SCIENTIFIC EXCELLENCE, EFFECTIVENESS AND PRODUCTIVITY

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Indicative Summary

Some of the extensive literature on the actual and desirable performance of scientists is reviewed. Emphasis is given to the low average productivity of publications and the high value of citations. Factors that influence the productivity, visibility, and management of scientists are systematically arranged and discussed.

The results of a survey of the views of Research Division scientists about the assessment of excellence, effectiveness and productivity are summarized.

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* Minor improvements (e.g. typographical errors or other inaccuracies) were made in May 1992 before placing a copy in the CALM Library

1. INTRODUCTION

Few research administrators seem aware that, just as biological scientists study plants, animals and other organisms, there are researchers who study scientists. Although these investigations are necessarily based on surveys and not experiments, they enjoy considerable empirical support: 1 300 US scientists (Pelz and Andrews 1976), 11 000 participants in 1 200 research units in 6 European nations (Andrews 1979), and 1 400 US scientists (Busch and Lacy 1983). Their general aim is to study how factòrs of individual motivation, group structure and organizational process bear on the performance of scientists.

As a professional group, scientists share the major characteristics of professionals: autonomy in work, divided loyalty, tensions between professional values and bureaucratic expectations, and peer evaluation of work (Moses 1988). As scientists employed by CALM, our first commitment must be to executing the objectives of the Department, the Mission Statement and Primary Objectives of Research Division, and the Aim, Primary Objectives, 20 year and 5 year goals of the Research Program of which each scientist is a member (CALM 1989).

However, unlike most other staff of CALM, we as scientists can also be judged by our peers outside CALM through our effectiveness in satisfying the standards of the broader scientific community, especially the quantity and quality of our most tangible outputs, publications. As practitioners of science we can rightfully claim membership of the national and world body of scientists. To do this effectively we need to have contributed to scientific knowledge and just as importantly to have had some influence on the ideas found useful by other scientists. The size of one's publication list, the standard of journals published in, and the number of citations (other than self-citations) are commonly used criteria in other scientific organisations such as Universities and Government agencies around the world. Apart from a handful of staff (mainly in the Research Computing, Research Methods and Herbarium programs) these criteria are also applicable to CALM scientists.

2. SCIENTIFIC IMAGES

Science is a highly stratified and elitist system with skewed distributions of productivity and rewards (Andrews 1979). Characteristics of science include universalism (information is available to all and can be assessed by all), communality (information is the property of all), organized scepticism (results are never taken on trust) and disinterestedness (commitment to objective knowledge) (Landsberg 1989). Imaginative research, by definition, challenges the status quo by adding to knowledge and proposing new ideas, approaches, methods and applications.

Until the mid nineteenth century, the prevailing image of the scientist was Cartesian (Busch and Lacy 1983). This scientific type was a neutral observer, who composed grand and elegant theories, and with the help of technicians and apprentices, tested them by observation and experiment. The ultimate objective was to discover laws. This image was subsequently largely replaced by a Baconian one of a group of scientists working together producing results immediately applicable to problems of the State. The ultimate objective was to change the world by controlling it. This transition was described by Price (1963) as the replacement of little science by big science.

In reality, however, the distinction and transition just described are not clearcut, and in fact both images exist today. It is therefore more usual (and more helpful) to divide scientific research into several types.

3. TYPES OF SCIENTIFIC RESEARCH

Landsberg (1989) distinguished three types of scientific research. Basic research is concerned with producing knowledge without attempting to determine its likely value, other than that it adds to general knowledge. Strategic research is basic research needed to achieve practical results. Applied research produces knowledge for clearly defined practical purposes.

An equally useful, but different, scheme recognizes 5 R & D functions (Pelz and Andrews 1976). Research (the discovery of new knowledge, either basic or applied) is distinguished from Development (the translation of knowledge into useful form (information)). This classification can be fully described as follows:

• General knowledge relevant to a broad class of problems	) Research
• Specific knowledge for solving specific problems	) Research
• Improving existing products/processes	) Development
• Inventing new products/processes	) Development
• Consultation, troubleshooting, analysis by standard techniques	) Technical Services

The Research Division of CALM does all 3 of Landsberg' categories, with most emphasis on the strategic and applied varieties. In the other classification, items 1, 2, 3 and 5 are about equally addressed.

4. SYSTEMS OF SCIENTIFIC RESEARCH MANAGEMENT

Three systems of managing scientific research may be recognized (Landsberg 1989). In the laissez-faire system, management is minimal and the choice of projects is left to individual scientists. Economic considerations do not rate high. Most communication is with other scientists. Pursuit of publications is given very high priority. The view is usually taken that the practical development of results is someone else's job.

In the applied system, there is a hierarchy of management. The policy-making part defines the most important problems to be worked on, but the methods and approach used are largely left to the scientists involved. Communication takes place with users of research findings as well as scientists. Performance assessment is largely concerned with practical successes.

The third system recognized, the mixed-mode system, is a mixture of the above two models. Publication of results in scholarly journals brings kudos to both the scientist and organization, and implementation of research results by users leads to practical benefits.

CALM Research Division best fits the mixed-mode system.

5. ACCOUNTABILITY

Accountability is built into the applied and mixed-mode systems of scientific research management. It satisfies an interested person's need to know the use to which resources are put, and to gauge the efficiency and effectiveness of the research being supported. Government research agencies are of course obliged to let the public know how their money is being spent. However, because one of the characteristics of professional work is lack of close supervision, the very act of evaluation can lead to discontent (Moses 1988). Vanity, arrogance and pomposity are, after all, common human traits. Nevertheless, the benefits of being accountable are many, and include feedback, clearer goal definition, and orderly changes in direction.

The period when exponential growth of R and D overlap is when little attention is given to the effectiveness of research (Andrews 1979). Consequently it is usually during a subsequent period of declining resources that more attention is given to accountability. In addition, in times of stringency, staff become less tolerant of those who do not pull their weight (Moses 1988).

Lloyd (1966) described three broad ways of increasing the efficiency of research. Better methods can be sought for attacking the problem under study, more effective ways of "selling" the results can be found, and the training of the scientists and technicians can be improved.

6. PUBLISHING IN SCHOLARLY JOURNALS

The institutional goal of science is the extension of certified knowledge (Merton 1957). It is therefore no surprise that the most fundamental social process of science is communication and exchange of research findings (Fox 1983). Publication in scholarly journals is the main way this is achieved. It diffuses new knowledge as rapidly as possible, serves as a permanent record, and minimizes wasteful duplication of effort. It also allows other scientists to verify the reliability of information and to assess its relative importance, and permits the author to obtain critical response. It is through publication that scientists receive visibility and professional recognition. Indeed, publication is so central to productivity that work becomes a "work" only when it is published. Scientists must publish also in order to advance their careers. A cynical view is that publication certifies that a scientist is a "reliable producer of approved words" (Caton 1989).

Despite all this, it has been estimated that at most only 10% of what is published is a genuine contribution to knowledge (Kochen 1987). The Science Citation Index includes only 6.7% of the world's scientific journals, yet includes 75% of all cited papers (Price 1980). And, according to Bradford's law, a mere handful of journals account for most of the major publications in any field (Garfield 1988a). A very large proportion of the world's 50 000 journals now current must be recognized as "merely a distant background noise" (Price 1965).

Most of the premier journals have very low acceptance rates of submitted papers. Clearly, there is an enormous wastage of publications and considerable competition among scientists to publish their findings in the best journals available. Scientists tend to restrict their publishing to a small number of journals (Busch and Lacy 1983). In the scientific community, the currency is recognition from colleagues: journal articles are written for one's peers, not laypersons (Havelock 1971).

7. PUBLICATION PRODUCTIVITY AMONG SCIENTISTS

Despite the centrality of publication to scientific endeavour (Fox 1983), the average rate of publication is extremely low. However, the variance between scientists is very high. Some averages (No publications/scientist/year) are: 1.0 (Rockefeller University 1977-8, Cohen 1980), 1.5 (Melzer 1956), 1.6 (U.S. agricultural scientists, Busch and Lacy 1983), and 1.0 (CALM Research Division scientists, see Fig. 1).

Eminent biologists in the twentieth century averaged 3.6 publications/yr (range 1.4-8.4) and their high productivity tended to persist over many years (Roe 1972). Nobel Laureates publish 5 times as many papers as average scientists (Garfield 1988a).

Only a small and select minority of scientists produce the bulk of the scientific papers published (Lotka 1926, Busch and Lacy 1983). Price (1963) showed that the square root of the number of scientists produces half of the scientific papers. In the Research Division of CALM, $\sqrt{51} \approx 7$ scientists produced 50% of publications (Data from Table 1). Or, expressed in another way, 20% of the scientists in the Division produced 61% of the papers published in the period 1981-6 inclusive.

8. REASONS FOR THE LOW AVERAGE PRODUCTION OF PUBLICATIONS

Many influences are involved - there is no single reason for poor productivity of publications. Deficiencies in some factors can very likely be overcome by exceptional strengths in other factors.

The correlates and determinants of publication productivity can be, following Fox (1983), grouped under four categories: psychological/sociological characteristics, demographic characteristics, work habits and work environment. The first two factors are either fixed or very difficult to alter in contrast to the last two factors.

Psychological/sociological attributes

a) Naive view of the process of science.

Hypothesis-generation and hypothesis-testing through data collection and analysis are two vital components of the so-called scientific method readily acquired through secondary and tertiary education. But equally important is marketing. Researchers act as reporters and market their research in reports (Busch and Lacy 1983). Hence good writing skills, persuasive (but honest) marshalling of facts and care in selecting journals in which to publish cannot be overrated. Any scientist with experience in refereeing knows how widespread ignorance of these matters is.

b) Undervaluing of peer recognition

Only those who value the rewards which follow from recognition by the scientific community are motivated to publish (Box and Cotgrove 1968). Whether this undervaluation of rewards is deliberate or unintentional is uncertain; however, the latter follows from having a naive concept of science.

