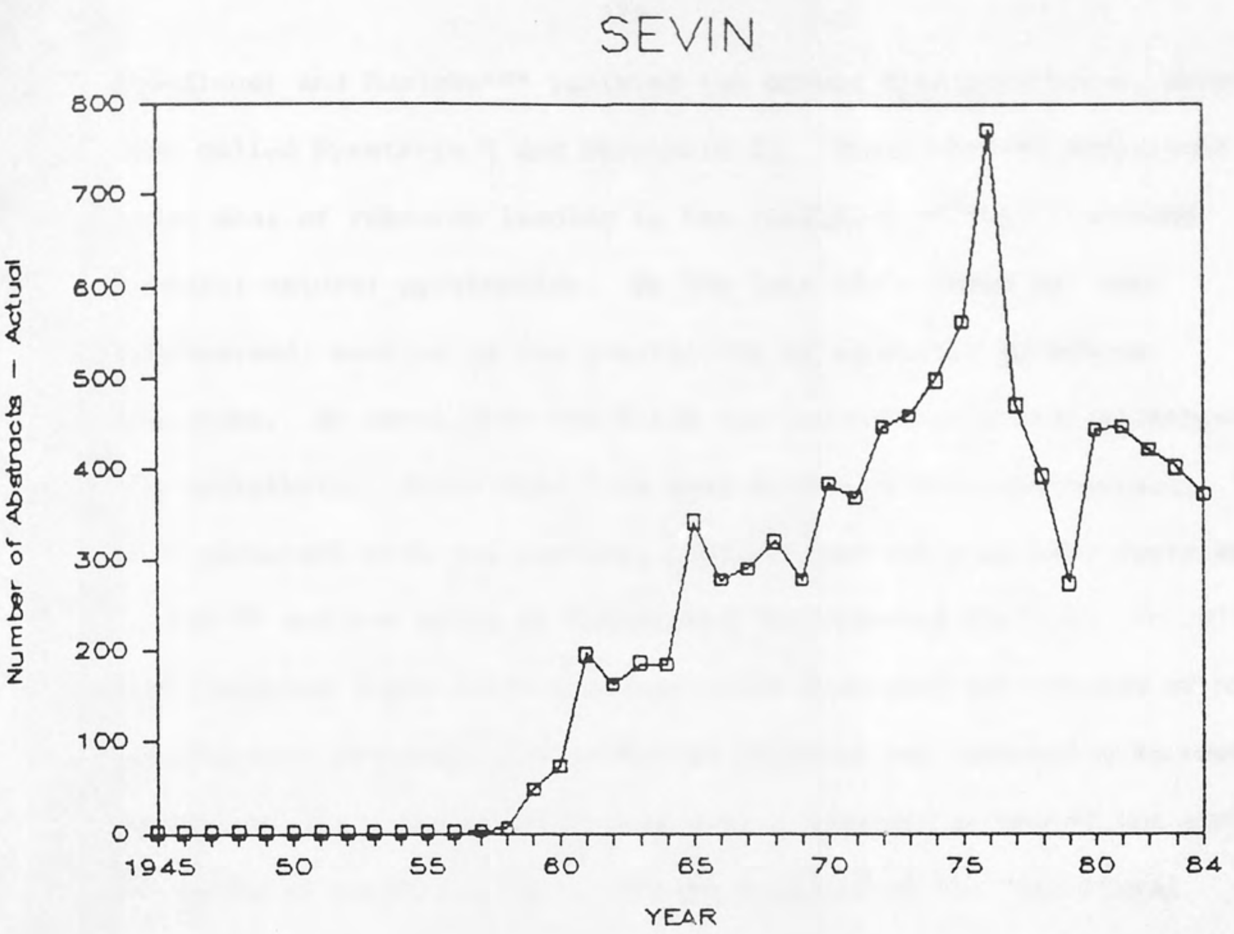
I have already discussed pyrethrum itself, along with other botanicals, however, I consider that synthetic pyrethroids deserve a separate treatment. The latter, according to the bibliometric data, look like being the insecticides of the next decade; in 1984 they dominated the league table, occupying four places out of five.

To understand the story of these compounds it is necessary to return first to pyrethrum. Chemists have studied pyrethrum since the mid 19th century. By 1909 Fujitan[183] isolated "pyretyrone" an active constituent, which he showed to be a mixture of esters. In 1924

---

[182]. Fukuto, (1976) has said of carbamate research that "...greater emphasis has been placed on the design of materials less toxic to mammals". p.313. He describes research on safer carbofuran derivatives.

[183]. Martin (1936) p.189.


SEVIN
Number of Abstracts - Actual
800
700
600
500
400
300
200
100
0
1945
50
55
60
65
70
75
80
84
YEAR

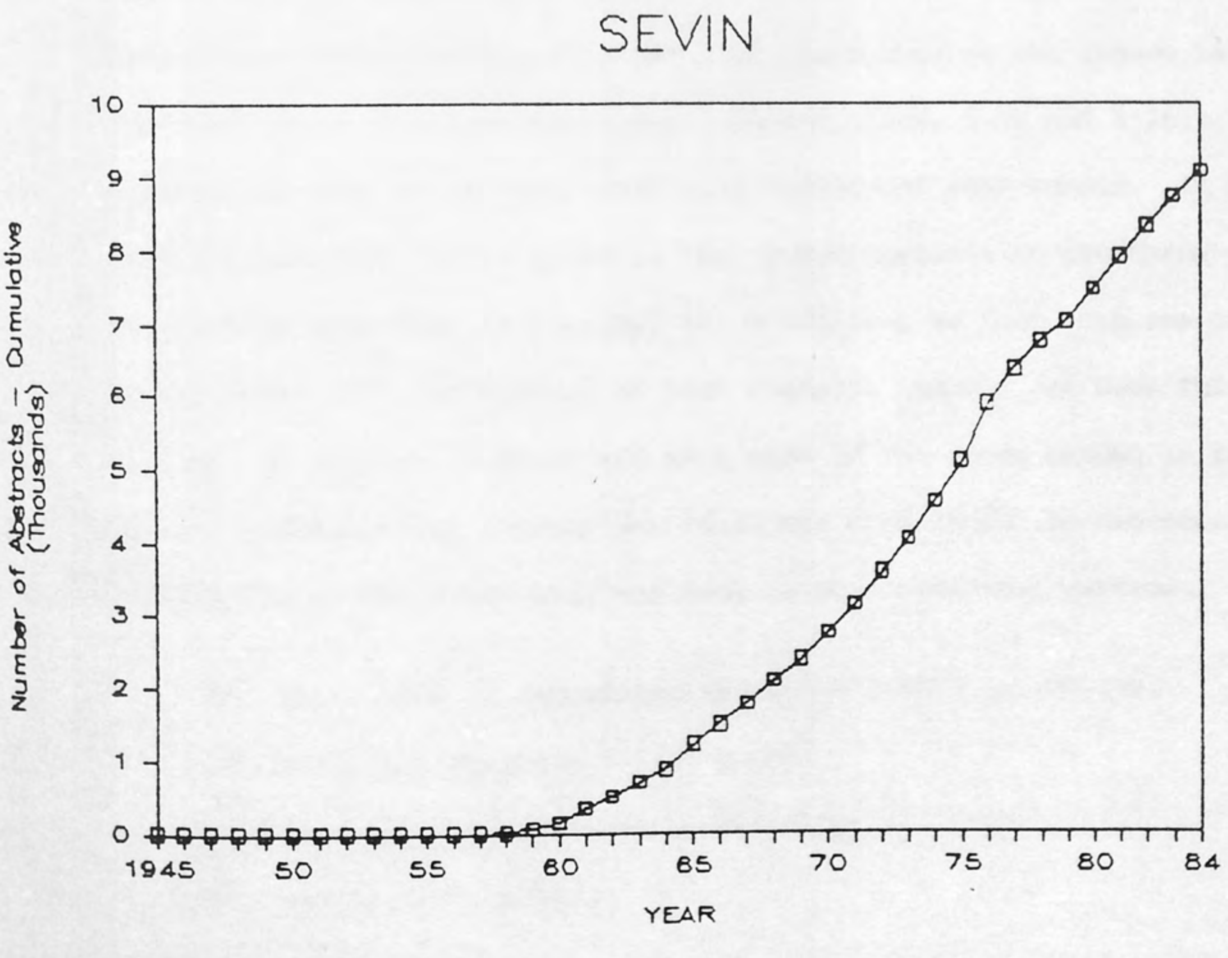

SEVIN
Number of Abstracts - Cumulative (Thousands)
10
9
8
7
6
5
4
3
2
1
0
1945
50
55
60
65
70
75
80
84
YEAR

Fig. 5.24

Standinger and Ruzicka[184] isolated two esters from pyrethrone, which they called Pyrethrin I and Pyrethrin II. Their work[185] encouraged a great deal of research leading to the isolation of four (ignoring isomers) natural pyrethroids. By the late 1940s these had been synthesised, opening up the possibility of synthetic pyrethrum analogues. By about 1950 the first two had been produced; allethrin and cyclethrin. Since that time many more have been synthesised. The most important work is, perhaps, that carried out over many years by Elliot[186] and his group at Rothamsted Experimental Station. In 1973 they reported their first successes with synthetic pyrethroids of high insecticidal activity, low mammalian toxicity and possessing increased photostability (photolability was always regarded as one of the great drawbacks of pyrethrum use). Having established the "structural requirements for photostabile pyrethroids" the Rothamsted was able to embark on a systematic synthesis of a series of new compounds; several have proved highly successful. Four of these entered the league table in 1984. This is a remarkably rapid growth (Figs. 5.25 and 5.26), however, we much not forget their long history of antecedents. It has been claimed that "It is probable that investigations on pyrethrum and pyrethroids have been in progress for a longer time than with any other insecticide".[187] The history of that research has not yet been fully written, it differs in some ways from that of the other groups in that it was, perhaps, less crudely empirical and more linked to science. Much of the breakthrough work was done in non-commercial centres.

