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From Formalin to Fortran

Basic Biology in Canada

By P.A. Larkin
and W.J.D. Stephen

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Some Facts and Futures about Basic Biology in Canada

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Larkin, Peter Anthony

B.A. (Governor General's Gold Medal), M.A. (Rhodes Scholar, Saskatchewan), D.Phil.

Born: 1924
Place: New Zealand

Employment
Chief Fisheries Biologist, B.C. Game Commission, 1948-55.
Director, Institute of Fisheries, UBC, 1955-63.
Director, Fisheries Research Board of Canada Biological Station, Nanaimo, B.C., 1963-66.
Professor, Department of Zoology and Institute of Animal Resource Ecology, UBC, 1966 to present.
Chairman, Fisheries and Wildlife Committee, Science Council of Canada. Co-author of this report on future of biology, 1970.

Publications
Numerous publications, chiefly in the fields of limnology, fisheries biology and population dynamics.

Other Responsibilities
Member of various professional associations.
President, B.C. Natural Resources Conference, 1954.
Chairman, Canadian Committee on Freshwater Fisheries Research, 1963.
Chairman, PM Subcommittee of the CCIBP.
Second Vice-President, Canadian Society of Zoologists, 1971.
Fellow of the Royal Society of Canada, 1965.
Nuffield Foundation Fellow, 1961-62.
Senate, UBC, 1966 to present.
Honorary Life Governor, Vancouver Public Aquarium.

Stephen, William John Douglas

B.S.A., M.S.A., Ph.D.

Born: October 9, 1930
Place: Sudbury, Ontario

Employment
Wildlife Biologist, Manitoba Department of Mines and Natural Resources, 1958-59.
Research Scientist, Canadian Wildlife Service, 1959-66.
Supervisor of Lands, Canadian Wildlife Service, 1966-69.
Science Adviser, Science Council of Canada, 1969-70.
Research Manager, Canadian Wildlife Service Edmonton, 1970 to present.

Scholarships and Awards
Toronto Anglers and Hunters Award, 1957.
Canadian Industries Limited Fellowship 1957-58.
Wildlife Management Institute Grant, 1958.

Publications
Author or co-author of 17 scientific and technical publications.

Other Responsibilities
Canadian Society of Wildlife and Fisheries Biologists.
Alberta Institute of Agrologists (Agricultural Institute of Canada).

Foreword

The need for a study on Basic Biology in Canada was originally seen by the Science Secretariat, who entered into a contract in July 1967 with the Biological Council of Canada and the Canadian Federation of Biological Societies to have this study prepared under their guidance and direction. This work was undertaken by the late Dr. Kenneth C. Fisher. Under Dr. Fisher's direction the study was broadened to "An account of Canada's activities towards generating knowledge about the fundamental biological processes upon which the production of food and fibre for her citizens depends and upon which their health depends and upon which the control of the natural environment required for her citizens' well-being also depends". The basic assessments were delegated to 30 panels, whose areas and membership are listed in Appendix 3 of this report. Dr. Fisher himself took on the monumental job of synthesizing the results.

When the Science Council obtained its own staff in November 1968 and a division of responsibilities was made between the Science Secretariat and the Science Council, the Council itself became responsible for the contractual arrangements with the two national biological societies, and through them with Dr. Fisher, for the study.

Dr. Fisher had just completed the first draft of his report and had reached agreement with the Council and with the two national biological organizations on the work remaining to bring his labours to a publishable conclusion, when we were all shocked and saddened by his sudden death.

As a result of a careful assessment of just where we were, the Committee of the Science Council charged with these matters, in consultation with the two national biological organizations, came to the conclusion that the 26 panel reports should be turned over to the two national organizations for duplication and distribution among the scientific community of biologists, in order that the wealth of relevant material in these reports would be generally available while it was still fresh.

It was regretfully realized that the draft of Dr. Fisher's report was so much a part of him that, while it was not publishable in its present form, it was not possible for anyone else to take it on and finish it in a manner that would have met the goals and emphases he had set for himself. It must therefore remain as an unfinished symphony of a man who through his work and leadership gave much to the field of the life sciences. His manuscript in the state that it was at the time of his death is in the archives of the Science Council for those who wish to consult it, and a bound copy has been presented to Mrs. Fisher.