Publication is the main way by which reputation for scientific excellence can be acquired.

c) Stamina and dedication

The capacity to work hard and persist in the pursuit of long-range goals is essential. Commitment, diligence and high motivation ("zest") are not widespread attributes especially in combination.

d) Creative ability and competence

Scientists unable to produce many ideas, think through ideas of others or combine old ideas with new ones can be expected to produce little of value to other scientists.

"Looking back, I think it was more difficult to see what the problems were than to solve them" Darwin. "I am a firm believer that, without speculation, there is no good or original observation" Darwin.

e) Ego strength

Once a project is approved, a scientist normally has substantial latitude in deciding the approach, methods and analysis to be used. Lack of self-confidence in one's ideas, lack of independence and lack of self-sufficiency are not conducive to producing outputs in the form of scientific papers. Productive scientists are not overly concerned with attaining approval for the work they are doing.

A strong ego seems indispensable for the study of high risk problems, for which the chance of failure is very high.

Demographic characteristics

a) Age

There seems little agreement about the role of age. Some argue that it is not relevant as most scientists remain low producers throughout their careers. The often documented peak around midlife and subsequent decline (Lehman 1953) may really reflect "burnout" by "shooting stars" (Hammel 1980) or the movement of productive scientists into administration (Knorr *et al.* 1979). Pelz and Andrews (1976), however, observed a second peak 10-15 years later (before retirement).

Intellectual atrophy, increased time spent on administration, less motivation to achieve ("resting on your laurels"), and staleness may also be implicated, as they should increase with age.

b) Career age (professional experience)

It seems obvious that for the first few years after graduation (say age 25-28) publication productivity will be low, since it takes time to choose a problem worthy of study, collect and analyse data, and publish a paper. Increased facility and experience then results in a backlog of research waiting to be written up, so the production of papers accelerates, at least up to midlife (35-40).
However, it is difficult to separate the effects of age from professional experience because of high correlation (Knorr *et al.* 1979). There is evidence that supervisory position outweighs age or professional experience as supervisory position leads to better access to resources.

Work habits

a) Time

Lack of time is often blamed for poor productivity, and as in any sort of work, careful time budgeting can boost productivity. However, several studies show that the relationship between time and productivity is curvilinear. Optimal productivity occurs when about two-thirds of the work time available is spent on scientific research (Peltz and Andrews 1976, Busch and Lacy 1983). According to Knorr *et al.* (1979), there is a broad plateau of maximum productivity of publications covering the range 10-60% of time spent on research. All studies agree that spending 100% of time on research actually results in fewer publications.

My review found no discussion about the balance between time spent in the field, office and laboratory. My personal conviction is that this matter is not often carefully considered by scientists - an honest answer to the question "Is this field trip (or time spent in the office...) really the best use of my time?" is required. The attendance of senior scientists on field trips collecting data easily collected by technicians may also be a waste of professional skills. A supervisor/unit head spending at least 30% of time on research attains high productivity because these scientists tend to put more of their precious research time into thinking and writing; this offers better opportunities for publication than devoting time to the more tedious task of collecting data (Knorr *et al.* 1979).

Data presented by Andrews (1979) indicate that the productivity of a team leader peaks when the unit head spends c.11-24% of time on research in the research unit. This may be compared to a staff scientist, whose peak occurs at about 75-90%.

Too little or too much time pressure can result in poor productivity (Pelz and Andrews 1976). The first is the unhurried, academic stereotype where the work expands to meet the time available. The second leads to stress and poor health.

b) Library use

My own observation indicates that most scientists make poor use of library facilities - Pareto's principle would suggest that 20% of scientists are responsible for 80% of borrowings, photocopying, interlibrary loans etc. Unfortunately the CALM library only keeps suitable records of interlibrary loans. Analysis of records for the first 11 months of 1989 shows that 20% of scientists are responsible for 72% of ILL requests.

Scientists who do not keep abreast of current literature are very likely working on problems already solved or no longer of great relevance at the frontiers of knowledge.

c) Breadth

If the number of problems worked on over a period is small or if a problem is too narrowly defined, then outputs in the form of published articles should be correspondingly few.

d) Inefficiency

Scientists who are poorly organized and who work to unclear objectives cannot expect to produce scientific papers efficiently. Idle curiosity and serendipity are mere excuses for inefficient work practices.

e) Preoccupation with the insoluble or the trivial.

Both preoccupations can be expected to lead to low productivity of scientific papers. According to Medawar (1967), good scientists study the most important problems they think they can solve. It is their professional business to solve problems, not merely grapple with them.

Pursuit of the trivial is the preoccupation of those scientists who desire a quiet, easy life. Nonetheless, it is possible to be productive in a routine way.

A related matter, bandwagon research, concerns preoccupation with fads. According to Abrahamson *et al.* (1989), a fad is an attractive concept that fools scientists, receives more attention than it deserves, is vacuous in the long term, but can only be recognized in hindsight.

f) Reluctance to discuss ideas with other scientists or carry out research in a team

Scientists who make frequent contact with colleagues perform better than those who do not (Pelz and Andrews 1976), with the major exception of research conducted in tightly co-ordinated settings.

The increased scale and corporate character of most modern research has led to a tendency for scientists to publish more in co-authored form. Scientists who isolate themselves from this trend can expect to fall behind their peers in productivity of publications.

Work environment

a) Insufficient resources

The actual resources available for research purposes are not always related to subjective perceptions of their adequacy (Stolte-Heiskanen 1979). A "halo effect", e.g. in providing adequate technical support staff, often results in scientists being highly satisfied with resources in general.

In theory, scientists working on the most important problems should not be hampered by insufficient resources. In practice, however, status of the researcher may enhance access to resources (Knorr *et al.* 1979). Hence low status scientists (frequently the youngest and most recent recruits) should have difficulty in publishing papers in their first five years of research.

Productivity does not decrease as supervisory duties are taken on (Knorr *et al.* 1979). If the most capable and most productive scientists advance to leadership positions, they then have increased access to resources, permitting further rises in productivity.

It is harder for scientists working on interdisciplinary problems to receive as much support as scientists investigating disciplinary ones (Busch and Lacy 1983). Possible reasons include: disciplinary problems are more easily defined, easier to assess in terms of (disciplinary) significance, and are more likely to contribute to (disciplinary) knowledge.

Provision of sufficient resources does not of course guarantee effective research (Box and Cotgrove 1968). A research unit can be poor but effective or rich but ineffective.

b) Poor supervision

Too little or too much supervision may cause dissatisfaction, resulting in low output of scientific publications. It is the business of research management to find the right mix of co-ordination and autonomy. Of major concern is that the freedom essential for scientific creativity may become limited as the degree of organization increases.

In loosely co-ordinated settings, the most autonomous scientists do poorly (Pelz and Andrews 1976), perhaps because they isolate themselves from stimulation and/or they feel ignored (both situations of maximum security and minimum challenge).

c) Insufficient rewards

Poor promotional prospects are likely to reduce publication productivity. It is around midlife when most scientists research their "career asymptote". Lack of further incentives may explain the midcareer decline in publications alluded to earlier.

9. CITATIONS

One common method of evaluating productivity of scientists is citation counts. The average scientific paper has 15 references, of which 12 are to journal articles (Price 1965). About 7 new papers are published every year for every 100 previously published papers in a given field. This results in 105 references back to the previous 100 papers. Thus, on average, every scientific paper ever published is cited about once a year (see also Garfield 1989).

In any given year, about 35% of all existing papers are not cited at all. A further 49% are only cited once in a given year. Hence, in any year, only 16% of all papers are cited.

In reality, 10% of all papers are never cited, and after a decade, very few papers continue to be cited (Price 1965). Indeed, science as a whole looks to the very recent past (the last 5 years) for roughly half of all citations (Griffith 1989).

The number of scientific publications produced in a specified unit of time is a significant indicator of scientific output. However, this is not a measure of quality, creativity, significance, or impact of the research. Furthermore, co-authors gain the same credit as the principal author, and a short paper has equal value with a longer paper. Most importantly, counts of the number of paper has equal value with a longer paper. Most importantly, counts of the number of papers published make no distinction between good and poor or between the highly original and the repetitious or pedestrian.

The conventional and convenient, though not faultless, way of assessing quality is by measuring the frequency of citations to a particular paper or even using lifetime citation counts. Citations are a way of evaluating scientific contribution i.e. whether published papers help move the field forward. Citations indicate that the work cited is relevant to the citing author's research (otherwise it would not have been cited). It is a way of crediting predecessors for their contribution to current research. Citations therefore serve as a form of recognition. According to Cole and Cole (1967), it would be difficult to sustain an argument that a scientist who has no or few citations was widely visible in the scientific community. Nobel class scientists receive 50 times more citations than does the average scientist (Garfield 1988a).

As noted above for number of publications, the frequency of citations per scientist varies enormously. In the Research Division of CALM, 20% of the scientists contributed 79% of the 419 citations recorded in Table 1, col Q. (See also Fig. 1B).

It is important to stress that citations measure quality and usefulness of a paper to other scientists, not usefulness in the sense of assessing overall value of a piece of research to an organization.