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[184]. Their work is summarised in Martin (1936) pp.189-191.

[185].Martin and Woodcock (1983) p.195.

[186]. This has been reviewed by Elliot <u>et al.</u> (1978).

[187]. Boyce (1976) p.482.

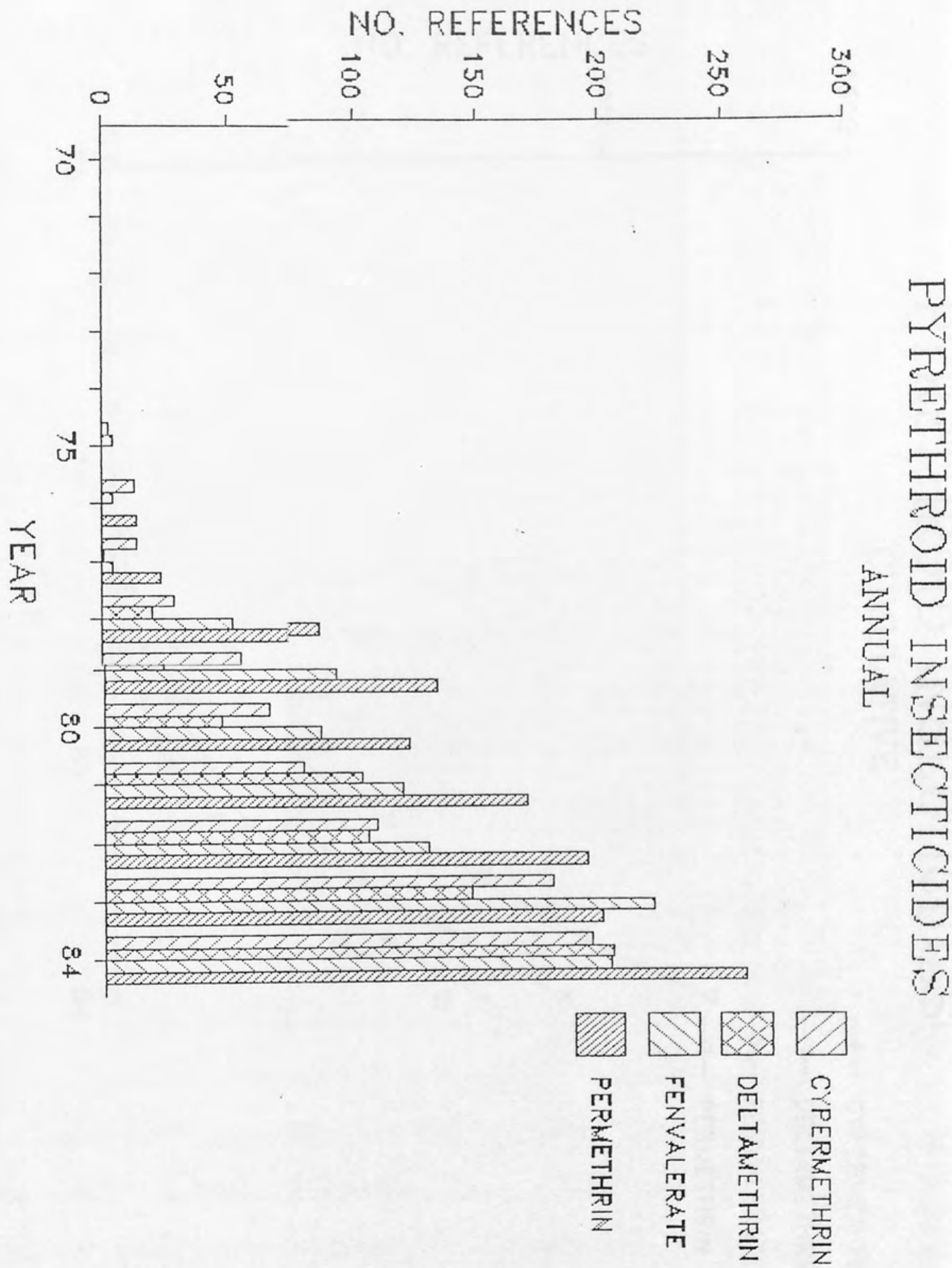
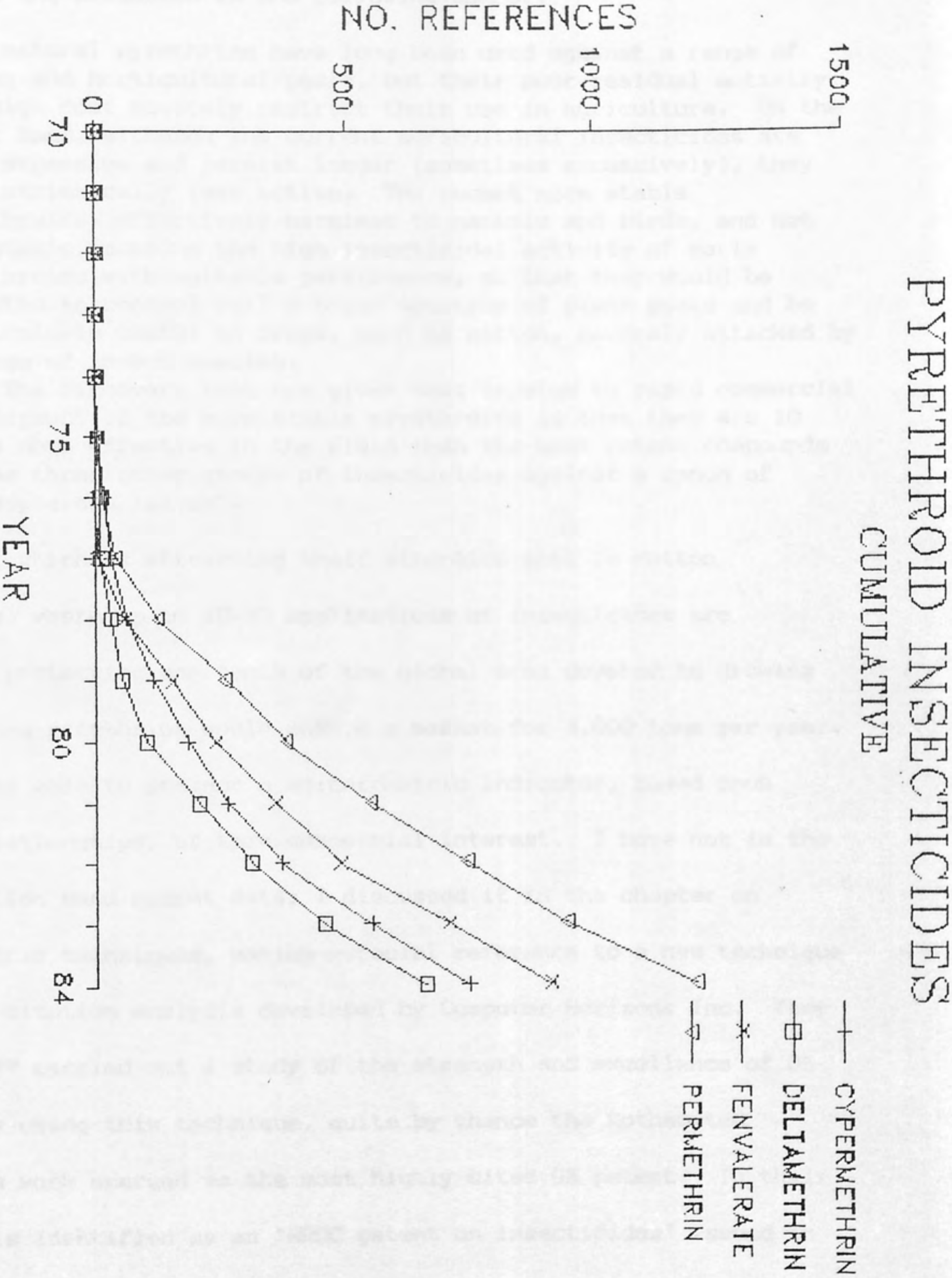

PYRETHROID INSECTICIDES
ANNUAL
NO. REFERENCES
0
50
100
150
200
250
300
70
75
80
84
YEAR
CYPERMETHRIN
DELTAMETHRIN
FENVALERATE
PERMETHRIN

Fig. 5.25



PYRETHROID INSECTICIDES
CUMULATIVE
NO. REFERENCES
0
500
1000
1500
YEAR
70
75
80
84
CYPERMETHRIN
DELTAMETHRIN
FENVALERATE
PERMETHRIN

Fig. 5.26

At long last the synthetic pyrethrins seem to have arrived and their commercial potential is recognised. Elliot and his co-authors[188] summarised the situation in the following manner.