The Science Council then decided that it would be best to return to the original concept of writing a report about those biologists principally found in university faculties of arts and science who, in the jargon of today, are frequently referred to as the uncommitted biologists, to differentiate between them and their colleagues found in faculties or government laboratories addressing themselves to agriculture, forestry, fisheries and similar problem areas. This report, then, was conceived as having quite a different goal from that set for himself by Dr. Fisher, and while initially it was thought that some of the statistical data assembled under Dr. Fisher's guidance could form a companion piece to this new report, this did not turn out to be practical.

The Council were fortunate in being able to attract Dr. Peter Larkin to tackle this new job. In this he was joined by Dr. Stephen, who had been the last of several science advisers associated with Dr. Fisher.

The results of the labours of Dr. Larkin and Dr. Stephen are embodied in this present report. The two authors had as source material the panel reports prepared under Dr. Fisher's guidance and Dr. Fisher's own draft, and recognition of this by them is contained in their introduction.

We hope this report will stimulate discussion. One controversial aspect may well be its scope. The Biological Council of Canada and the Canadian Federation of Biological Societies urged the Council to extend the report to give equal attention to those scientists who are engaged in basic biological research in mission-oriented faculties and government and industrial laboratories. The Council considered the urgings very carefully, but is of the opinion that the contribution of these important groups had been or would be more appropriately covered in the other reports already published or commissioned, such as agriculture, fisheries and wildlife, forestry, marine science and the health sciences.

As with all other reports in this series published by the Science Council, it is a report by the authors to the Council and therefore does not necessarily reflect the views of the Council. The Council's views and recommendations are published separately, but it is the Council's hope that by publishing this report they will have contributed to the general understanding of that part of the life sciences which is represented by the uncommitted biologists–their problems, their challenges and their futures–and thereby added to the goals of many to achieve greater cohesion among the life sciences through better public and internal understanding of their several components.

P.D. McTaggart-Cowan
Executive Director
Science Council of Canada

January 1971

Preface

This report is about those of Canada's biologists who are usually spoken of as the "pure biologists". They are most commonly found in university departments of biology or botany or zoology or microbiology, in faculties of arts and science, or faculties of science. Though this is their "type locality", they are also found in other departments and faculties of universities; and many of similar ilk can be found in government laboratories.

The future of the science that is fostered by these biologists is basic to the many applications of biological knowledge to man and his activities. And it is a future that looks terrifying to pessimists, sublime to optimists, challenging to pragmatists and full of potential disenchantments to the cynical. To his power over the atom, man is now close to adding a power to control life and its many processes. The contemporary literature abundantly testifies to the need in the future for a good stomach, a sense of humour, and well-developed perspectives. Added to these intellectual stimulants to action are the twofold reminders of more people and more pollution in the decades immediately ahead.

Canada is only a small contributor to the stream of biological research. If all Canadian biology were to cease tomorrow, it would scarcely affect the future of science, but it would drastically influence the future of the country. Our great challenge is to use the world's knowledge wisely.

To meet these future prospects, Canada has a strong group of applied biologists in government and university laboratories, but one of lesser strength at universities; a strong cadre of specialists in the traditional disciplines of biology, but a weak representation of those in the most modern research areas. Pervading the whole picture of biology in Canada is a paucity of good research facilities, a lack of excellent translation and library facilities and the need for more vigorous national scientific journals. Of greatest cause for concern is the fragmentation of biologists into a great variety of small groups. There is need for a national identity and for organization which would better enable basic biology to perform its national service.

The prime intent of this report is to bring the foregoing assessment into sufficiently sharp focus to provide a basis for major policy decisions by the several sectors and institutions that will collectively shape our planning for the future.

Many particular features of the Canadian administrative machinery are then reviewed and suggestions are made for change. The National Research Council is applauded (with reservation). The report expresses astonishment at the lack of representation of biologists on the Council, recommends continuation of the Council's "in-house" research program, and makes suggestions for more rigorous grant selection committee procedures. Particular emphasis is given to the need to support individuals of outstanding merit and groups that wish to do collaborative research. The messiness, at the grass roots level, of the awarding of grants by various government agencies is a matter of comment.

In striving to achieve a nationally balanced effort that relies on other than the complexities of a pluralistic granting structure, it will be desirable to invest substantially in strategic research grants, and to develop institutional flexibilities that are designed to cope with national problems. The greatest obstacles to future efficiency are likely to be the too rigid definitions of duties, the too defensive reactions of empires, and the too fussy attentions to administrative rituals. The emphasis should be placed on making the best use of the total community of biologists. The free flow of scientists among government, university and industry should be encouraged. The wide use of advisory boards with members from outside sectors is strongly endorsed where it occurs and encouraged where it does not.