Citations can also be regarded as a form of persuasion (Garfield 1988a). A scientist with true, important results has to persuade the scientific community to share this opinion, for it is only with consensus that research findings will become part of scientific knowledge. The idea that the validity of facts alone within a paper is sufficient to persuade a researcher stems from a naive view of science (Sect. 8a). In reality, the facts are buttressed by support from authoritative papers in the field (Garfield 1989).

Other functions of citations are as a label for intellectual property (Merton 1957) and as a recognition of originality (Garfield 1989). The struggle for authority concerns scientific property rights. To achieve authority in a scientific field means that recognition for this authority must be extracted from one's competitors (i.e. other scientists working in the field).

Nonetheless, citation counts do need to be treated cautiously. They may be influenced by the total number of scientists active in a research area (Cohen 1980). Thus, scientists working in unfashionable areas of science (such as taxonomy) would be little cited compared to scientists active in cancer research. It has been suggested (Garfield 1988a) that citations themselves should be weighted - there is considerable difference between one citation in a footnote and 20 citations in one paper.

Despite these reservations, the number of citations and number of articles published are positively correlated (Cole and Cole 1967, Knorr *et al.* 1979; see also Table 3). Lifetime citation counts are becoming more commonly used in US universities in awarding tenure, promotion and salary increased (Kochen 1987).

Paradoxically, the ultimate compliment for a paper is zero citation rate. This comes about through obliteration by incorporation (Garfield 1989). Thus, nowadays no research physicist would cite works by Archimedes, Newton or Galileo.

10. MOTIVATING SCIENTISTS

What, then, can be done to boost the performance of scientists, especially at the start of their career and in midcareer? The clear conclusion that comes from this review of literature is that there is no single way of motivating scientists to publish more frequently and publish better quality. Both the personal qualities of a scientist and the scientific environment interact. What works for one scientist in one scientific environment will not apply to the same person in a different setting. Thus, the research administrator needs a certain finesse and good sense in deciding how to provide the conditions under which a particular scientist will thrive. Moderation is often the best approach - too little or too much of a factor can hinder productivity.

Each of the many personal, group and scientific environment factors with a role to play is considered in tern below.

a) Self-motivation

A satisfied need is not a motivator of behaviour. Thus, in Maslow's hierarchy, one can assume that physical needs (for air, water and food), safety needs and social needs (the need to belong) of scientists are satisfied. The next level - ego needs - seems the most unlikely to be completely satisfied. Self-worth (involving self-confidence, self-reliance, independence, personal achievement) and reputation (based on recognition, appreciation and respect shown by others) will usually be the most powerful incentives for a scientist to produce more and be more creative (risk-taking) (Lloyd 1966).

Self-motivation does not mean isolation from others but an independence of thought and confidence in one's own judgement (Pelz and Andrews 1976).

A positive feedback loop operates: scientists experiencing early success (e.g. in publishing a paper which is cited by others) reinforce their self-esteem and reputation. Such success should of course have practical consequences, with increased access to facilities and support, which makes production of further publications more likely.

b) Tension between interaction (communication) and independence (isolation)

Collegiality is an important process in scientific endeavour, as ideas cannot be born, nurtured or refined within a single mind (Fox 1983). Exchange of ideas therefore enhances productivity as it provides new ideas, information, helps detect errors and promotes competition and reward. Questioning of a scientist's ideas is needed to prevent intellectual sluggishness developing.

Planned contact (attendance and presentation of papers at meetings, workshops, seminars) is essential for rapid progress. Unfortunately, Pareto's Principle applies - only 20% of scientists attend 80% of seminars and 20% of the scientists present at a seminar provide

80% of the discussion. There is evidence that scientists exchanging information with few people outside their own groups tend to perform poorly (Pelz and Andrews 1976).

Furthermore, best performance does not necessarily occur when scientists are left to make their own decisions (Haraszthy and Szanto 1979). Some form of time pressure is necessary to stimulate achievement (Pelz and Andrews 1976): Ivory Towers are not the best habitat for achievement.

Pelz and Andrews (1976) have argued that the creative tension between challenge (i.e. disruption of established patterns) and security (i.e. assurances of stability and continuity) is essential for good performance. Independence/self-reliance is the prime source of security and interaction with colleagues is the prime source of challenge.

The proportion of challenge to security varies with experience. Young scientists already face challenge because their work is new; they therefore need security. Older scientists already possess security and hence need challenge. By this argument, midcareer scientists have the best balance between challenge and security and so should be the most productive. Up to age 34, 2-3 yrs on a topic is sufficient to give security, whereas after age 40-50 scientists require more risks in their research. They show more interest in probing deeply into a subject.

It is possible that feedback may occur between security and challenge. High performers may expose themselves to contact and stimulation, thereby enhancing their achievement.

The tension between security and challenge was also highlighted in a different context by Kuhn (1970). He expressed it as a balance between systematizing knowledge and restructuring knowledge.

c) "Controlled freedom" - the balance between imposed organization and autonomy

Autonomy refers to the degree to which scientists can select their own research projects or be influential in this procedure, the amount of worktime made available for the pursuit of their own research interest, and their ability (either alone or with their immediate supervisor) to terminate projects (Box and Cotgrove 1968).

The dilemma for the research administrator is nicely illustrated by a mountain - climbing analogy (Pelz and Andrews 1976): There are many mountains to climb. The job of the research administrator is to show the scientist which mountain to climb, otherwise scientists may spend their time looking for mountains to climb or climbing the wrong ones.

A research organization must accomplish the objectives for which it is financed; this requires co-ordination of scientists towards specific goals without compromising the needs of individuals. It is important to satisfy the high desire for self-direction shown by high performers by allowing them to influence the choice of problem they work on. According to Box and Cotgrove (1968), dedicated scientists were more productive working under a high degree of organizational freedom. Organizational freedom made little difference to the productivity of scientists not dedicated, thereby implying that commitment to science is prerequisite for high productivity.

A loosely co-ordinated organization provides security but little challenge. Freedom to do what one wishes to may lead to specialization (in the sense of narrow interests), complacency, a tendency for individuals to isolate themselves from the stimulation of colleagues and even atrophy (Pelz and Andrews 1976). These factors tend to hinder achievement. In a demanding organization, a scientist has to solve problems important to the organization but is usually given the freedom to find the best solution.

As situations become looser, a high level of either inner motivation or external stimulation becomes increasingly important for high achievement (Pelz and Andrews 1976). In loose situations, autonomy inhibits performance, possibly because no one takes an interest and so the autonomous individual loses interest (Pelz and Andrews 1976). In contrast, where organizational freedom is low, high commitment will lead to dissatisfaction (Box and Cotgrove 1968).

At some point, research administrators usually end up giving proven mediocre scientists less autonomy, by assigning tasks. This action initiates a positive feedback loop, further limiting the chance of future growth. The wise administrator therefore needs to stimulate scientists by matching the challenge, the abilities of the scientist, and the freedom to pursue the challenge. This philosophy also serves to minimize typecasting of scientists.

Autonomy also tends to interact with resources (Meltzer 1956). Productive researchers are most productive under two conditions: high degree of autonomy followed by provision of ample resources; or plentiful resources followed by increase in autonomy. The converse situations (low freedom followed by an increase in resources; inadequate resources followed by an increase in autonomy) resulted in a little improvement in number of publications.

The lesson of this study is that the goal of research administration should be to supply adequate amounts of resources (needed to support research) and freedom (needed for motivation to produce).

Pelz and Andrews (1976) argue that the greatest productivity gains come from autonomy in moderately co-ordinated settings. Those scientists who do not withdraw into narrow specialization but keep an interest in a variety of research problems seem to benefit most.

d) Balance between disciplinary and practical concerns.

All applied scientists throughout their careers need to strive to better balance these factors - usually one is grossly underdeveloped (Busch and Lacy 1983). Practical concerns are of great importance in CALM, where the result of much of the research done should be to improve existing functions, develop greater economies, provide expert advice, protect assets and provide justification for particular functions.

e) Breadth of knowledge and interest - the balance between specialization and diversification

Scientists who have specialized in diverse areas tend to perform better (Pelz and Andrews 1976). This is not a matter of a little knowledge about a lot, but rather a good grasp of at least 3 areas of knowledge. However, the reason diversity enhances performance is not well understood (Andrews 1979) - possible explanations include acquisition of directly useful intellectual resources and indirectly useful skills; self guidance; security, allowing for the failure or completion of a project. All projects are unlikely to fail or be completed together.

The astute research administrator therefore encourages scientists to develop several specialized skills during the early years of their careers. An appropriate mix of short-term low risk research and more high risk research is also desirable (Busch and Lacy 1983). Pelz and Andrews (1976) found that even the best performers carried out 4 of the 5 R and D functions itemized in Sect. 3. In short, specialization (in the sense of a lot of knowledge about a little) is the "easy road in the intellectual journey of life" (Hutchinson 1944).

f) Research groups

There are two contrasting vies of the purposes of research groups (Pelz and Andrews 1976). The conventional one is of a unit to which resources are provided so that scientists can conduct research. The other is of a forum for interacting scientists to stimulate each other to produce high quality research.

The question of optimal size of research groups was investigated by Cohen (1980) who concluded, on the evidence of numbers of publications produced, that there is no optimal size; publication rate per capita is independent of group size. This is unexpected as a priori the bigger the group, the better the productivity (because of shared equipment, ideas, common motivation) up to a point (too much talking and not enough thinking and writing, bureaucratisation, passiveness).

Andrews (1979) also showed that group publication productivity was largely explained by the productivity of individual members. In the Research Division of CALM, productivity of research programs seems to reflect the number of scientists in them (Fig. 2).