> "The natural pyrethrins have long been used against a range of garden and horticultural pests, but their poor residual activity and high cost severely restrict their use in agriculture. On the other hand, although the current agricultural insecticides are less expensive and persist longer (sometimes excessively), they are intrinsically less active. The recent more stable pyrethroids, effectively harmless to mammals and birds, and not phytotoxic, combine the high insecticidal activity of early pyrethroids with suitable persistence, so that they would be expected to control well a broad spectrum of plant pests and be particularly useful on crops, such as cotton, severely attacked by a range of insect species.
>
> The discovery that has given most impetus to rapid commercial development of the more stable pyrethroids is that they are 10 times more effective in the field than the most potent compounds of the three other groups of insecticides against a range of lepidopterous larvae".

The market which is attracting their attention most is cotton protection, where up to 10-30 applications of insecticides are frequent; protecting one tenth of the global area devoted to growing cotton using pyrethrins would ensure a market for 3,000 tons per year.

One is able to present a scientometric indicator, based upon patent relationships, of this commercial interest. I have not in the investigation used patent data; I discussed it in the chapter on scientometric techniques, making especial reference to a new technique of patent citation analysis developed by Computer Horizons Inc. They recently[189] carried out a study of the strength and excellence of UK technology using this technique, quite by chance the Rothamsted pyrethrins work emerged as the most highly cited UK patent. In their study it is identified as an "NRDC patent on insecticides" issued in 1977, cited in 1984 98 times. Their findings are summarised in Fig.

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188. Elliot et al. (1978) p.460.

189. Narin and Olivasto (1987) pp.41-42.

5.27; which

> "is a diagram showing each of the 98 patents citing the NRDC patent. On the diagram, patents owned by the company whose patents cite the NRDC most frequently are in the centre. The number of the citing patents appear above the company abbreviation. Thus FMC Corporation own 34 patents citing the NRDC patents. Other heavily citing companies are Shell and Imperial Chemical Industries and Ciba Geigy. This diagram, then, illustrates the impact that a single NRDC patent had on subsequent technology".

The application of this form of analysis could be a useful adjunct to historical studies of technology, no doubt the data which CHI garnered could be obtained for a further detailed study in the light of a historical study of the pyrethrin work at Rothamsted and its subsequent diffusion.

My own data are summarised in Figs. 5.25 and 5.26; they illustrate the rapid 'youth' phase of growth for four synthetic pyrethroids: permethrin, developed in 1973 at Rothamsted; deltamethrin; cypermethrin, developed in 1975 at Rothamsted and now being developed by ICI and Shell; Fenvalerate, is associated with Sumitomo Chemical Co. and with Shell.

CONCLUSIONS

First I need to reiterate the conclusions of our paper (Rothman and Lester) "The Use of Bibliometric Indicators in the Study of Insecticide Research".

> "Our qualitative approach produces a picture of the development of insecticides that fits the accepted view derived by qualitative historiography, it is very sensitive to trends in pesticide research, and might be a useful adjunct to technology forecasting as well..."

The case study material I have here presented reinforces, in my opinion, the first two conclusions; I have not here been able to further explore the third point, on technology forecasting.

The most powerful feature of my results is the clarity with which they depict the broad evolutionary trends in the development of insecticides with respect to choice of compounds. I have been able to pick out the periods of gradual incremental change and those where change was rapid, revolutionary even. These were described at the beginning of the chapter.

At a less aggregated level I have been able to plot and describe the research life cycles of numerous compounds. Research does not occur at random over time, there appears to be an awesome "lawfulness". Interest in compounds grows, matures and declines, and once interest dies rebirth seems impossible. On those rare occasions where resurrection might be said to have occurred, as for example with pyrethrum, the second coming is quite different. All that seems to differ in the life cycles is the rate at which the various stages are traversed, and the heights to which interest rose. I have been able to plot this with almost mathematical exactitude and in so doing provide a wealth of data and problems for orthodox historiography to tackle.

There are limitations to my approach which need to be discussed if its true value to historical studies is to be realised. It is my intention to discuss these in a critical and constructive fashion, not as an excuse for studies not done but to point the way to future paths that might lead to a more profound and deeper understanding of a most important area of the history of technology.

My study has concentrated on a limited number of compounds, are they representative? I picked those substances, which at some quinquennial since 1914 were the most frequently cited compounds by the Rev. Appl. Ent. (Ser. A). With the "first generation" compounds this really raises no problems because during that period there were so few. Within the "second generation" there has been over the last 30 years a veritable flood of compounds, especially within the organophosphorus group. I feel that a reading of the pest control literature would support, in the main, the actual choice of compounds that emerged through the "league table struggle". However in addition to those compounds I collected time series data for almost a hundred insecticides which at some point since 1945 had been frequently cited. Unfortunately, to have included them all in this case study would have overburdened it, making it unnecessarily complex, whilst adding little to the attempt to illustrate the value of the scientometric approach. Nevertheless, their analysis could open up some pertinent lines of historical investigation. One might, for example, use the data base to make a systematic study of the types of growth curves exhibited; do "successful" compounds have a different shape, how early in life cycle does the future pattern become established? The data could also be analysed with respect to contributions by countries, institutions and companies.

I have been asked how my research life cycles compare with the product life cycles of the compounds. This is an important question, unfortunately, it was not one which I was able to investigate. Market and production data for individual compounds is exceedingly hard to obtain, it would have a separate and mighty research task itself. I am not aware of any published reliable time series data, global or for single countries. Many countries produce aggregate export and production data on insecticides. In Britain one finds, for example, the statistics produced by the Business Statistics Office lumped every compound together under headings like "Insecticides and fungicides", these are quite useless for my purposes. Without production and market data I am not able, of course, to assess whether research activity, as I have measured it, of a compound is correlated positively with its market importance. I suspect as far as most of the compounds I have discussed that it is, but I lack direct evidence.

I have some figures which give substance to this suspicion. Thus my research trends showed that by the mid 1970s organochlorine compounds had been overtaken by organophosphorus and carbamate insecticides. Green et al. (1977) give[190] the following table of world insecticide sales for 1975:

Organophosphates	-	\$1,100 million
Carbamates	-	\$ 470 million
Organochlorine	-	\$ 320 million
Arsenicals	-	\$ 20 million

Of more historical interest one can cite the data in Table 5.2. This shows US insecticide production (excluding sulphur and petroleum oils) for the years 1945 and 1955. In 1945 the arsenicals had a greater production than DDT, BHC or parathion, and in the research publication league table for 1945 lead arsenate ranked 2nd, after petroleum oils (which are not given in the table). This fits in well with lead arsenate's top ranking figure for 1945 production levels. One can see from the table that by 1955 lead arsenate's production had fallen to a fifth of the 1945 figure, and we know that by then it had disappeared from the top 5 in the research league. However, one is able to see that by 1955 the top ranking organic insecticides in production; DDT, BHC and parathion were also ranked 1st, 2nd and 3rd respectively in the research league table. Table 5.3 gives US production and usage figures for 1971 which again give support to the idea of a linkage between them and my research interest data. Of the top five insecticides for US production only toxaphene is not a member of the top 5 in the research league table for 1970: DDT is ranked 1st

190. Green et al. (1977) pp.14-19.

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in the research league and 2ns in US production; parathion 5th and 3=; carbaryl 3= in both; and malathion 4th and 5th.

It seems reasonable to suppose that a growing curve of research activity might be associated in some manner with the market diffusion of a compound. The converse, a declining research activity might not be true, arsenates are still widely used despite the lack of research interest. A possible way of resolving this question, without taking on the enormity of creating a set of global statistics, would be to gain the cooperation of a manufacturer and investigate the relationship with respect to compounds they made.