The recipes for developing excellence, and terminating it when it fades, have to date eluded us. We lack a national conviction of the values of uninhibited scholarship. International involvements in research will be greater in the future. We should participate with enthusiasm, administrative clear-headedness and, hopefully, some inspirations of our own.

The development of general biology programs at major universities is viewed as a desirable trend that will help ensure production of both generalists and specialists for the future. University professors need frequent opportunities for retraining. The current overproduction of biologists is not serious but effort should be directed to better manpower predicting machinery.

The report concludes that, for the readily foreseeable future, there will be hard competitive business reasons, convincing philanthropic reasons and compelling national social reasons for substantial investments in the life sciences in general and the basic biological sciences in particular.

Most of the views expressed in this report have been distilled from what others have said and the report has benefitted from quite a variety of criticism. It nevertheless probably still has lots of weak points. Those who do not agree with all of the report or any of its parts are encouraged to say so, for it is one of the weaknesses of Canadian biology that it suffers from a lack of vigorous public debate.

P.A. Larkin
W.J.D. Stephen

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Introduction

This report is centred about the future of a particular group of people in the whole picture of research in the biological sciences in Canada. It is in some ways a nebulous group to which many belong only in part. The core of the group is those who, by virtue of their place of employment, may be said to be "administratively uncommitted" in their research activity.[1] Their area of study is based on what their conviction or curiosity or conscience suggests. They may do things that have immediate application to pressing national problems, they may be seeking understanding that could lead to a variety of applications in the long term, or they may even choose something of no apparent relevance. The essential thing is that in their research they make a personal choice which is not dictated by their employer's commitment to a particular set of applied objectives.

The academic centre of gravity of the group is the 500 or so biologists in the arts and science, or science, faculties of Canadian universities. A larger academic membership is reflected by the more than 1100 applications to the biology grant selection committees of the National Research Council. These applicants include members of faculties of agriculture, forestry, medicine, and a few others, and a few federal and provincial government scientists participating in university work. In aggregate, this assemblage may be said to be a national pooled effort in "basic biology" at universities.

In this report the main emphasis is on these people, as distinct from those who, by reason of their institutional affiliation, may be said to be flying under the flag of "mission orientation". The employees of the government scientific agencies in resource and health sciences fields are thus not included in this review, but this does not reflect on either the quality or "purity" of their scientific effort. Similarly,

[1]The authors' terms of reference are given in Appendix I.

those research activities in university faculties that are committed to a specific applied goal by virtue of the source of funds supporting the work are not specifically reviewed here. All such enterprises, whether by those in government agencies or by those in universities who are working on missions, are substantially reviewed in other Science Council reviews such as those on health sciences, agriculture, forestry, fisheries and wildlife, and so on.[2]

But it is important that these groups should not be excluded from the reader's attention. Much of the work in these agencies is just as "fundamental", "basic" or "pure". More to the point, much of the structure of biology in Canada has been built on close associations between biologists, regardless of their institutional commitments. And for the future, the growth of the whole fabric will be more important than growth of its parts.

In some ways it is a mixed bag of work that is being reviewed, but taken from the perspective of those who are doing it, there is a distinctive attitude that provides a central theme. Anyone familiar with research is aware that important findings may frequently turn up in unlikely places, and that it is often surprising how particular kinds of knowledge suddenly shoot from obscurity to the forefront of relevance. The national investment in "administratively uncommitted" research, wherever it takes place, is thus a hedging of bets–a recognition that, by preserving a range of interests, there is less chance of being caught lacking, and by encouraging unfettered scholarship, there is always a reservoir of informed and intellectually unprejudiced opinion.

This report was written with the background of 30 panel reports prepared by leaders in various fields of biology in Canada. It also makes use of many comments by Canadian biologists on a questionnaire that was sent to them as part of a basic biology survey. The questionnaire and panel reports were part of a study conducted jointly by the Canadian Federation of Biological Societies and the Biological Council of Canada, under the direction of the late Dr. Kenneth C. Fisher. That study, in the words of Dr. Fisher, was "An account of Canada's activities towards generating knowledge about the fundamental biological processes upon which the production of food and fibre for her citizens depends, upon which their health depends, and upon which the control of the natural environment, required for her citizens' well-being, also depends". Although this report does not attempt such a comprehensive assessment of all aspects of biology in Canada, it leans heavily on the assessments of Dr. Fisher and his colleagues. A list of panel members and chairmen is included in Appendix III. The list of persons who also made outstanding contributions to this study, and whose charity remains anonymous, is at least equally long.