The fundamental issue is whether research by individuals or collaborative research in a group is more effective. An analysis by Stankiewicz (1979) produced the following conclusions:

- Given a high level of cohesiveness, the effectiveness of research tends to increase with group size, but there seems no evidence of an optimum. Nevertheless, a group of 3-5 scientists was proposed as a manageable unit.

- When cohesiveness is low, there is a strong decline in performance for groups of 7 or more scientists.

- The relationship between size and performance is strong in groups headed by leaders with long research experience. It is weak in groups headed by young leaders. These groups show a negative relationship between productivity and group size.

- In groups characterized by high levels of cohesiveness and/or directed by experienced leaders, group age (i.e. the time the group has been in existence) has little effect on performance.

It is more effective for a group to work on few projects, although there are data indicating that publication productivity of a group increases as the number of projects increases (Andrews 1979).

Studies by Wallmark (cited by Stankiewicz 1979) indicate a positive effect of increasing group size on performance but no evidence of an optimum. The improvement in performance is exponential - it was calculated that 50 scientists in a team is equivalent to 138 scientists working alone.

Groups decline in performance after several years, but less if members become cohesive and intellectually competitive. Group age (the average number of years each member had belonged) was optimal up to 16 months (Shepard 1956) or up to 4-5 years (Pelz and Andrews 1976). Pelz and Andrews (1976) hypothesize that groups offer a focal point for intellectual tension and playing off intellectual uncertainty against emotional security in order to maximise scientific achievement. Uncertainty is stimulated by the search for a better (or the best) solution to a problem and by group members offering different backgrounds and dissimilar approaches to solving a new problem and being free to express disagreement. Security is necessary for scientists to wish to pursue the search for new solutions to a problem.

The prediction of this hypothesis is that newly formed groups will experience considerable anxiety and uncertainty - these groups should benefit from conditions promoting reassurance. Longer established groups should be more secure and should benefit from conditions preventing certainty.

Groups with a strong degree of this intellectual tension showed the most usefulness after 4-5 years. Those with weak tension showed most usefulness during the first year (Pelz and Andrews 1976). As groups age, members become more isolated as groups meet less frequently. Cohesiveness peaked at 4-5 years. Liking for broad new areas declines from a maximum during 0-1 years. Older groups become more relaxed and show less rivalry, less hesitation about sharing ideas, and more interest in depth than breadth. The trick with managing old groups to ensure continued achievement is to see that they behave like young ones, particularly in maintaining the energy of young groups.

g) Rewards, incentives and recognition

First rate work should be handsomely rewarded, but in what form? First, there is promotion, entailing increased salary and possibly provision of larger office/laboratory, new title, assistant staff and more research funds. Promotion follows largely when the goals most valued by the organization have been achieved. The second type of reward - papers published, citations, prizes and honours - is more related to the scientist's commitment to science.

Although rewards should be commensurate with achievement, "recognition, far more than money, is what makes the scientific world go round" (Garfield 1989). Apart from recognition by colleagues, the other major reward consists of research administrators providing more challenges.

Box and Cotgrove (1968) provide an extensive list of rewards sought by scientists, in no particular order:

- Higher salary
- More free time
- More support personnel
- More research funds
- Better promotional prospects
- Opportunity to referee outputs of peers
- More influence in choosing projects
- Improved condition of laboratories
- More influence over hours of work
- More influence in deciding when projects are terminated
- More attention taken by management of suggestions
- More prestige and status
- More influence in long term planning of own research
- More opportunities to attend scientific meetings
- Invitations to present papers at conferences
- Better opportunities to associate with executives
- Less supervision

- More use of the scientist's capabilities and skills
- Assignment of more challenging problems
- Solving important problems first
- Satisfaction of personal curiosity
- Satisfaction of meeting organizational goals

There do not seem to have been any studies of the relative importance of these rewards, though there can be little doubt of a hierarchy.

Extrinsic rewards, such as increased salary, more responsibilities and better opportunities to associate with top executives, cannot be relied upon to motivate achievement (Pelz and Andrews 1976). But, when achievement occurs, these extrinsic rewards should be consistent. Financial rewards can become an irritant when staff are treated uniformly with no distinctions for performance (Lloyd 1966).

Box and Cotgrove (1968) suggest that simply being allowed the time to take work to the point where it is publishable is an important reward. Scientists should not be expected to pursue a new problem as soon as one has been concluded.

The only adverse comment found about rewards was that organizational rewards tend to create dependence (Pelz and Andrews 1976).

h) Leadership

The essence of leadership is in the promotion of conditions which help scientists to achieve. Good management is one of the reasons some research groups show higher levels of performance than others (Andrews 1979). Able leaders create the challenging environment in which low achievers cannot but do better.

Over the last few decades the idea of management by control has been largely replaced by participative management. The logic behind this move is well summarized by McGregor's Y theory (1960):

- Management is responsible for organizing the factors of production, such as ideas, money, materials, and people.
- People are not by nature passive or resistant to organizational objectives. (They may have been made to behave in a passive or antagonistic way because of poor management procedures).

- The potential for development of competence, the motivation for constructive activity, the capacity for assuming responsibility, and the willingness to direct behaviour towards organizational goals are all present in people. (Management can thwart or encourage these factors).

- The essential task of management is to arrange the organizational structure and rules so that staff can achieve their own goals best by directing their own efforts towards the goals of the organization. (Management can help staff resolve any conflict between personal goals and organizational goals).

Thus, good leadership, involving stimulation, planning, co-ordination and evaluation of peers and subordinates is indispensable if participative management is to be effective. Good leadership should result in good morale, which is essential for increased effort and therefore higher productivity. The leader, through high technical performance and personal motivation, sets an example for others to follow (Lloyd 1966). The leader encourages all group members to participate in the management of the group.

Hammel (1980) summed up the situation succinctly: Little can be done to affect the least productive, and nothing need be done that could affect the most productive. The scientists in the middle who offer a good deal are a good target for efforts to increase productivity.

It is particularly important that leadership both prods young scientists into early achievement and pushes its visibility and recognition (Pelz and Andrews 1976). This gives the young scientist a solid foundation for success. Leadership also needs to facilitate communication with supervisors and peers. The former assures organizational relevance and the latter scientific relevance (Pelz and Andrews 1976).

Leadership should also provide challenge and security. Security is encouraged when scientists can publish, have near autonomy in choice of project, can spend 2-3 years on a project, have the opportunity to influence their leader, and are able to work in a cohesive group (Pelz and Andrews 1976). Challenge is encouraged by allowing frequent contact with colleagues, periodic regrouping of teams, and encouraging diverse interests and research on more than one project.

Stankiewicz (1979) indicates that productivity of scientists is above average when the leader of a research group spends more than one third of his/her time consulting with the group. Without this time commitment, management problems will arise and persist. Two of the most serious occur when staff (particularly junior scientists) hesitate to argue scientific matters with senior staff, including the leader. Worse still, junior scientists may agree even if they don't really (Lloyd 1966).

Two basic leadership types are recognizable (Stankiewicz 1979). The first contributes to the total effectiveness of the group through their own individual effort - this type exerts little influence on the group members. The other type of leader mobilizes and directs the resources of the group as a whole. The time that the group has been in existence should also influence the leadership type required. In new groups, the leader needs to help with ideas and be careful with criticism and judging. In old groups, the leader need only act as a neutral sounding board.

The leader's dilemma is how to inspire scientists to work to organizational goals. Insistence that they tackle assigned problems may reduce their enthusiasm. Freedom to pursue their own goals may result in their addressing goals irrelevant to the organization. Furthermore, the complete protection of scientists from administrative duties is mistaken (Pelz and Andrews 1976). It is also erroneous to give maximum autonomy and a minimum of distractions to scientists at midlife, as they may vegetate.

Good leaders provide their best staff with sufficient funds to solve important problems (Busch and Lacy 1983). Allocation of resources should be related to performance, otherwise the advance of science is obstructed (Fox 1983). The modern trend for scientists to become opportunistic research entrepreneurs is wasteful of much time and effort - Busch and Lacy (1983) argue that formula funding is the most efficient way to provide adequate continuous research support.

The "shotgun" approach to research by some leaders was criticized by Busch and Lacy (1983) on the grounds that it results in too many projects being undertaken. Most of these projects are understaffed and under-funded.

To be effective, leaders need to know the technical details of subordinates' research, for otherwise it is very difficult to critically evaluate and influence the research goals of subordinates. Especially important is the formulation of a research problem - this process effectively limits the range of acceptable solutions. Leadership is needed to help scientists select projects of significance (Busch and Lacy 1983).

Research leaders should often play the role of "honest broker" in bringing together scientists and interested users, particularly those willing to rapidly adopt new technologies (Busch and Lacy 1983).

Research leaders also need perspicacity in considering the problems 5-20 years ahead. The alternative is to be solely preoccupied will immediate results, with attention focused on "bushfires" and other pressures of the moment.

11. RECRUITMENT

In many organizations, the only way that new directions can be achieved is through the appointment of new staff (Busch and Lacy 1983). It is clearly imperative that good judgement is required if high performers are to be recruited.

It has long been known that the earlier a scientist publishes, the more productive is that scientist's career (Meltzer 1949). Unless a person achieves a qualitative piece of research during the first 5 years, it seems unlikely that person will do so during the next 5 years, or at any time during that person's career (Lightfield 1971). The presumed reason is that publishing early reflects competence, curiosity, self-confidence and involvement (Pelz and Andrews 1976). Early success then reinforces these qualities, leading to continuous rewarding and cumulative advantages (Fox 1983).

It is more difficult to decide whether quality of graduate school can predict future productivity (Fox 1983). However, according to Trimble (1989), graduates of the more prestigious US universities tend to publish longer than those from other universities.