The research life cycle curves that I have created should be regarded perhaps as envelope curves, within which many there exist other curves. My curves say nothing directly of these hidden trends; such as trends in insecticidal effectiveness (which has several parameters), selectivity, toxicity to workers, environmental persistence and so forth. I am aware of this and did collect a great deal of data relating to such matters, and hope when my analysis is complete to publish it in due course.

My analysis assumed that all research references were equal, which is a gross oversimplification. I am able to say little about the nature of the research I plotted. We know, for example, that DDT continued to be highly cited for many years after it had been restricted or banned by most First World countries. Why was this, was DDT being used as a "marker " standard for gauging the effectiveness of new compounds? It is also of great importance to find out how research changes over the life cycle of a compound, would one find that certain topics are characteristically associated with particular life cycle phases?

I believe that by refining and expanding my techniques that one could investigate some of these questions. The Rev. Appl. Ent. index does contain information which might allow research to be coded with respect to some appropriate classification (such as those which I have already mentioned). To do this for all compounds would be enormously laborious; a more attractive approach initially would be to carry out such a study on a selected group of significant compounds, say DDT, Parathion, Malathion, and build a database of their research patterns and trends. From such a database one would be able to develop a quantitative research life history of each insecticide, one which would reflect not only their agricultural use by also the research response to health and environmental problems associated with their use.

I have succeeded in indicating in qualitative manner basic insecticide research patterns and trends during the last 70 years. I am aware that this does not in itself constitute the history of insecticides. There will be many possible histories, and I have been able to illustrate important facets of one such history, the discovery and adoption of new insecticidal compounds.

CHAPTER 6

CONCLUSIONS

Arnold Thackray[1] has said that:

> "To apply quantitative methods in the history of science, three things are required. First there must be a methodological conviction - a belief in the worth of those tools and procedures implied in the phrase quantitative methods. Second, there must be a desire to discern the patterns that occur in time and a wish to comprehend the changes, continuities, regularities and singularities implied by the word history. Third, and most obvious - but not trivial- the subject of the methodological conviction and the orientation must be science".

This thesis has sought to meet these requirements in so far as its goals allowed. These were to explore the value of quantitative scientometric methods in analysing historical research trends in economic entomology.

I have reviewed in Chapter One the historical development of quantitative studies of science and outlined the range of techniques, particularly bibliometric, which are available, and also their advantages and shortcomings. In Chapter Two I discussed the nature of economic entomology, its social and economic importance as an applied science. In particular I delineated a number of characteristics it possesses which make it a worthy subject for the study. The subjective nature of its object of study, the "pest", the large number of techniques for controlling pests, and the science's schizophrenic division into chemical and biological approaches to control. I also analysed and devised various classifications of pest control techniques, some of which were drawn upon in the quantification studies of research trends in control techniques.

Three major quantification studies have been described: the analysis of databases of key papers on chemical control and biological

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[1]. Thackray (1977) p.12.

control (Chapter Three); a content analysis of a core journal, the Journal of Economic Entomology (Chapter Four); research trends in insecticides based on analysing references in an abstract journal (Chapter Five).

In addition, seven of my published papers are presented in Appendix A, as relevant to matters discussed in the thesis:

* Publication Trends in Biological Control
* The Changing Pattern of Research in Economic Entomology
* The Use of Citation Patterns to Identify Research Trends
* The Use of Bibliometric Indicators in the Study of Insecticide Research
* Biotechnology Policy in the 1980s and Beyond
* An Experiment in Science Mapping for Research Planning
* The Public Relations Activities of the Association of British Manufacturers of Agricultural Chemicals.

In this chapter I will summarise the methodological and historical significance of the quantitative studies on research trends. Further, I will discuss them in the light of socio-cognitive considerations regarding the scientific and technological paradigms associated with economic entomology and also in the context of the general structure of agribusiness. Throughout the chapter I shall discuss the findings with respect to future research.

I have shown that there are several ways of classifying pest control methods and discussed the criteria for those used as the basis for my quantitative studies of research trends; for example my classification of insecticides was based on chemical types to enable me to discern historical substitution of one type by another, and the classification of control techniques was devised to identify trends with reference to the changing balance between chemical and biological approaches.

I shall now summarise the major findings of the three quantitative case studies.

Scientometric Analysis of Papers on Chemical Control and Biological Control.

Sets of papers were classified according to whether they were on chemical or biological control. The reasons for and implications of their different sampling frames were explained. The chemical control papers were grouped according to pesticidal type: insecticides, herbicides, fungicides and rodenticides. Within these types they were further sub-divided into "historical" papers dealing with innovation of novel active compounds, and "biological" dealing with toxicological aspects of the compounds. The biological control papers were classified into six groups: entomophaga basic, entomophaga applied, microbial basic, microbial applied, autocidal and integrated control.

I tested hypotheses concerning differences in: national and institutional activities between these different fields, financing of research, location of research and so forth, using publication productivity data. I also hypothesised that there would be differences between fields with respect to cognitive structure as indicated by journal citation linkages.

National demographic findings

The USA dominated the production of chemical control papers, followed by: UK, Germany and Switzerland. Japan was missing because the database was too old to pick up the Japanese chemical industry's growth of the 1970s. Differences with respect to national strengths according to pesticide type were found, for example, the UK showed greatest strength in herbicides and Germany in insecticides. The national demographics for biological control differed in certain respects from those found for the chemical control fields. The USA still dominated but was followed by the USSR and Canada. Japan, Germany, France and the UK were also well represented. Switzerland, strong in chemical control, was notably weak in biological control. Both for chemical and biological control national productivity was highly skewed, a few countries producing most of the papers.

The data also showed differing national productivities between the various biological control fields. The USA and USSR were strong across the board, there were also discernible differences between countries with respect to basic and applied research. The global distribution of research productivity was wider for basic than applied research; and for the USSR comparatively ranking was higher in applied than basic, for the UK it was the reverse. The USSR was noticeably strong in the microbial control fields, and Germany and the Netherlands in integrated control.

Certain countries (USA, Germany, UK, France) were well represented in both chemical and biological control. But the USSR was missing from chemical control and was strong in biological control fields, whilst the reverse situation applied to Switzerland.

Industrial Location

Wherever possible institutional addresses were classified by type: industry, university, government, foundations. This was not a perfect classification but it proved sufficient to examine a number of hypotheses about institutional divisions of labour with respect to the research fields. The data show that industry dominated the chemical control "history" (innovation) productivity, followed by government, and last were university locations. With chemical control "biology" the institutional distribution changed; universities were ranked first followed by government, and industry last. I discussed several explanations for this difference, the most likely being that industry seeks recognition for the active compound since there is obvious commercial benefit. This is not the case for toxicological data, which they prefer to present in confidence to regulatory agencies. Clearly there are negative implications here for scientific quality control,[2] and deliberate suppression of research findings[3] has been documented. I sought evidence for collaborative research indicated by papers emanating from more than one institutional type, but the data was too sparse to come to any conclusion. Very little research occurred in Foundations.

Institutional type location was studied with respect to country and I found different distributions in different countries. In the USA, for example, there was an even split between industry, government and university research locations. However, in Germany and Switzerland location were mostly industrial. I cannot explain these differences from the data I have, but would suggest that investigations into differences in national research cultures might prove fruitful.

Analysis of individual locations, research centres, confirmed the chemical control research strength of such companies as: American Cyanamid, Bayer, Ciba-Geigy, ICI and Shell. The analysis was able to show that these companies were not necessarily equally active across the pesticide spectrum; for example ICI was stronger in herbicides than insecticides, and Bayer was strongest in insecticides. These findings fitted information from other sources. The historical, commercial and other reasons for such focussing by companies would be a valuable topic for further research. It proved more difficult to identify

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[2]. See Ravetz (1973).

[3]. Van den Bosch (1980) describes several such incidents concerning pesticides research.

"outstandingly prominent" individual government and university locations. Those which did stand out were usually American, although London University was prominent. Generally, prominent university centres produced the Biology chemical control papers.

Biological control

One hypothesis that this analysis confirmed was that industry was not much interested in biological control. Industrial activity was virtually absent from the biological control database. Output was dominated by government and university centres, with some evidence of a slight bias by the latter to basic research and by the former to applied. Autocidal control was dominated by government locations. It must be noted that research data for biological control was less complete than that in the chemical control database. It was possible, however, for the North American data to identify some outstandingly productive centres: University of California, USDA, Sault Ste Marie, and Belleville - their importance is verifiable from other sources.