[2]Appendix II summarizes the coverage of life scientists in other Science Council reports.

The Future of Biology

The Long Term

There is no lack of well-written and informed literature on the future of biology[1], nor is there any shortage of sensationalized biology to titillate the layman. The popular science magazines of 30 years ago were loaded with projections of space travel, "atomic" power and the miracles of contemporary physics and chemistry. Today this kind of miracle is largely taken for granted. If a physicist or chemist were to announce almost anything as a new discovery, few people would question it, and few would be very surprised. Science fiction that relies on the "hard" sciences to get its punch no longer has much impact. In its place, science fiction, as well as the rendering of science for the "intelligent layman", is now focussed on biology. Instead of *The Shape of Things to Come*[2], it is *Brave New World*[3]; in place of *The Universe Around Us*[4], it is *The Naked Ape*[5]. And all of this is no whim of literature. It is one of the best signs that, as a science, biology has come of age. It has caught man's imagination.

The reasons for the relatively late flowering of biology are easy enough to see. The living world is made up of an enormous number of kinds of plants and animals. The initial pursuit of science is gathering of facts as a prelude to generalization. For biology, this was a large chore which is still far from finished. As a problem of interrelationships, the periodic table of the elements is a fairly simple array compared to the systematics of only a modest-sized Family of plants or animals. In consequence, many biologists are still tidying up the exploration and pigeonholing job that was started by Linnaeus over two hundred years ago.

But, just as many astronomers moved on to things more exciting than mapping stars, biology became more mature once the theory of evolution provided the major generalization about the origin of the diversity of the living world. In the last half of the last century, evolution was as clearly demonstrated in the way organisms work as in the way they were constructed. There was a blossoming of a multitude of biological subdisciplines, with a variety of new kinds of equipment and techniques, that soon indicated the wide breadth and the potentially great complexity of biology.

Since then the expanding study of living organisms and their physiology and biochemistry has spawned extraordinary technological capacities in medicine, veterinary science, and plant husbandry. The functions of plants and animals are extremely complex and there is still much more to be known, but already our ability to preserve and enhance life of all kinds is truly awesome. The machinery of growth and development is sufficiently understood that we can selectively retard or accelerate many living processes, forcing plants or animals to assume (within limits) characteristics which we wish to impose on them. The life histories of scores of disease organisms have been unravelled, giving us new insight into the techniques of their control. The understanding of the physiology and biochemistry of plants and animals is the basis for modern competence in plant and animal husbandry. And in a truly remarkable way, we continually rediscover that natural selection has resulted in much the same conclusions as modern science. Birds evolved a technology of flying that provided inspiration for man to follow suit–and, of course, the principles turned out to be the same. The "design" of organisms is almost invariably an essay in optimality–the best cost-benefit ratio; and the structure of plants and animals is

[1]For example, to name only a few: René Dubos, *So Human an Animal*; Isaac Asimov, *An Intelligent Man's Guide to the Biological Sciences*; Isaac Asimov, *Fact and Fancy*; Gordon Rattray Taylor, *The Biological Time Bomb*; Nigel Calder (*ed.*), *The World in 1984*, Vols. 1 and 2; Theodosius Dobzhansky, *Mankind Evolving*; Arthur C. Clarke, *Profiles of the Future*. For a comprehensive, academic, and most recent treatment, see the review by the United States Academy of Sciences, P. Handler (*ed.*), *Biology and the Future of Man.*

[2]H. G. Wells.

[3] Aldous Huxley.

[4]Sir James Jeans.

[5]Desmond Morris.

rich in examples of cleverness that man has struggled to emulate.[1] The most recent potential "spin-off" is the quite incredible possibility that man, like nature, might use molecular architecture as the *ne plus ultra* of information storage. If a brain uses nucleic acid molecules for memory, if the plan for a whole man is contained in a sperm and an egg, why not use the same system for our library purposes? As one Canadian biologist said, "Imagine Hansard since Confederation in a 'book' no larger than a sperm!"