Most scientists do not alter their ideas, approaches and commitments after graduating (Fox 1983).

12. ATTITUDES OF SCIENTISTS IN RESEARCH DIVISION OF CALM ABOUT THE ASSESSMENT OF SCIENTIFIC EXCELLENCE, EFFECTIVENESS AND PRODUCTIVITY

a) Preamble

One of my duties is, on behalf of RDGP, to develop criteria for measuring and assessing Research Division's efforts in fostering scientific excellence.

Currently, the only way in which research performance in Research Division is assessed is by subjective supervisor and peer review. It is proposed to supplement this with more objective means, including frequency of publication, frequency of SCI citations, invitations to present papers at conferences, success in obtaining external grants, and service on important committees. However, the danger is that an objective scheme in the hands of bureaucrats could have unforeseen and unintended consequences detrimental to Research Division. Yet it needs to be repeated that accountability is a feature of modern corporate management.

The only formal rating scheme in Australia that I am aware of is that used by CSIRO Wildlife and Rangelands Division (Appendix 1). Scientists scoring high on this scheme receive more research funds than scientists scoring low. However, this procedure does not appear to rate the importance of the topic being researched.

b) Previous analysis of research productivity in CALM

Per Christensen in November 1986 calculated and collated statistics for the mean number of publications per year for scientists in the Wildlife Research and Forestry Research Groups in CALM (as they were then known) and for comparable University Departments (Agronomy, Botany, Soil Science and Plant Nutrition, and Zoology at UWA).

The proportion of scientists publishing at least one paper per year was 35% in CALM and 73% at UWA. The median number of publications/year was 0.65 in CALM and 2.0 at UWA.

The conclusion to be drawn from this comparison is that, even though CALM scientific staff do no teaching, they produce only one third as many publications as staff in the four UWA Departments included in the survey.

c) Present analysis of CALM research productivity

In 1988, I collated publication lists for each scientist for the period 1981-6 inclusive, extracted citations to these papers from SCI for 1985-7 inclusive, and with the help of David Ward looked at correlations between 6 other factors and number of publications and citations.

I than discussed this information and other matters individually with the 51 scientists then in Research Division.

i) CSIRO Wildlife and Rangeland Research Accountability Procedure

The first issue discussed was whether CALM Research Division should adopt the CSIRO scheme. The possible benefit of this was that Research Division could then compare itself with at least one CSIRO Division, more comparable to CALM than any University Department.

34 scientists did not support use of this scheme by CALM Research Division. 17 did support it.

ii) R.A. Leary's framework for assessing research productivity

I adapted the model of Leary (n.d.) (Fig 3) to suit CALM, specifically in defining generality to apply principally to this state and by including application of research results (Fig. 4). Discussion soon resulted in improvements, the main one being that Application of the Research was better treated as a third axis as it was quite separate from evaluating the difficulty of solving a problem (Fig. 5).

The way in which I envisaged this scheme being used was that each scientist would decide where each of their papers published in the last few years titled in Fig 5. The summed points (Some examples are shown in Table 2) could then be used as a measure of how well each scientist's publications were serving both CALM and the Research Division's objectives.

46 scientists supported the concept of this scheme. Only 5 opposed it.

This scheme is not intended to apply to the members of the Research Computing and Research Methods programs and possibly certain members of the Herbarium program who are not expected to publish.

iii) Some factors affecting numbers of publications and citation.

I also presented an analysis based on numbers of publications and citations for the 51 professionals in Research Division in relation to several easily measured factors (Table l) - age, highest qualification, year in which this was attained, status (current level inJ State Public Service hierarchy), and numbers of committees attended.

Spearman correlation coefficents were computed for every pair of variables. Most proved to be significant (Table 3). Total number of publications and total number of citations were positively correlated, as was total number of publications and total number of committees. Perhaps this latter reflects basic "drive" and commitment (of Sect. 8). I had expected an inverse relation between committee load and publications produced .

A profile of professional members of Research Division shows that the median number of publications produced in the 6 year period is 5-6 (cf. Sect 7). The median number of citations is disappointingly low, at 1-2 for a 3 year period.

The applicability of citation counts to taxonomists (most scientists in the Herbarium program) is questionable, reflecting the current low regard in which taxonomic research is held worldwide. Perhaps the number of valid descriptions of taxa is a more relevant metric.

13. OBTAINING HIGHER PUBLICATION RATES

There are several ways this can he achieved, though there is a trade-off between quantity and quality of publications.

i) More thoughtful formulation of hypothesis under test. Is the hypothesis testing what it is supposed to test? A problem incorrectly stated will lead to collection of data useless to address the intended problem. Thorough knowledge of current literature is essential.

ii) More efficient methods of collecting data. There is an optimal number of cases that need consideration, beyond which time, effort and money are wasted in collecting further data.

iii) Striving for a better balance between routine, simply solved problems and difficult but important problems. It is good tactics to research some problems soluble in the short term while working on a long term problem. It is too risky to put all eggs in one basket.

The RPP guidelines are intended to ensure that points i) and ii) are properly addressed by scientific staff.

14. OBTAINING HIGHER CITATION RATES

Other things being equal, good science should be more cited than poor science. But other things are not equal. Chief among these is the "impact factor" of scientific journals, but author's reputation, controversial nature of the paper, circulation of the journal, cost of the journal, its coverage by indexing services, and the number of scientists in the discipline should not be disregarded.
The "impact factor" is a measure of the frequency with which the "average article" in a journal has been cited in a given year. It is the ratio citations published/citable items.

The impact factor tends to discount the advantage of large journals over small ones, of frequently issued journals over less frequent ones, and of old journals over newly established ones.

The impact factors of relevant journals contained in the SCI Journal Citation Reports are organized by broad topic (Table 5). None of the CALM serials are included in the SCI list but all of the CSIRO/Australian Academy of Science journals are included.
The implications of this table are manifold:

- Publish as much as possible in high impact journals.

- They are harder to get into because the number of MSS submitted vastly excess what each can publish. Being published in such journals in itself is a mark of distinction.

- It is a regrettable fact that most scientists do not put sufficient effort into thorough literature searches. It is far easier to examine a recent issue of a high impact journal in order to find a start than systematically search through thousands of tomes of obscure journals. This partly explains why many good papers published in low impact journals are never cited.

- Although a paper in a high impact journal will be more visible to the scientific world, this is no guarantee that it will make an impact.

- Prospective authors therefore need to be sensible in selecting journals to publish in. It is a waste of time to attempt to publish parochial matters (even though of good science) in Nature. The hierarchy international/national/local/CALM needs careful evaluation. It is an equal waste of effort to publish material of international or national significance in CALM or WA journals.

- At least once in their career, scientists must write a good review of the research topic in which they have been most active. Such reviews should be selective rather than encyclopaedic. The most useful ones outline the current state of an active area, identify areas of agreement and of conflict, and indicate approaches which might be worthwhile pursuing in order to solve the key problems (Garfield 1988a). Good reviews will always be useful to others, and hence be well cited.

15 . CONCLUSION

There are several lessons from this review that bear on the improved management of Research Division.

1. Research Division is remarkably free of bureaucratised procedure, with only two forms in existence (Research Project Plan; Approval for Publication). These procedures serve to ensure that all research is conducted alòng the lines approved in the RPP and that research submitted is of a high standard and checked for policy implications.

   However, Part 10 of the current Research Plan implies that only half of the programs are working to newly approved RPPs. This indicates an imbalance between imposed organization and autonomy.

2. More research should be conducted in better integrated teams of scientists and technicians. In this way scarce resources are marshalled and focussed on the most important research problems. The current Research Plan lists 488 projects in the 12 research programs. Application of the Pareto Principle indicates that these could be reduced to 98, giving a decrease in average number of projects/scientist from 11 to 2. The money and time spent on the other 80% of current projects would be better directed to the most important problems. (The scheme outlined in Fig. 5 may be helpful in deciding priorities).

3. The role of program leaders should be re-assessed. At present the view of RDPG is that PLs fill short term positions because administrative duties are seen as a chore. The proper role for PLs is as manager/mentor; consequently RDPG should be developing leadership skills in competent scientists and making better use of the many Level 7 scientists.

4. More rigorous methods for evaluating scientific productivity need to be introduced and incorporated into the annual appraisal. The present scheme is highly subjective and takes no account of modern performance indicators such as citations. This is not to say that there should no longer be any room tor judgement, but clearly everyone benefits by knowing what the judgement is based on and how it was arrived at. After all, teachers and lecturers long ago abandoned subjective assessment of their students.

5. Faraday's 1821 dictum ("There are 3 necessary stages of useful research: the first to begin it, the second to end it, and the third to publish it") needs to be more seriously observed by scientists. Where necessary, RDPG should take action, including withdrawal of research funds and technical assistance until publication backlogs are overcome:

6. RDPG should be more involved with scientists in the selection of journals to which papers are submitted.

7. RDPG should promote awareness of the benefits of time management and arrange for the attendance of all staff at appropriately designed courses.

8. RDPG should ask scientists for their preferences concerning reward systems.

9. RDPG should consider rewarding scientists showing high productivity (using the extra resources made available under item 5).

10. In the areas of publication and application of results, RDPG should more often be aware of Havelock's dictum, quoted in Visart (1979): Who transfers what by what channel to whom and to what effect?