Financial support

Research location is not the only indicator of institutional type activity. It seemed likely, for example, that industry might often contract out research to public sector research centres, a possible indicator of this could be acknowledgements for financial support. 8% of university located research and 10% of government located research acknowledged industrial support. This seems a low figure, given the widely held belief that public and private sector research in chemical control is closely linked. However, when one breaks down the data into national groups high figures occur in certain countries: in Germany and Switzerland it is nearly 90%; in the USA 39% of university research acknowledged industrial support, and 23% government support. In the UK the figures were 29% and 26% respectively. If one looks at the balance between "history" and "biological" chemical control university located papers, history was more frequently associated with industrial support and biology more frequently with government agency support. I was surprised by this finding, having expected to find industry contracting out biological testing more frequently than innovative research. Clearly this is something which requires further investigation.

With respect to biological control, the data were rather incomplete. Government support was far more frequent than industrial. Judging by the acknowledgement data, what little industrial support there was tended to be concentrated in the microbial applied and integrated fields.

Cognitive Analysis Based on Journal Structure of Fields

The analysis utilised both source and cited journal data. The major hypothesis was that chemical and biological control would be related to different scientific disciplines, and that there would also be discernible differences between the various research fields, e.g. between entomophagous control and microbial control, and between applied and basic research fields. On the whole the data supported this. Thus one finds insecticide history associated with clusters of chemistry, agriculture, and pest control journals. Their interrelationships show a movement from chemical to agricultural plant science, with the Journal of Economic Entomology (J.E.E.) as a key link, whereas in insecticide biology one finds clusters of biomedical and toxicology journals linking up with plant protection. The journal analysis was able to express the underlying disciplinary structures of six chemical control fields (rodenticides proved too small to study). A more comprehensive journal citation base within a consistent time frame would have led to less noisy maps.

Biological control fields. Biological control proved to be far harder to cluster, having a journal structure which proved more fragmented, less coherent. The level of coherence varies between fields, the applied fields seemed to be less coherent than the basic (except for autocidal, which had a very small database). Significantly, for the content analysis of a core journal, J.E.E. proved to be ubiquitous. It was also shown that certain journals acted as disciplinary or speciality markers, for example the Journal of Invertebrate Pathology in the microbial control fields. The possibility of using their presence as indicators of field maturity was discussed, particularly in the light of their absence from the autocidal and integrated control fields. Great differences were observed in the complexity of journal structures of the chemical control and biological control databases, the latter being more complex, in the sense of being less coherent and containing more journals. The reasons for this were speculated upon and given the importance that has been attached to the conflicting paradigmatic structures associated with economic entomology, there is a need for further studies. These might establish whether the causes for differences in coherence are due to socio-economic or cognitive factors, or combinations of these, since coherence could be a result of a strong paradigm or strategic focussing for commercial or political reasons.

A few journals are strongly represented in both chemical and biological control databases. One can mention J.E.E. and Hilgardia, and significantly they link with chemistry journals in the former and ecology journals in the latter database. I believe that this is perhaps an indicator of the conflicting chemical and biological approaches which have riven pest control science. However, a more thorough investigation is called for using databases specifically created to examine this matter. Other valuable observations were made.

For instance, microbial control showed linkages between pest control and microbiology, and in the journal map of microbial applied J.E.E. and J. Insect Pathology occur together. It also became clear that the integrated control structure brings together chemistry, pest control and ecology journals, and that autocidal control links pest control with genetics and radiation journals.

The biological control maps were noisier than the chemical control ones, and possible reasons for this were given, for example, different sampling frames, and different cognitive problems - biology is more observational and geographically variant than chemistry - and socio-economic factors. Nevertheless a strong signal emerged from both databases, which contained a similar core of pest control journals linked more strongly to chemistry, patents, and agriculture in the chemical control database, and to ecology, microbiology and genetics in the biological control database.

Further Journal Maps. The pest control journal maps were recomputed using data from the Journal Citations Report and analysed by multi-dimensional scaling (MDS). Two maps were produced showing journal structures: (i) showed the relationship of entomology to other disciplines; (ii) showed the journal structure of entomology. The first map confirmed the original finding that certain applied entomology journals were closer to chemistry and biochemistry, e.g. J.E.E., whilst others, e.g. Entomophaga, concentrating on biological control, showed two axes, one "basic-applied" and the other "experimental-observational (systematic)", and it was possible to relate known pest control journals with respect to these axes. Pest control journals were applied, national entomological society journals tend to be basic. However, certain insect control journals tend to be more experimental, e.g. J.E.E. and J. Invertebrate Pathology. On the other hand certain journals were more into the observational sector, these tended to be classical biological control, e.g. Entomophaga, Canadian Entomologist. This work suggests that the certain aspects of the chemical-biological approached structure of pest control are amenable to analysis using such techniques. I would hasten to point out that my methods were relatively crude and could be further refined.

Research Trends in Journal of Economic Entomology.

J.E.E. is a core journal for insect pest control, and was central to all the journal maps of insect pest control fields, chemical and applied. It was argued that its historical development mirrored that of economic entomology (albeit with a certain US bias.. I have discussed this previously elsewhere[4]). The J.E.E. contents were analysed and classified over the period 1910-1985 to elucidate the major research trends in techniques for insect control and problems associated with pest insecticide use. The main findings were:

i. The balance between biological and chemical approaches to control changed in a wave-like fashion, biology being dominant before World War II, followed during the period 1945-60 by almost total chemical dominance. Subsequently, there was a swing back towards biology.

ii. The trends for over 50 topics of research were obtained, which are discussed in detail in Chapter 4, and presented graphically in Appendix 3.

iii. Insecticide trends by broad chemical types (inorganic, petroleum oils, botanicals, organosynthetics, and synthetic botanicals) were examined. These confirmed findings obtained in a different fashion, and discussed in Chapter 5.

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[4]. Rothman and Woodhead (1972) with respect to a comparison with the UK journal Annals of Applied Biology.

iv. The relationship between increased emphasis on chemical control and insecticide-induced problems were examined. Residue and resistance problems were shown to have been research topics since before 1914. However, a massive increase in these topics was associated with the rise in organosynthetic insecticide research, with a time lag of 5-10 years. Not all aspects of insecticide related problems were equally well treated by J.E.E., user and wild life toxicity studies seemed to have gone on the whole to other journals.

v. A revitalisation of biological research was observable after 1960. However, this was clearly not a simple return to old, but neglected, topics. Classical biological control topics also increased, but not inordinately. The main increase was represented by quite novel biotechnical topics; autocidal, pheromone and developmental control chemicals. Their trends emerge sharply and quite suddenly during the early 1960s, arguably new technological trajectories. Traditional cultural and pest resistance plant breeding also became more popular topics. There are signs of decline already in some of the biotechnical research trends, perhaps showing a realisation that they, like pesticides, are not going to produce permanent technical fixes. These findings supplement and support my earlier published quantitative analyses of biological control trends.[5]

Insecticide Research Trends

These were obtained from analyses of references to specific compounds in the abstract journal Review of Applied Entomology (Ser. A). over the period 1916-1984. The technique and mode of trend

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[5]. Rothman and Woodhead (1968).

analysis was described in a previous publication of mine[6], however, Chapter 5 discusses the trends within their historical context as part of an endeavour to integrate quantitative and orthodox historical approaches. The main findings were:

i. Research on insecticides has explored a succession of compound groups over time; research on these groups and individual member compounds seems to follow a modified S curve; from the point of view of major compound groupings the history of insecticide research can be represented by a series of substitution curves. With few exceptions once a compound declines it does not grow again. One important exception is pyrethrum, which has revived in the 1970s.

ii. A "league table" of leading insecticides was developed and all historical league members (the league membership changes over time) were examined as to key events in their innovation and usage. It proved generally possible to understand changes in the league table in the light of these.

iii. The quantitative data is representative and matches data obtained by more conventional means, and also through alternative quantitative routes.

iv. The methodology is surprisingly sensitive to trends in insecticide research. Research in new types appear linked to decline in older types. The succession of types is: prior to World War II, inorganic compounds, petroleum oils and botanicals; after World War II, these are substituted for by organosynthetic compounds, which have their own internal trajectories, organochlorine, organophosphorus and carbamate compounds; by the 1970s these too had

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[6]. Rothman and Lester (1985).

been replaced by the sharp rise of synthetic pyrethrins.

v. The research suggests a series of possible investigations. Do the types of compound life cycle curves change with time? For example, are modern R & D agencies able to "gut" a compound more rapidly than their predecessors? What is the relationship between the R & D publication curves and actual compound use? Does the mix of institutional type change over the life cycle, if so how? Do the companies that originally innovated a compound dominate research on it over the compound life cycle? Why do certain compounds such as DDT have a longer life cycle than others? Following on from this, why, even after its use had been banned in most developed nations, did DDT survive as one of the most frequently indexed compounds in Rev. Appl. Entomol.?[7] How does research on a compound diffuse, between kinds of research problem (toxicity, usage against particular pests, specific situations, effectiveness relative to other compounds and so forth) between nations, companies, institutions etc.? A comparison of my publication data with patent data would be useful, particularly if it was designed to see what percentage of patented compounds were researched further.[8]

Comparison with other Historical Data

I have already compared wherever appropriate my quantitative

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7. Such an observation suggests that one ought perhaps to examine and classify the nature of the research done on a compound over a complete life cycle. I suggested in Chapter 4 how this might be done.