Each year our studies of the living world give us new power to control it to our advantage and new inspiration to use the whole of evolution as a textbook for success.[2] The panel reports of the basic biology survey attest to the wide scope and pertinence of biological studies of many kinds, and in the wider literature of current biology, the panorama of investigation and potential application is enormous. In biology it is not so much a question of what to do next, but how to meet a host of chores and challenges at the same time.

Two major questions of biology provide central intellectual themes, one concerned with the mechanism of evolution, the other with the mystery of organization. The critical question of evolution is, "What are the driving forces?" It had long been known that man could breed "special races" of plants and animals. Luther Burbank had many predecessors. Even the art of breeding special kinds of human beings is as old as the first dynasties. But this was an amateur technology that could only explain its failures or successes with invented mysticalities. The "problem" was "inviting solution" and, with the turn of the century, the mechanisms of inheritance were vigorously studied. In less than a lifetime it has become increasingly clear that the living world (including man) has been built on chance as well as choice, and can be built on choice instead of chance. It was only a matter of time until the biochemical machinery of heredity was explained. Once this was known, man could perhaps create life and direct evolution, and dream dreams of a custom-made world. And here we are–a gene has been made. The genetic engineering dreamers are very busy in the current literature of prophesy. The prophets of doom are equally active, and perhaps with good reason. We can look to the prospect of adding to our command of the atom a knowledge of life with which we may eventually build Utopia or destroy ourselves.

The other philosophical question of almost equal impact in modern biology is, "How are living systems organized?" At every level of structure, "co-operation" is an avenue of advantage. At the molecular level, the capacity for duplication depends on the "co-operative efforts" of nucleic acids and proteins. Cells require an intricate balance and interaction of pools of molecules and structural organelles. Multicellular organisms are "co-operatives" on an increasing scale of complexity requiring communication and interdependence among cells. Populations of single species of plants and animals adopt quite various organizational strategies of survival. Whole groups of single species populations form ecosystems, organized entities with parallel structure in several parts of the world. The basic question is, "What are the secrets of successful organization?"

Progress in this direction in the last quarter century has been spectacular, chiefly through technological advances such as radiochemical techniques, chromatography and the electronmicroscope, which have enabled exploration of the world inside the cell. They disclose a microcosm as complex in its way as a whole organism or an ecosystem. Patterns of organization have begun to emerge

[1]The art of applying the knowledge of living systems to solving technical problems is called "bionics". See Lucien Gérardin's book, *Bionics*, and Robert Rosen's book, *Optimality Principles in Biology*.

[2]The impact of our appreciation of plants and animals as organic machines is rapidly spawning a new "bio-technology" in which "bio-engineers" will soon develop a great variety of specialties.

at all levels of biology—molecular, cellular, organismic, population and ecosystem.

To the question "What are the properties of these complex systems?", the use of the computer promises a revolution as profound to biology as the invention of the microscope. Analytical problems of mathematics are no longer an obstacle to understanding.[1] Even the extraordinary "equation" of Rashevsky, which purports to describe the whole of organic evolution, could readily be evaluated with a computer of sufficient capacity. With the availability of this kind of technical assistance, many biologists are now acquiring mathematical skills and talking the jargon of positive and negative feedbacks for which biology provides a profusion of examples. In these enterprises they share an enthusiasm with the social scientists, for social evolution has resulted in "systems" with remarkable similarities to biological "systems". The common meeting ground of the biologists and the social scientists is man. One consequence has been that "ecology" has almost overnight become a word which identifies an interest in the understanding of complex biological or social systems.

As yet, the new sciences of biological organization are characterized more by promise than performance. Given the chance to direct the affairs of either the natural world or man's world, no ecologist nor committee of even the best ecologists would have much to offer on the secrets of natural systems. The same is true of "systems analysis" applied to parts of the body; for example, to the questions of brain function. At present we only dimly perceive the principles upon which the remarkable properties of the nervous system depend. Systems theory is also currently being applied to problems of biochemical regulation, cell metabolism, enzyme synthesis and the behaviour of simple organisms, again with exciting promise. As yet, there are only a few examples of the new power of perception of the anatomy of complexity, but a world of new understanding seems ready for exploration as the simulation capacities of computers are increasingly developed in conjunction with analytical experiment.

[1]The difficulties of formal mathematical analysis of biological problems have long been a bottleneck. The choice was always between oversimplification with tractable mathematics, or more realistic representation with intractable mathematics.