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Table 1. Publication productivity measures of Research Division scientists and other factors used for a correlation analysis

A	B	C	D	E	F	G	H	I	J	K	L	M	N	O	P	Q
47	3	72	7	3	2	7	5	4	9	11	3	34	35	30	39	99
56	3	87	3	0	0	0	0	0	0	0	1	0	0	0	1	0
46	1	67	7	10	0	0	1	0	1	0	0	3	1	1	2	5
58	1	81	5	0	0	0	0	0	0	0	0	0	0	0	0	0
60	1	81	5	3	0	0	0	0	0	0	1	0	0	0	1	0
42	3	68	9	16	1	4	3	13	4	1	1	0	5	0	26	5
50	3	86	5	1	1	1	3	0	1	2	2	0	1	0	9	1
54	1	76	6	2	0	3	0	0	2	2	1	0	0	0	8	0
45	1	66	6	1	0	0	0	0	1	0	1	0	1	0	2	1
40	3	76	8	5	0	4	2	0	2	6	1	3	23	9	15	35
53	3	79	6	1	0	2	3	2	2	3	1	7	7	3	13	17
56	3	83	4	0	0	0	0	0	1	2	1	1	1	2	4	4
42	3	67	6	0	0	1	1	3	0	3	2	2	4	5	10	11
55	3	86	3	0	0	0	0	0	0	0	0	0	0	0	0	0
52	3	78	6	1	0	3	2	0	5	3	1	4	1	1	14	6
51	3	81	6	2	0	1	3	2	1	1	1	2	2	5	9	9
57	2	78	3	1	0	1	2	0	0	0	0	1	1	1	3	3
55	3	82	6	3	0	3	1	2	2	5	4	0	2	3	17	5
63	1	86	3	0	0	0	0	0	0	0	0	0	0	0	0	0
48	2	74	6	6	1	6	2	4	5	4	3	1	0	1	24	2
51	3	78	8	11	1	7	1	7	3	2	4	21	17	14	33	52
59	2	85	3	3	0	0	0	0	0	0	0	0	0	0	0	0
50	2	71	6	1	0	20	30	15	24	5	7	10	4	3	101	17
45	1	73	6	3	5	12	4	5	3	3	5	0	0	0	32	0
33	3	70	6	0	0	0	0	1	1	1	0	5	9	5	3	19
48	2	72	6	2	0	1	0	1	0	3	1	0	0	0	6	0
50	1	71	7	4	1	3	2	1	0	1	1	0	0	0	8	0
39	3	70	7	0	0	5	2	2	2	1	3	1	0	1	15	2
46	2	77	7	2	0	2	7	5	3	4	0	3	6	3	21	12
59	1	84	4	0	0	0	0	0	0	0	0	0	0	0	0	0
58	2	79	5	3	0	0	0	1	0	0	1	0	0	0	2	0
53	3	80	6	5	0	1	2	5	3	0	5	7	2	2	16	11
55	3	82	6	2	0	0	0	0	4	0	0	2	5	0	4	7
45	2	76	6	1	0	6	1	15	3	0	2	0	0	4	27	4
51	1	74	6	3	1	1	1	1	1	1	2	0	0	0	7	0
53	2	81	5	5	0	3	0	1	2	2	0	2	1	1	8	4
44	2	66	5	0	0	1	1	0	0	0	0	0	0	0	2	0
62	2	83	4	0	0	0	0	0	0	0	0	0	0	0	0	0
43	2	80	6	3	0	1	0	1	0	0	3	0	0	0	5	0
42	3	78	6	4	0	1	0	1	3	2	2	0	0	0	9	0
51	2	73	5	0	0	1	0	0	0	0	0	0	0	0	1	0
52	3	80	5	0	0	1	3	2	2	0	0	1	1	0	6	2
45	3	75	6	4	0	1	1	1	1	2	0	13	9	7	6	29
42	3	74	7	5	0	2	0	2	1	0	0	1	2	0	5	3
46	3	74	7	3	0	1	0	3	0	0	2	2	2	0	6	4
57	1	80	5	6	1	0	0	0	0	0	3	0	0	0	3	0
51	2	74	5	0	0	0	1	0	1	0	0	0	0	0	2	0
49	3	79	6	1	1	3	5	3	2	2	1	1	22	15	16	38
57	2	85	5	1	0	0	0	0	1	0	2	0	1	0	3	1
44	2	65	5	0	0	0	0	0	1	0	0	0	0	0	1	0
28	2	66	7	3	0	1	2	2	1	1	1	0	0	2	8	2

Table 1 (continued)

Explanation of columns

A	Year of birth (19_)
B	Highest degree (1=Bachelor, 2=Bachelor (Hons) or Masters, 3=PhD)
C	Year in which highest degree was attained
D	Current level in State Public Service Hierarchy
E	Committees - internal and external representing CALM
F	Committees - relevant external but non Departmental
G	No. publications in 1981
H	" in 1982
I	" in 1983
J	" in 1984
K	" in 1985
L	" in 1986
M	No. citations in SCI in 1985
N	" in 1986
O	" in 1987
P	No. publications 1981-6 inclusive
Q	No. citations (SCI) 1985-7 inclusive

NB * Publications includes scientific papers, reports, SWANS, Forest Focus or Landscope articles. Excluded are book reviews, abstracts and conference proceedings.

* Citations excludes self-citations and citations to unpublished work, including theses. Citations to papers in which the author is not first author are not included.

* Staff of the Research Computing and Research Methods programs are excluded from analysis as their duties do not require them to write papers. They help others write papers.

Table 2. Some worked examples of the Index defined in Fig. 5.

		Axis		Index
	A	B	C	(A + B + C)
1 A list of plant species on Reserve x	1	1	2	4
2. A list of plant species in all reserves in Kimberley Region	8	1	8	17
3. Measurement of impact of a pest insect on jarrah wood increment	2	4	8	14
4. A method of controlling fox numbers on CALM land	2	8	8	18
5. Flora writing - South Coast Region	8	2	4 or 8	14 or 18
6. Fire behaviour in Triodia desert	2	8	8	18
7. Revision of genus *Acacia* in WA	4	2	4 or 8	10 or 14
8. Revision of genus *Trymalium* in WA	4	2	2	8

Table 3. **Half-matrix of statistically significant correlation coefficients (Spearman) between the variables listed in Table 1. Blank spaces represent coefficients with P>0.05. Symbols as in Table 1, except for X (=E+F).**

	A	B	C	D	E	F	G	H	I	J	K	L	M	N	X	P	Q
A																	
B	-.28*																
C	.77#																
D	-.70+	.25*	-.60+														
E				.57+													
F				.28*	.41#												
G	-.45+	.24*	-.36#	.64+	.39#	.42+											
H	-.33#	.26*	-.28*	.46+		.43+	.67+										
I	-.46+	.32#	-.34#	.63+	.37#	.33#	.71+	.59+									
J	-.33#	.35#		.54+	.32#	.27*	.66+	.58+	.55+								
K	-.33#	.31*		.49+	.26*	.34#	.69+	.56+	.47+	.58+							
L				.40#	.37#	.45+	.51+	.33#	.53+	.38#	.43+						
M		.52+		.45+			.38#	.44*	.41#	.50+	.44+						
N	-.25*	.61+		.49+	.23*		.34#	.45+	.41#	.49+	.46+		.80+				
O	-.30*	.45*		.44+			.48+	.54+	.51+	.48+	.60+	.25*	.75+	.68+			
X				.58+	.98+	.54+	.44+	.24*	.40#	.36#	.30*	.42+					
P	-.47+	.38*	-.30*	.69+	.42+	.44+	.89+	.75+	.81+	.80+	.75+	.66+	.48+	.50+	.60+	.47+	
Q	-.33#	.61+		.56+	.25*		.47+	.55+	.53+	.61+	.52+		.87+	.93+	.86+	.24*	.63+

* $P<0.05$ # $P\leq0.01$ + $P\leq0.001$

Table 4: Profile of professional members of Research Division (N = 5l). Excluded are members of the Research Computing and Research Methods Programs (N = 4) whose duties do not require them to write papers.

	Percentile		
	25	50	75
Year of Birth	1944-45	1950	1955
Highest degree	Bachelor	Bachelor with Honours or Masters	PhD
Year attained	1972	1977	1980-1
Level	4	5	5
No. committees (internal + external representing CALM)	0	1	3
No. committees relevant external but non CALM)	0	0	0
No. publications 1981	0	0-1	2-3
No. publications 1982	0	0-1	1-2
No. publications 1983	0	0-1	1-2
No. publications 1984	0	0-1	1-2
No. publications 1985	0	0	1-2
No. publications 1986	0	0-1	1-2
Total publications 1981-6 inclusive	1-2	5-6	14-15
No. citations 1985 SCI	0	0	1-2
No. citations 1986 SCI	0	0	1-2
No. citations 1987 SCI	0	0	2-3
Total citations 1985-7 inclusive	0	1-2	6-7

Table 5. Impact factors of relevant journals in SCI list

Botany		
	Adv. Bot. Res.	4.875
	Bot. Rev.	4.105
	Ann. Rev. Phytopathol.	2.762
	Phytopathol.	1.536
	New Phytol.	1.426
	Vegetatio	1.083
	Syst. Bot.	0.970
	Taxon	0.947
	Can.J.Bot.	0.923
	Aust.J.Bot	0.738
	Plant Dis.	0.637
Ecology		
	Adv. Ecol. Res.	7.600
	Ecol. Monogr.	4.231
	Ann. Rev. Ecol. Syst.	4.182
	Evolution	2.835
	Ecology	2.784
	Amer. Nat.	2.607
	Wildl. Monogr.	2.500
	J. Anim. Ecol.	2.293
	J. Ecol.	1.776
	Oecologia	1.614
	Oikos	1.607
	J. Biogeogr.	1.057
	J. Appl. Ecol.	1.026
	Aust. J. Soil Res.	0.735
	Pedobiologia	0.714
	Aust. J . Ecol.	0.691
	J. Wildl. Mgt	0.632
	Biol. Cons.	0.612
	Rev. Ecol. Biol. Sol.	0.200
Entomology		
	Ann. Rev. Ent.	3.333
	Ecol. Ent.	1.402
	Ento.exp. appl.	1.043
	Bull. Ent. Res.	0.899
	Env. Entomol.	0.748
	Ann. Ent. Soc. Amer.	0.663
	J. Econ. Ent.	0.662
	J. Aust. Ent. Soc.	0.304
	J. Appl. Ent.	0.183