8. I know from my own data that many compounds have a very short research life, also the work of CHI, discussed in Chapter 5, demonstrates the potential of following patent families through patent citation techniques. Furthermore, such studies would throw more light on the commercial property aspect of research, which I discussed to a limited extent in Chapter 3 when dealing with the industrial contributions to Chemical Control key papers.

findings with alternative historical sources, both quantitative and qualitative. The more important can be summarised as follows:

i. Insecticide trends. My data on the succession and substitution of compound types confirms and adds to what we know from the literature. It was able to pick out the impact of World War II research, confirmed by authors such as Dunlop and Perkins.[9] The league tables of dominant compounds do reasonably reflect what has been published in other sources about usage, although for some compounds a high usage continued after they had ceased to be intensively researched, e.g. the arsenicals; and the contrary situation for DDT research which still continued to maintain a place in the league table after its banning in USA and Europe. The reasons for this might be usefully investigated.

ii. The triumph of chemical control over non-chemical approaches is clearly documented quantitatively, when it occurred, and also its collapse and the return of biological approaches to research on pest control. These results have been confirmed by the pest control scientific literature itself and by some sociological and historical studies, notably Perkins[10]. The quantitative data produced unexpected findings in so far as they clearly demonstrated that the turn-away in research from chemical control was underway prior to the publication of Rachel Carson's Silent Spring.[11] This does not, of course, in any way diminish Carson's

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[9]. Dunlop (1978, 1981) and Perkins (1978).

[10]. Perkins (1980,1982).

[11]. In Britain K. Mellanby, former Director of Monks Wood Laboratory, a centre of British studies on the environmental impact of pesticides recently wrote "... in Britain the most important controls of pesticides that had been shown to have harmful ecological effects were introduced, with the fullest co-operation of the chemical industry, some months before Silent Spring was published". Mellanby

achievement in alerting the public and politicians to the dangers of chemical control, and to the potential that biological control held as a more environmentally benign alternative. In fact these findings serve to underpin her own stated position that she was reflecting the state of scientific research, but from the view point of an ecological paradigm.[12] One of the easier ways to understand the ideological, metaphysical and socio-economic basis of the chemical approach to insect control is to read the responses of industrial spokesmen (and they were invariably men) to Carson's book.[13] I have included in Appendix A my report[14] on the response of UK industry to Silent Spring. The analysis of key papers in chemical control and selected papers on biological

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(1986).

[12]. Carson discusses these in her final chapter "The Other Road", which sums up her feelings to the chemical control approach and biological alternative. "Through all these new, imaginative and creative approaches ... there runs a constant theme, the awareness that we are dealing with life - with living populations and all their pressures and counterpressures, their surges and recessions. Only by taking into account such life forces and by cautiously seeking to guide them into channels favourable to ourselves can we hope to achieve a reasonable accommodation between the insect hordes and ourselves. The current vogue for poisons has failed utterly to take into account these most fundamental considerations ... [the] extraordinary capacities of life have been ignored by the practitioners of chemical control who have brought to their task no 'high minded orientation', no humility before the vast forces with which they tamper... The concepts and practices of applied entomology for the most part date from the Stone Age of science. It is our alarming misfortune that so primitive a science has armed itself with the most modern and terrible weapons, and in turning them against the insects it has also turned them against the earth". Carson (1962) pp. 256-257. I suspect Sorokin would have seen such sentiments as highlighting the distinction between a sensate and idealistic mode of thought. Perhaps he might have argued that the crisis in economic entomology was but one symptom of the more general crisis of our sensate culture prior to its replacement by a more idealistic form.

[13]. Sobelman (1970) gathers together some of these on behalf of "the DDT Producers of the United States".

[14]. Rothman (1969) "The Public Relations Activities of the Association of British Manufacturers of Agricultural Chemicals."

control shows that industry supported only the former. Furthermore, chemical control papers had few citational links with ecology, unlike biological control, which was strongly linked to ecology journals but not to chemistry journals.

An examination of the charts derived from my analysis of J.E.E. show that the quantitative approach was sensitive to the main components of the pesticide controversy, that the triumph of chemical control can be associated with: the increase in pesticide residue problems; the rapid growth of insecticide resistance problems; pest resurgence and pest substitution problems. Further that in the chronological wake of these there occurred increased research into new techniques, biotechnical methods, and a resurgence of research into older biologically oriented techniques. Two major works[15] that deal inter alia with the history of post-war research into American research programmes in pest control support my findings with "soft" data derived from interviews and use of orthodox documentary sources.[16]

Pest Control Paradigms

I have argued elsewhere that my findings do support the notion of economic entomology as a two strand science divided into chemical and biological approaches[17] . There is a need to explore the implications of this rather more deeply. This cannot be done in a directly

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[15]. Dunlap (1981) and Perkins (1982).

[16]. A detailed content analysis of the fundamental ideas of members of the ecological school in pest control would have been included if there had been time and space. Many of the basic positions of the ecologists had been propounded by the 1950s; indeed I attended the "insect ecology and population dynamics" course of one of them - Professor Alec Milne at Newcastle University Faculty of Agriculture. The outstanding articles include: Pickett (1949), DeBach (1951), Ulyett (1951), Massee (1953), Solomon (1953), Kennedy (1953), Glen (1954), Chapman (1955), Jacob (1958), Stern et al. (1959), Varley (1953), Milne (1965).

[17]. Rothman (1969), in Appendix A.

quantitative fashion, although my data do imply such division, by indicating that certain groupings of control techniques, and problems resulting from their use, move counter cyclically with respect to each other. To explore this further one requires soft data based on analysing the thoughts and practices of the scientists, and also their institutional and socio-economic cultures. Perkins[18] has provided the most thoughtful and detailed analysis of the changing paradigms of American economic entomology since World War II. I propose, therefore, to discuss my findings in relation to Perkins.

In my experience proponents of chemical control, unlike the proponents of biological control, rarely 'philosophise' about their theories and style of research, which are taken for granted as they get on with the job. Thus their views have to be inferred for their actual practice, and their responses to criticism from opponents. Kennedy has provided[19], I think, a fair description of their position.

Perkins would not, I suspect, disagree with Kennedy's general line since he accepts the existence of a "chemical paradigm" in American economic entomology.

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18. Perkins (1980, 1982).

19. Kennedy (1953) p.1329. "Coming to it armed only with lethal substances... [the controller] must necessarily think of pest control first and foremost as the direct killing of insects. All the other means of controlling their numbers or damage are at the very best supplementary to his chemicals. Killing insects is for him just another chemical action, still within the domain of his science. If this approach, perfectly consistent on the part of a chemist, be brought into the domain of another science, biology, that does not transform it into a biological approach or make it any less of a chemical one. If it comes to prevail in a biological field, as it undoubtedly does in applied entomology today, it simply displaces the biological approach in that field. And a non-biological approach in a biological field is unscientific... if biologists compromise with an unbiological approach in their field, the first victim is biological science... further... the right choice of methods cannot be made with an unbiological approach, so agricultural productivity, too, is at stake".

"The more immediate impact of the new insecticides was that they stimulated the development of a new paradigm for agricultural entomology; the major tool for controlling insects would be the application of toxic chemicals to them. Other methods were not forgotten, dismissed from research, or left totally unused: but they were for the most part relegated to secondary importance. This chemical control paradigm attracted many entomologists away from competing lines of research and provided numerous problems for them. Particularly important were the questions of which chemical, applied how, and at what time, and in what amounts. Entomologists continued to maintain that insects could be controlled by many different means, but when drawing up their own research plans, they tended to select a chemical as the foundation of the experimental design".[20]

Perkins divides the history of innovation in insect pest control 1945-1978 into three phases:[21]

i. "Euphoria and the crisis of residues" (1945-55), characterised by employment of DDT and the triumph of chemical control, and later by scientific and political debates on residue problems and the toxicological implications for people eating insecticide residues on food.

ii. "Confusion and the crisis of the environment" (1954-72), characterised by resistance, pest resurgence and secondary pests, new research trends in pest control, especially the rise of biotechnical techniques; and also public environmental protests.

iii. "Changing paradigms" (1968-present). There were, argues Perkins, three paradigms involved, not two as Kennedy and others have implied. These were: the chemical control paradigm, I have quoted Perkins definition; the integrated pest management paradigm (IPM); and the total population management paradigm (TPM). Thus Perkins subdivides the biological approach into two paradigms on the grounds that TPM seeks in certain cases "... total eradication of a species". This allows him to identify a "metaphysical"

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[20]. Perkins (1982) pp.12-13.