When biology adds these new levels of understanding to its present array of knowledge, there is the prospect that the world of the future in its every living aspect could conceivably be made to be what man wants it to be. The promises of biology to give gradually the power to create and control life are not false. They will not be fulfilled too quickly because the living world is complex, there is much yet to be learned and consolidated, and man has himself to contend with. But the potentials are now clearly visible. Little wonder that we are almost daily made aware of new opportunities, and almost as frequently, hear pleas for a moratorium on science until we get accustomed to our new responsibilities.

The Short Term

For the more immediate future, there appear to be some rather urgent world problems which have a substantial biological content and which will undoubtedly influence the direction of research. The world population explosion will, of course, not happen on a particular Tuesday when we will all share the last handful of peas among our relatives, but the prospect for the next few decades is for increasingly severe "density dependent" regulation of the human population, either from competition for food or other resources. It is equally obvious that contamination of the world by the waste products of both people and industry will help to underline that the world really is a "global village" with a garbage problem.[1]

[1]Another current metaphor is to liken the earth to a spaceship with self-regenerating life support systems. Leaving metaphorical eloquence aside, more people means more problems.

The difficulties that we may face may be heightened because many of the quick-fix techniques of increased agricultural production have proven to have serious pollution side effects and other biological repercussions. Rather obviously, there should be some prizes awarded for people who can provide fertilizers, insecticides, fungicides and other agricultural chemicals which increase production, cleanly and without disastrous side effects.

The problems of food, people and pollution have grown rapidly in the past few years. The International Biological Program (IBP), which had as one of its slogans, "Food for the 5th Billion", was conceived with considerable foresight, but even the planners of this scheme have been surprised at the growth in world population that has taken place in the last ten years. The proposed "Man and the Biosphere" (MAB) program of UNESCO has already been given wide publicity and underlines the international concern that is being generated on the questions of the human environment. It seems safe to assume that a substantial proportion of the effort in biological research throughout the world in the next two decades will be aimed at the whole group of biological research activities that are entrained in these social problems.

A large proportion of this research is rather less glamorous than the questions which are related to the origin of life and the nature of complexity. They nevertheless have challenges and require that particular kind of sophistication that is involved in doing truly relevant investigation. Much of the work required is "old-fashioned" in concept, and involves such elementary steps as study of the morphology and natural history of common economic pests. All of it must be done with a sense of urgency if it is to meet the scale of the problems.

In this context it seems likely that botany may need a much bigger emphasis than it has been given in the past. There is probably at least ten times more plant production than animal production in the world as a whole. As a food source, enriched plant products are much more abundant than animal products. It will be necessary in the world as a whole, as it has been in many heavily populated countries, to eat more plant food and less animal food. There is thus particular long-term relevance to basic studies of plant genetics, plant physiology, plant pathology, and plant biochemistry. While our natural anthropomorphic curiosity may be more attracted to studies of animals, more practical considerations will probably lead us to a greater emphasis on studies of plants.

It is perhaps worth an aside that, to do most good, much of this research should be done in the underdeveloped, overpopulated countries of the tropics. The development of appropriate techniques of maximizing yield in tropical environments will not be achieved by a simple transplanting of the temperate zone agricultural or forestry technology. For a variety of reasons, tropical environments pose their own kind of ecological problems.

Animal studies will in some degree centre about questions of secondary and tertiary productivity with which many ecologists are now concerned. But, again, in the broad view, it seems very likely that the "hunting procedures" of world fisheries will gradually be replaced by more intensive aquaculture, just as chicken factories and beef yards are replacing the chicken coop and the wide open ranges. These developments will generate a substantial research requirement on diseases and parasites, physiology, behaviour, nutrition and genetics of readily domesticated and palatable animals.

A great amount of the research that is done on animals is designed primarily to gain knowledge about man. It is thus not uncommon to find different groups of people doing virtually identical pieces of research, some with the object of discovering principles of animal biology, others with the object of better understanding man. Because the work that is done is mutually complementary, the research futures of medicine and biology are in many respects common, and certainly no comment on the future of biology would be complete without reference to its importance to the future of medicine.

The twin problems of greatest current concern to medical research are cancer and cardiovascular diseases. Both are research topics which have led to ever more searching questions about the nature of living processes. For each there is a multiplicity of apparent causes and an increasing susceptibility with age. The findings, which eventually lead to better understanding, are as likely to be made by biologists working within non-medically oriented environments as without, and the contributions of both groups will add up to great progress in the next few decades.