Forestry	Can. J. For. Res.	0.916
	Silvae Genet.	0.690
	For. Sci.	0.563
	Wood Sci. Technol.	0.516
	Eur. J. For. Pathol.	0.509
	For. Ecol. Mgt	0.385
	J. For.	0.366
	Aust. For. Res.	0.247
Marine/Freshwater Biology	Mar. Ecol. Progr. Ser.	1.867
	Adv. Mar. Biol.	1.857
	Mar. Biol.	1.484
	J. exp. Mar. Biol. Ecol.	1.274
	Coral Reefs	0.960
	Aust. J. Mar. Fr. Res.	0.805
	Hydrohiol.	0.641
Multidisciplinary	Nature	14.999
	Science	14.304
	PNAS	9.384
	Bioscience	1.867
Ornithology	Auk	1.507
	Ibis	0.990
	Condor	0.837
	Emu	0.612
Zoology	Wildl. Monogr.	2.500
	Syst. Zool.	2.475
	J. Zool.	0.786
	Mamm. Rev.	0.700
	Copeia	0.698
	J. Mamm.	0.671
	J. Herp.	0.406
	Aust. J. Zool	0.372
	Aust. Wildl. Res.	0.330
	Mammalia	0.190

Figure captions

1. Frequency distribution of (a) publications 1981-6 inclusive and (b) citations 1985-7 inclusive for CALM Research Division scientists.

2. Productivity of research programs in CALM Research Division in relation to number of permanent professional staff. The two lines represent the line of equality (one publication or report per scientist per year) and the line of best fit to the data.

   B=Biogeography
   EX=Executive and Admin Support
   FA=Fauna Conservation
   H=Herbarium
   R=Rehabilitation
   WU=Wood Utilization
   E=Entomology
   FI=Fire
   FL=Flora Conservation
   P=Plant Diseases
   S=Silviculture

   Data extracted from the 2nd and 3rd editions of the Research Division annual Research Plan

3. Framework for evaluating the research productivity of scientists, as proposed by Leary (n.d.)

4. Leary's framework for evaluating research productivity of scientists, adapted for CALM Research Division - 1988 proposal.

5 Refinement of Fig. 4, following discussion with all Research Division scientists in 1988.

APPENDIX 1

DIVISION OF WILDLIFE & RANGELANDS RESEARCH RESEARCH ACCOUNTABILITY PROCEDURE

The criteria and the procedure used in determining the research accountability ratings of scientific staff for this year were as follows:

1. Scientific Publications (SP score)

- past five years only (i.e. 1981 -)
- publications judged by the committee to be "popular articles" were excluded, and considered instead under "Communications".
- rating. Scientists own evaluation of their publications from 1 (minor significance) to 3 (major paper) were altered by the committee only where necessary. Benefit of the doubt was mostly granted, but some changes were made (both up and down)
- joint authorship. The publication score was divided by the number of scientific staff authors (including outside scientists), and an extra 0.5 was given to the first author
- books:

i)	Author	- a maximum of 15 for a substantial, original work (not just a review). Joint authorship allocated as for papers
ii)	Editor	- maximum of 3
iii)	Full chapter	- as for a scientific paper, but a maximum of 10 points per person for chapters in any one book
iv)	Species write-ups	- a score of 1 per write-up to a maximum of 5 for a set

- nature of the publication. Papers resulting from work which was done in the Division and which was not within the project on program objectives earned only 50% of the publication value
- score. The sum of the publication scores was placed into one of 21 classes (0-20) based on an equal class interval of 2.5 up to 45. Class 9 was 45.1 - 50, and class 10 was > 50.

2. Research Effect (RE score)

Determined as the sum of two component scores, each from 0-10 (therefore a maximum of 20).

i) Science Citation Index (excluding self-citations) The sum of the SCI's for 1984 and 1985 were placed into one of the following 11 classes (0-10)

0 - 0
1-5 - 1
6-10 - 2
11-20 - 3
21-30 - 4
31-40 - 5
41-50 - 6
51-75 - 7
76-100 - 8
101-150 - 9
>150 - 10

ii) Evidence for the effect on science, management or other application

- the case made by each scientist was evaluated independently by each of the three committee members
- emphasis was placed on the effect of the work done or published in the previous two years
- promise of future effect was not taken into account. Funding for potential value will be done by the Chief via this discretionary component of the budget
- very vague statements without any indication of evidence were downgraded, but again the principle of benefit of the doubt was used.

3. Communication (C)

- This should more correctly be called "Communication and Committments"
- Each scientist was considered in terms of involvement in official committments (committees and other necessary duties), general scientific committments, and involvement in communication
- Ratings were again made independently by the three committee members, and the scores were averaged
- Only the past two years of activities were considered
- Program leaders received a basic score of '6'. Those who are OIC as well received a '9', and those who were only OIC received a '7'.

4. New Staff

   For staff who received their PhD within the last 6 years, or who have been working as a research scientist for less than 6 years, the SP score was multiplied by 6/x, where x is the number of years since PhD or employment as a scientist.

   If x was ≤ 2, the scientist was not rated, and the program concerned was given instead the mean accountability score.

5. Although all staff have been assessed, those who are paid from non-appropriation funds have been excluded in the final analysis of the percentage scores used to determine budget allocation.

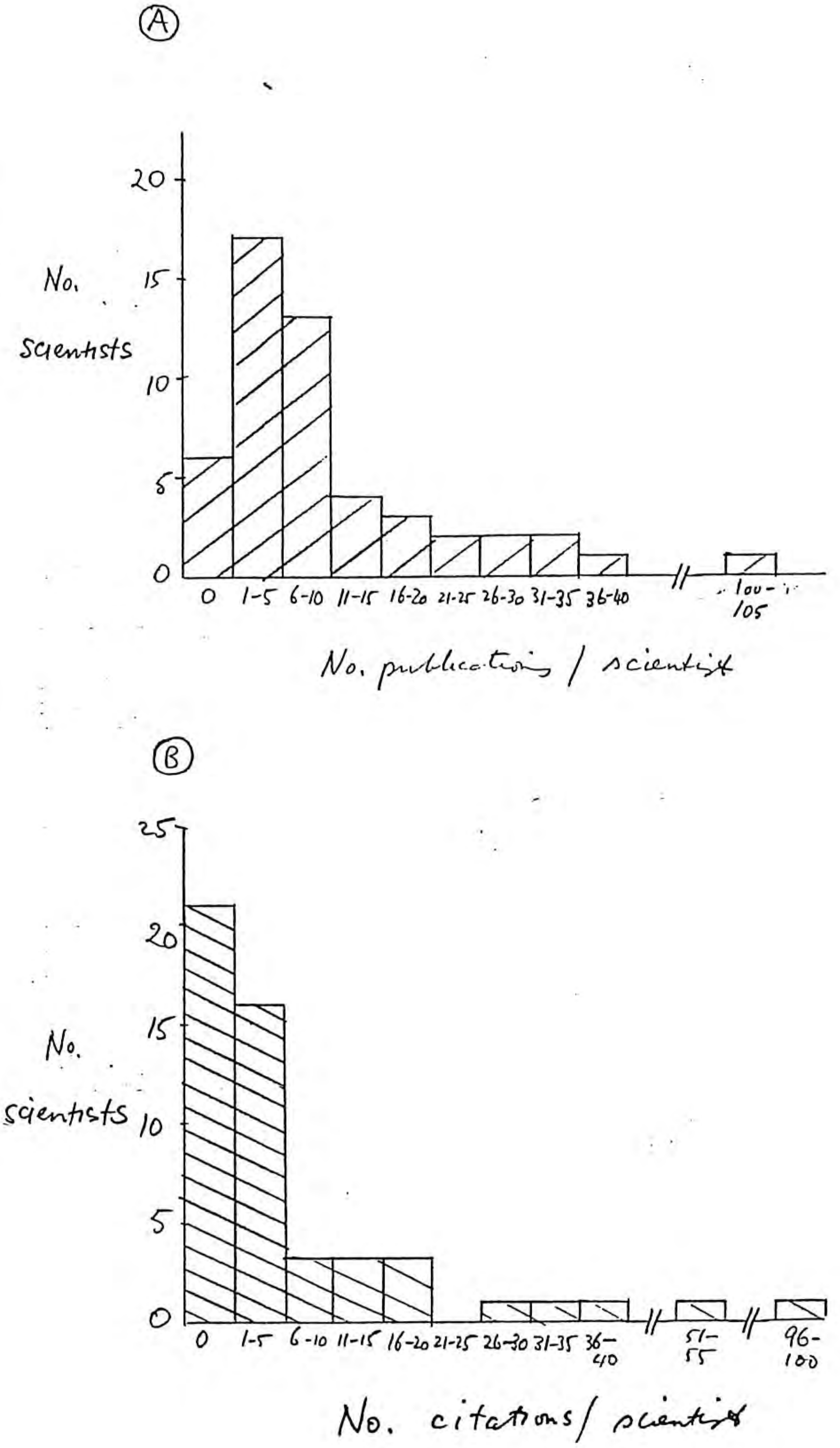
Ⓐ
No. scientists
20
15
10
5
0
0
1-5
6-10
11-15
16-20
21-25
26-30
31-35
36-40
100-105
No. publications / scientist
Ⓑ
No. scientists
25
20
15
10
5
0
0
1-5
6-10
11-15
16-20
21-25
26-30
31-35
36-40
51-55
96-100
No. citations / scientist