[21]. Perkins (1980) pp.26-46.

distinction between the two paradigms; and Perkins, with respect to their underlying "belief system", regards IPM as fundamentally "naturalistic" and TPM as "humanistic". These he defines as:

"Naturalistic: A belief system that man is part of the biosphere but cannot be total master of it. He may manipulate it for his own benefit, but there are intrinsic limits to his manipulative powers that reside in the properties of the material world. Humanistic: A belief system that man is part of the biosphere and that he can be master of it. He may manipulate it for his own benefit, and there are no intrinsic limits to his manipulative powers that reside in the properties of the material world. The limits such as they are derive from his current ignorance of natural processes".[22]

It is clear from Perkins' work that the TPM approach is associated with large bureaucratic organisations, such as the USDA, for whom large scale programmes tend to bring greater political and institutional reward. It might be argued that the TPM paradigm embodies a crude "externalism" and "ecological voluntarism"[23], which characterises such technological programmes as NASA's "man on the moon", National Institutes for Health's "cure for cancer" or the Soviet plans "to turn back the Arctic rivers to irrigate Central Asia".

The belief systems of which Perkins speaks need to be situated in their socio-economic environment. Perkins is aware of this but fails, I think, to give it sufficient attention. He acknowledges for instance that in technical practice the chemical paradigm still dominates, citing van den Bosch's[24] estimate that even in California, the centre of American biological control research, only 10% of control is integrated control. Why is this? If the biologists won the scientific

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[22]. Perkins (1980) p.58. For a philosophically profound analysis of the various ways of looking at the limits to scientific progress in general see Rescher (1978).

[23]. "The essence of the ecological variant of voluntarism is an absolutising of technical power without considering the biosphere's evolutionary possibilities"; see Novik (1979) p.292.

[24]. van den Bosch (1980).

argument why do they not yet control the technology?[25] The simple answer is, of course, because they do not control the technology; the relation between scientific theory and technological practice is about socio-economic power as well as ideas, facts and proof. The social reality of attempting to promulgate the IPM paradigm has been poignantly and angrily described by one of its greatest innovators, Professor Robert van den Bosch, for whom freedom for research was restricted, let alone the actual putting into practice of his research.[26] Poor van den Bosch saw this as a "conspiracy" by a pesticide "mafia", perhaps he was right. There is no way that the quantitative analyses that I have adopted could demonstrate such corrupting influences on research. They might, however, be seen as more profitably determined responses of a specific social system. Dave Eva has explored such a model with respect to research into the

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[25]. David Collingridge and Colin Reeve (1986) are sceptical about the ability of science to influence policy. The pest control controversy shows that the overt agenda of policy makers was set by the sort of research reported by Carson. The reasons why the biological paradigm failed to dominate actual pest control technology and practice are not, I believe, comprehensible from the Popperian approach of Collingridge and Reeve; rather I would support Barnes (1987) view that "Objectives and interests determine what 'knowledge' is preferred, not vice versa", p.560.

[26]. van den Bosch (1978) details the pressures put on him by chemical industry representatives directly or indirectly through US funding agencies and officials of his university. These included: verbal insults, slander and libel, threats to his continued employment, removal of grants, interference with publication, and scaring or bribing his colleagues etc. These sound like the ravings of a paranoid personality, however, a decade earlier I documented similar if less violent infringements of scientific freedom by American pesticide interests, see Rothman (1969); and Egler (1966) has reported similar interferences. There are also counter accusations, Gordon Edwards in a letter to Nature (vol 320, p.391, 1986) claims environmentalist lobbyists "... resorted to such unscientific methods as deliberately distorting, or omitting, all the data that refuted their allegations over, for example, the impact of DDT".

toxicology of pesticides.[27] Ravetz has argued that the institutional value system of employers of scientists may, under certain circumstances, be inimicable to the proper functioning of the quality control systems of science.[28] Clearly the nature of occupational roles, ideological values, cognitive norms and so forth will have a profound impact on scientific production in a field such as economic entomology, whose very subject matter, the pest, is a socio-economic construct rather than a natural biological entity.[29]

Economic entomology is an applied science whose research findings play a very important role in agriculture. The issues raised by Perkins must not be solely regarded as something embedded in science alone. Science and technology have a dialectical unity, often contradictory, each making ever-changing demands on the other. Clearly as far as the biological scientific paradigms in economic entomology are concerned the technology of pest control is in practice lagging, or perhaps more accurately being subjected to a different rationality. For this reason it is useful to re-examine our material in the light of Dosi's concepts of technological paradigm and technological trajectory.[30]

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[27]. Eva (1975), and M.Sc. thesis produced under my direction; and Eva and Rothman (1979).

[28]. Ravetz (1973); such circumstances may include the desire for secrecy to protect commercial or military interests.

[29]. The fact-value distinction has been questioned by some sociologists of science as an "... essentially positivist view of science... overly restrictive in limiting explanations of scientific controversies to factors "extrinsic" to science; values, bias and the like. When science is examined as a form of organised, intellectual production, a much more complex relationship between scientific concepts, theories and methodologies, on the one hand, and ideological and value commitments on the other, emerges, which also allows explanations of controversies in terms of factors "intrinsic" to scientific development". Gillespie et al. (1979) p.265.

[30]. Dosi (1982).

He defines, as an analogy with the Kuhnian concept of scientific paradigm, a technological paradigm as a model and pattern of solution of selected technological problems based upon selected principles derived from natural sciences and on selected material technologies. Whilst technological trajectory is taken as analogous to Kuhn's notion of normal science, that is "... the pattern of normal problem solving activity (i.e. of progress) on the grounds of a technical paradigm".[31] Amongst the properties of technological paradigms says Dosi[32] is "... a powerful exclusion effect[33]: the efforts and technological imagination of engineering and the organisations they are in are focussed in rather precise directions while they are so to speak 'blind' with respect to other technological possibilities... and (a definition of) some idea of progress". In the technology of insect pest control one might therefore expect the dominant chemical control paradigm to exclude biological control paradigms as it sought progress through newer insecticides and more powerful spraying machinery. Thus one finds plenty of quantitative evidence of research trends to maintain this paradigm's continued effectiveness with more scientific support. Scientific research trends which cannot be incorporated into the dominant chemical control technological paradigm are, one might conjecture, ignored. Dosi is, of course, setting up a suggestive, but speculative, analogy; there are differences in the cognitive structures of science and technology which lead Dosi to argue that his formulation of technological paradigm is "an approximation".

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[31]. Dosi (1982) p.152.

[32]. Dosi (1982) p.153.

[33]. One should also draw attention to the concept of technological suppression. (P.P. Saviotti, private communication) which I have discussed elsewhere in connection with innovation in biotechnology. (Rothman, 1984, B23-B25).

We may return to a question posed early in this thesis, what determines the choice of technique for killing pests? This could now be rephrased to ask, how do technological paradigms emerge, and how is one preferred over alternative paradigms? To answer such questions Dosi argues that technological trajectories are acted upon by various social and economic variables which act as "focussing forces".

> "(1) The economic interests of the organisations involved in R & D in the new technological areas, (2) their technological history, the fields of their technological expertise, etc., (3) institutional variables stricto sensu such as public agencies, the military etc."[34]

It seems that these ideas could be explored further in the context of pest control and also quantitatively, especially by studying how economic and social conditions interact with the process of technology selection. For example, Dosi makes an important distinction;

> "...between the process of search and selection on new technological paradigms and technical progress along a defined path... (new technology) selection... (occurs) through a complex interaction between some fundamental economic factors... together with powerful institutional factors... (whereas) technological change along established technological paths, on the contrary, becomes more endogenous to 'normal' economic mechanisms".[35]

Dosi says that historically this takes the form of emergence and maturity of an industry. What is the industry in the case of pest control, is it the agricultural chemical industry or the farming industry, or is it, as I shall suggest below, one which subsumes them both - the agriculture industry or agribusiness? If we look at the first suggestion, the agricultural chemicals industry, we can find supporting historical data, including some presented in this thesis relating to the corporate origins of new pesticides. Similarly Dunlap

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[34]. Dosi (1982) p.155.