Together with research on a host of other ailments, these findings will ensure ever greater human life expectancies. The consequences, while laudable and humane, will serve to further aggravate the problems of population.[1] They may also spur research effort to improve the quality of life for old people who have been spared from dying of "anything else but old age". Additionally, the "preservation" in the breeding population of an increasingly larger number of "defectives" will no doubt encourage research on genetic cures rather than skillful medical salvage jobs. For all of these areas of research, biology and medicine share wide common ground.

Progress in the understanding of mental disorders will also probably be substantial in the immediate future, perhaps partly because of its increasing frequency in the stressful circumstances of increasing population and our age of "communication". Again, research in animal behaviour has a most piquant applicability, particularly to understanding mental illnesses and the psychologies of individuals and groups. The use of drugs, both clinically and extra-clinically, will introduce man into an age of psychological tampering reminiscent of Huxley's *Island.*

Looking to both the short and the long term, it seems certain that the discoveries of the biological sciences will have great impact on society, and that society of the future will generate many problems for the biological sciences. Biologists will thus be even more important to governments of the future than they are to governments today.

There is one other contribution that biology may increasingly make to the society of the future. As Fred Hoyle, the astronomer, has pointed out, the whole world of biology possesses an incredibly large number of problems to satisfy the intellectual curiosity of both layman and scientist. As any biologist will tell you, variability is a key word in biology. When speaking of plants and animals, it is never appropriate to say, "When you've seen one, you've seen them all". This is one of the best reasons for adopting a strong position on the question of man's obligation to pass on to future generations a world as rich in living organisms as the one that he inherited. It seems probable that biology of one kind or another will, for many centuries, continue to provide a tremendous satisfaction to a large number of people. In so doing, the study and love of nature could become a major feature of our culture. In the view of some, this is a change in outlook which will be necessary for our survival.

[1]The effect of increase of lifespan on the population "explosion" is fairly complex and is greatly misunderstood. The current popular campaign for "zero population growth" by limiting families to two children is an example.

Canadian Biology

A Perspective

Canadian biological science as a whole is respectable by world standards. Our scientists are an accepted part of the international community; some of our work (particularly in applied fields) has been and is outstanding; and in the broad perspective, Canada's contribution is a high quality, small tributary to the total flow of the science.

By virtue of its smallness on a world scale, by almost any measuring device, Canadian biology, like the rest of science in Canada, is largely "me-too". Canada contributes about 3 per cent[1] to the world literature on the various subject areas that comprise biology, and while much of the work is unquestionably of high standard, in sheer bulk the work elsewhere is vastly greater. With ten times the population, and a proportionately greater national investment in research and development, the United States' production is well in excess of ten times that of Canada. The U.S.S.R., a relative latecomer, is probably producing a volume of research close to that in the United States, at least in the applied biological fields.[2] Western Europe, the past-master of science, is still highly productive.

It is perhaps for just these reasons of quantity that Canadian biology has not been particularly distinguished by its share of truly extraordinary research. Given that Canadians have no special monopoly on brains, it was inevitable that for almost anything we did, the "really good labs" were somewhere else. In consequence, the best people, with the usual passions of research, have frequently gone elsewhere, while the reverse traffic was not of the same calibre. Small scientific frogs have frequently found Canada a good-sized puddle.

Additionally, the dilution of scientific enterprise associated with the chores of development of a large country has slowed the growth of our "pure" biological science. To an even greater extent than for physics and chemistry, it has been necessary for biology at universities to provide service training for professionals (medicine, nursing, agriculture, forestry, fisheries) and "liberal" education in science for those in the humanities. Before 1950, only McGill and Toronto undertook biology as much more than a necessary part of the undergraduate curriculum. Additionally, many Canadian biologists were engaged in the ground work of systematics, morphology, natural history and biogeography, jobs on which Europe had a century or more of accumulated experience and a constellation of museum collections and facilities. In brief, until recently, most of the biology in Canada was devoted to the ordinary jobs which the stage of national development demanded.

As a consequence, fresh and original Canadian work, whether by government or by university, has been largely in the applied fields (medicine, agriculture, and fisheries in particular) and, until recently, much of the "basic" work that was done was most widely appreciated among the "old-fashioned" elements of international science. Prior to 1950, the developments of genetics, physiology, biochemistry, medicine, and virtually all of the progressive experimental or theoretical work of biology, were only sporadically influenced by Canadian contributions. In a real sense, Canada paid a small price for the large amount of world knowledge that was used in her development.