FIG. 1

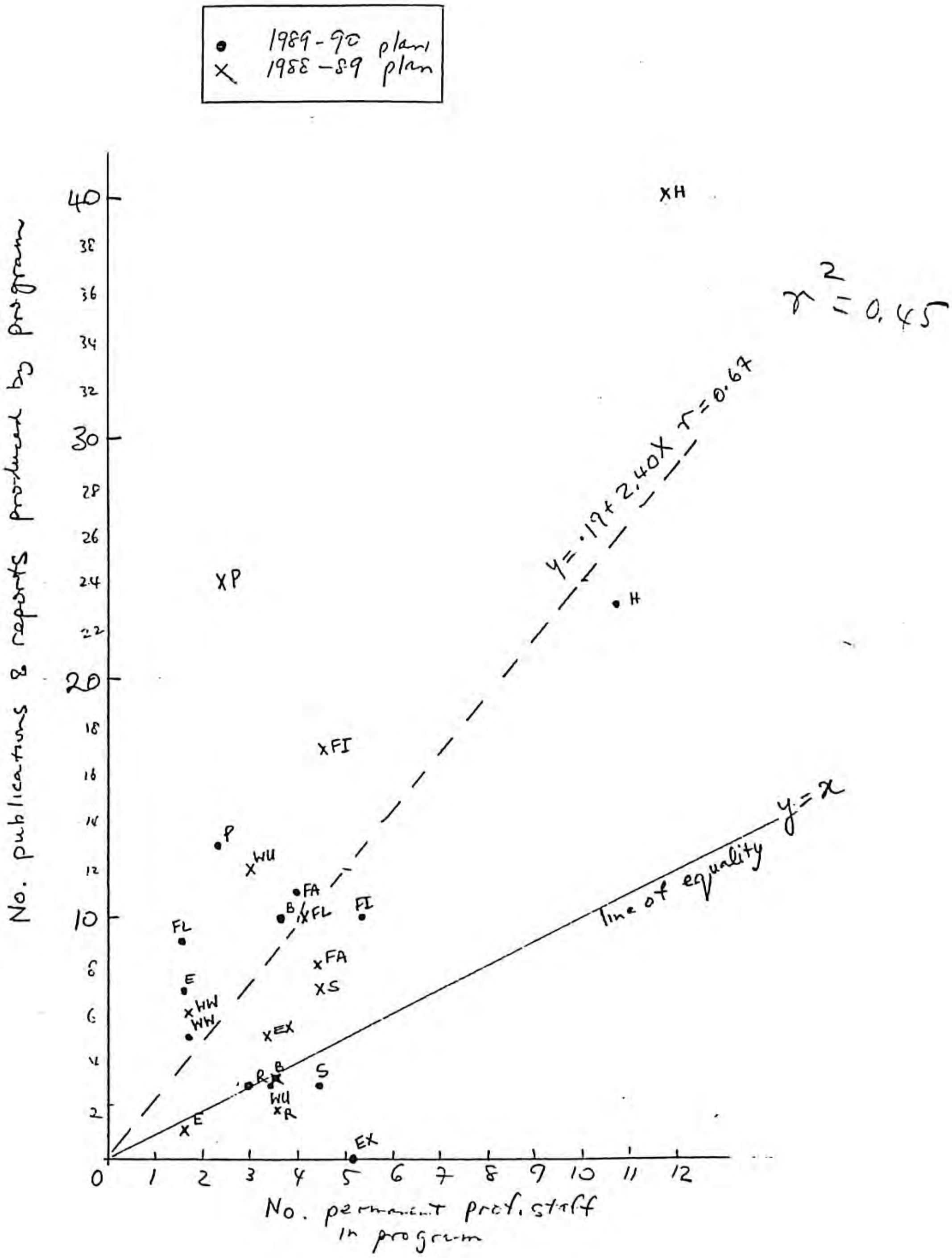

● 1989-90 plan
× 1988-89 plan
No. publications & reports produced by program
No. permanent prof. staff in program
0
1
2
3
4
5
6
7
8
9
10
11
12
2
4
6
8
10
12
14
16
18
20
22
24
26
28
30
32
34
36
38
40
y = .19 + 2.40X
r = 0.67
r² = 0.45
y = x
line of equality
XH
H
XP
P
XFI
FI
XWU
WU
FA
XFA
B
XFL
FL
E
XE
XHW
HW
XS
S
XEX
EX
R
XR
B

Fig. 2

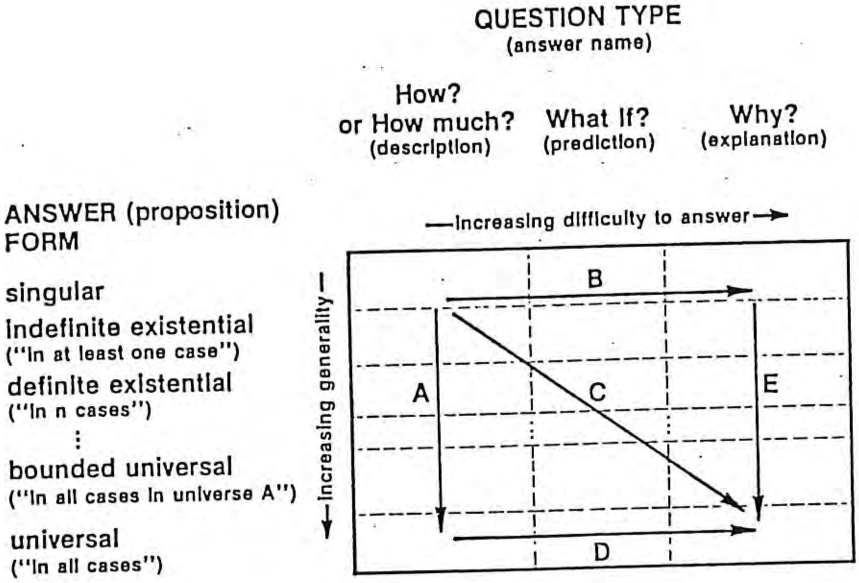

QUESTION TYPE
(answer name)
How?
or How much?
(description)
What If?
(prediction)
Why?
(explanation)
ANSWER (proposition) FORM
singular
indefinite existential
("in at least one case")
definite existential
("in n cases")
⋮
bounded universal
("in all cases in universe A")
universal
("in all cases")
—increasing difficulty to answer→
—increasing generality→
A
B
C
D
E

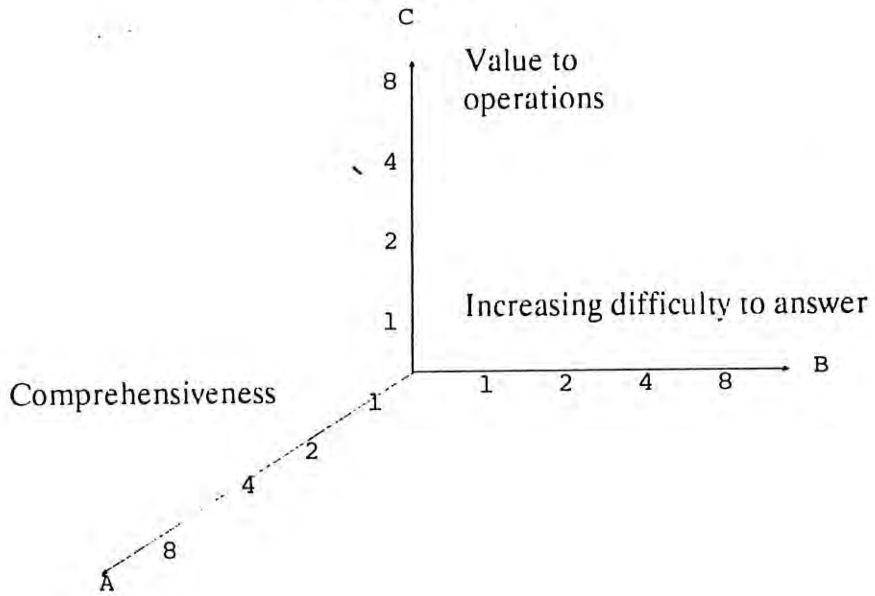
FIG. 3

FIGURE 4

Modified Leary system
for assessing quality of scientific publications

		1	2	3	4	5
Unique	1	1	2	3	4	5
In several cases in WA	2	2	4	6	8	10
In most cases in WA	3	3	6	9	12	15
In all cases in WA	4	4	8	12	16	20
In all cases in universe	5	5	10	15	20	25
		Qualit.	Quantit.	What if?	Why?	Value to mgt.
		How? How much? How many?				Results adopted by Operations
		DESCRIPTIVE		PREDICTIVE	EXPLANATION	EXTENSION

FIGURE 5



A
1 - involving research in one locality in WA
2 - involving research in several relevant localities in WA
4 - involving research in most localities in WA
8 - involving research in all localities in WA

B
1: Research is descriptive (qualitative)
2 Research is quantitative
4: Research is predictive (experimental or survey - answers question "What if?"; identifies new principles)
8: Research is explanatory (experimental - answers question "why?")

C
1: Research has/had no genuine value for Operations/CALM
2: Research could be/could have been useful to Operations/CALM
4: Research would be/was useful to Operations/CALM
8: Research is/was urgently required by Operations/CALM

Index = A + B + C
Minimum score = 3
Maximum score = 24