[35]. Dosi (1982) p.157.

and Perkins provide further support.[36] There was a steady incremental innovation of chemicals by chemical companies prior to the revolutionary breakthrough around 1939-45 associated with DDT and other novel powerful organosynthetic compounds. At that point pesticides were seen as a new and major profit making area by chemical companies, most of whom joined the hunt for new chemicals and applications. The eventual result was a mature chemical industry for which these compounds represented a vital source of profit. Furthermore, as Dosi points out, industrial maturity involves the development of an oligopolist structure, often multinational. Thus says Dosi:

> "... the production, exploitation and commercial diffusion of innovations are much less divorced and technical change often itself becomes part of the pattern of 'oligopolist competition'. The more a fundamental technological pattern becomes established, the more the mechanism of generation of innovations and technical advances appears to become endogenous to the 'normal' economic mechanism".[37]

The constant stream of new pesticides and their heavy promotion, is in part due to the competitive pressure generated by such an economic system. That the pesticides industry has such an oligopolistic structure[38] and is subjected to the most horrendously expensive competition can be born out by the following data regarding pesticide manufacturing structure and R & D costs. In 1979 a mere 24 companies accounted for 85% of pesticide sales worldwide, and Ruivenkamp[39] estimates that by 1990 12 companies will account for 75%

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[36]. See Dunlap and Perkins (1980) and Perkins (1982) especially Chapter 1.

[37]. Dosi (1982) p.158.

[38]. This is an oversimplification in so far as the agribusiness structure calls for specific forms of big company small company relationships, in which the former develop and manufacture the basic pesticide, and the latter formulate and distribute them for specific farming function. See Ruivenkamp (1985).

[39]. Ruivenkamp (1985).

of sales. My own data on modern insecticide innovation bear this out; I found that the bulk of organophosphorus compounds that were highly researched were the products of only 13 companies.

The cost of remaining competitive through pesticide innovation has increased continually over the last decades. The costs of developing new compounds was: 1950, $1m; 1960, $2m; 1970, $5m; 1975, $10m; 1980, $30m.

It is becoming harder to find suitable active compounds. The ratio of each pesticide marketed to number of compounds screened has the following trend:[40]

1966, 1:6,000; 1976, 1:12,000; 1980, 1:20,000.

These developments are linked to the "problems of insecticides", however, they also reflect structural problems of the industry, which they are resolving by concentrating, rather than diffusing, capital. Together these will create a pressure for change on the dominant technical paradigm. But, as Ruivenkamp has pointed out[41], there is no guarantee that any paradigm change will result in mechanical shift to one of the biological paradigms. There is a certain flexibility within the chemical paradigm for the chemical companies to continue to use it for their own ends. For example, the current research trends towards synthetic pyrethrins and selective compounds, which are more expensive, may in certain places be used in integrated programmes catering, perhaps, for expensive high cost residue free products. Or they might involve a new set of big company/small company relationships, where the latter provide the highly skilled consultancy and monitoring required by certain integrated programmes. On the other hand, in the Third

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[40]. Cited by Ruivenkamp (1985).

[41]. Ruivenkamp (1985).

World, where the large chemical companies do much of their business (Bayer for example has 30% of its sales in the Third World), broad spectrum compounds, which are cheaper and needed as key inputs to the Green Revolution crops and cash crops generally, will continue to be used, and, as Bull has documented,[42], kill workers and villagers lacking proper protection. If one looks at the likely impact of biotechnical (or biotechnology) methods I see no reason why their existence as techniques, rather than constituents of alternative biological scientific paradigms, should prevent them being incorporated into the chemical control technological paradigm. For example, microbial insecticides may be used in this respect like normal insecticides, likewise one might expect to see more effort put into pesticide resistant crop development rather than pest resistant crops.

I would argue that such developments will occur not as a result of a corrupt conspiracy, as van den Bosch asserts (although no doubt both corruption of farmers, scientists and officials and conspiracy against those seeking to change the dominant paradigm do occur and will continue to do so) but as the modus operandi of a complex socio-economic system acting as a sub-system within the dominant capitalist mode of production.[43]

How might one characterise this sub-system? In his original

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[42]. Bull (1982).

[43]. This is discussed by Eva (1975). I am aware, of course, that not all societies are capitalist, however, it could be argued that the capitalist mode of production is still dominant, in the context of this thesis, in so far as it continues to set the global agenda for changes in the forces of production. There are contradictions in the technological trajectories found in the "two camps", capitalist and socialist, and I have presented data showing suggestive differences in their demographic distributions of research into chemical and biological control. However the actual significance of these in agricultural practices remains to be demonstrated.

critique of pest control, Kennedy[44] noted that "The control of insects is not only a matter of insect ecology but... a part of 'agricultural ecology', a branch of biology we have to create". The development of such a science would need to encompass I think the agricultural socio-economic system, a profound discussion of which is beyond the declared scope of this thesis. I will, however, draw attention to the discussion of this topic by Levins and Lewontin[45] in as far as it offers some clues to understanding research trends in pest control which might be followed by future students of this topic.

The first thing to note about their views is that they distinguish between **farming** and **agriculture**. The former is the process of actually growing crops etc., whilst the latter includes farming and "... all those processes that go into marketing, transporting, and selling the seed, machinery, and chemicals used by the farmer and all of the transportation, food processing and selling..." from the crop leaving the farm to its use by the consumer. Their aphorism "Farming is growing peanuts; agriculture is turning petroleum into peanut butter"[46] neatly encapsulates the difference.

There has been a major mutation in the mode of production of agriculture, which had in turn a profound effect on its technological paradigm(s). First the locus of added value has changed. Whereas originally farming itself was the source of the greatest added value, today the greatest source of added value are the input and post-harvest activities. Levins and Lewontin claim[47] that "At present only 10% of

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[44]. Kennedy (1953) p.1329)

[45]. Levins and Lewontin (1985).

[46]. Levins and Lewontin (1985) p.210.

[47]. Levins and Lewontin (1985) p.211.

the value added in agriculture is actually added on the farm... farm production is now only a small fraction of agricultural production". Second, far fewer people are involved in farming since the labour process has been highly mechanised, to save costs and also to increase social control of the process. Thirdly, the chemical inputs have increased, for many reasons, some of which we have discussed and others, such as petrochemicalisation, we have had to leave out; and the processing of the crops has increased in complexity to provide new and more consistent standardised products for global rather than local and national markets. The economic result of all these changes has been to create a peculiar structure; one in which the capital concentration has been greater on the inputs and post-harvesting sides, leaving farming to little capitals (although even this might be changing), hence the political requirement to prop up farming with subsidies etc. The result is that agriculture is controlled by large capital and one finds therefore, argue Levins and Lewontin that "agricultural research although directly responsive to the demands of farmers, is, in fact, carried out on terms set by the concentration of capital".[48]

A more profound understanding of the history of economic entomology and the reasons for its two-strand nature as an applied science, and the continuing domination of the chemical control technological paradigm in agricultural practice can only be obtained if one can take on board a historical analysis of the development of the agricultural system we have outlined.

Thus the kind of quantitative historical analysis of science that

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[48]. Levins and Lewontin (1985) p.211; they believe that pesticides ought to be seen as ecological poisons and as commodities sold solely for profit. Granberg (1981) has shown that in Sweden government agricultural policies "... may serve to reinforce those economic pressures which make it difficult for users to move away from their present reliance on chemical control". p.61.

I have presented will require, on the one hand, to be enriched with clinometric studies of appropriate industrial and agricultural sectors. On the other hand, there is clearly a need for such studies to be done within the framework of a critique of science's contradictory dual social function as both support and critique of existing socio-economic power. In the history presented here one could argue that the chemical paradigm is the servant of power whilst the biological control paradigm, in its IPM form, is critical and potentially subversive of existing power structures.[49] That view, however, cannot be proven in purely quantitative terms, a conclusion that lends support to the plea for the primacy of studies concentrating on the "soft underbelly of science"[50], providing, of course, that one includes in that description those broader and underlying socio-economic elements that determine the environment of research. The value of quantitative research must lie ultimately, therefore, in the extent to which it is able to provide an intellectual corset, to firm up and support that soft underbelly, without which it is doomed to be a useless artifice.

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[49]. "The struggle to change agricultural technology is also a struggle to change the direction of research, a change that can be imposed only from the outside by the direct and indirect victims of pesticides in collaboration with dissident scientists". Levins and Lewontin (1985) p.241. Granberg (1981) expressed a similar sentiment with respect to his observation that the development of biological pest control "... can be attributed mainly to a public demand-induced functional change, rather than to the forces of discovery-push or market- (or user demand-) pull". p.64 "... a phenomenon which is likely to become increasingly important in the future; viz. the stimulation of a technological research field through a functional change which results not from the demands and expressed needs of the potential users of the technology, nor from the anticipation, by groups with a commercial interest in the technology, of future needs and markets, but rather from pressures emanating from a concerned public. The public, in this case, includes both laymen - as individuals and as members of various environmentalist and conservationist movements - and experts from such fields as ecology, toxicology, and public health". p.59.

[50]. Edge (1979).

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