Since 1950 there has been a gradual shift in the national role. Excellence in the applied fields led rather inevitably to greater involvement of "applied" biologists in "basic" work. Becoming sufficiently mature to question the sources of

[1]According to J. Lukasiewicz (Science Forum, February, 1970), Canada's share of world scientific output is about 1 per cent and is low relative to our Gross National Product. In his review, the late Dr. K. Fisher estimated Canadian papers as being 3 per cent of the total.

[2]Dr. W. E. Ricker of the Fisheries Research Board said that the Soviet literature in fisheries biology was equal in quantity to that of the United States and in quality to that of Canada. He did not enlarge to say exactly what he meant.

their knowledge, they began to embark on some critical basic work of their own. Much of this started outside of universities, and even today a major part of the basic work in biology in Canada is still done in various government laboratories.

Once the post-war increase in university enrolments got well under way, there was a substantial increase in Canadian university biological research. The influx of mature immigrant scientists to universities in the post-war period was an important factor in bringing Canadian biology through a rapid adolescence.

In the 1960s, growth of Canadian universities and all of Canadian science was rapid. Not surprisingly, then, we are now at a stage of considerable confusion. The rate of discovery in science has been accelerating and it is increasingly difficult to keep in touch with what is being found out. Both by importing scientists from other countries to fill our immediate needs, and by striving to catch up with the various front lines of research, we find that we are doing a little bit of a great many things and participating in some of the glamour of science. Thus, many Canadian university research activities make sense only as parts of continental or international sets of studies that have their origins in scientific or social problems which have been generated elsewhere in the broad flow of discovery.

In this context, Canadian biology still looks distinctly second rate. Our university biology departments fall far short of their counterparts in the United States, the United Kingdom and Western Europe. They are thus not yet the mature component of the total picture that provides the best base for the applied biological sciences in the country as a whole.

The Subject Matter

In the subject matter of biology, Canada's problem is not whether to creep or to fly, but rather how to creep, run and fly all at once. We have only recently developed competence in some of the traditional areas of biology; yet to keep up with the times, we must do new things before we are properly ready to do many of the old. In the discussion that follows, the treatment is from old to new, from traditional to avant-garde.

Much of the background of systematics, morphology, plant and animal natural history, descriptive ecology, biogeography and paleontology has not yet been done in Canada to the level that has been achieved in Europe. Much of this work does not have much appeal from the point of view of those who wish to participate in the intellectual frontiers of biological science, but this is often what is necessary as a base from which to conduct those types of studies that will eventually lead to informed manipulation of natural environments. It is a feature of Canadian field biology that we are commonly trying to do sophisticated research without having a sufficient knowledge of the living or fossil materials that we are handling. No other technologically progressive country, except possibly Australia, has such a high proportion of unstudied floral and faunal elements.

Thus, the panel reports make frequent mention of the need for studies of systematics of Canadian plants and animals, usually with particular reference to organisms of relatively small size or difficult taxonomy. Soil invertebrates, freshwater and marine micro-organisms, plant and animal parasites and disease vectors, are typical of some of the difficult groups for which substantial studies are needed as a service base for more advanced studies of function, ecology, and a wide variety of applied biology.

A first reaction to this state of affairs is to wonder why biologists of the right bent do not move into the sadly deficient areas. Considering how few traditional biologists we have in some subject areas (systematics and natural history of soil invertebrates), we perhaps have more than we need doing other kinds of work (for example, systematics and natural history of vertebrates). The impression is thus that, while the total investment of effort may be adequate, its distribution is not, and we should therefore encourage reorientation to new subject matter. But it is characteristic of much contemporary biology that its devotees, at an early stage in their careers, have become associated with particular species or groups of species of organisms rather than with particular kinds of disciplines. The redeployment of the organismic biologists might thus be quite difficult to achieve. Additionally, there is the tendency for good work of this kind to take a long time. Experience could easily be wasted by too vigorous a shift in new directions. Perhaps a slow readjustment is necessary, with emphasis on producing young people with interests in the biology of little-known groups.

In the whole field of organismic biology (virtually any "ology" with a phyletic connotation), there is without doubt several decades of descriptive work to be done and, until then, the lack of it will, from time to time, hamper progress on particular applied problems. The essential chores should thus not be forgotten (for example, the National Museum is woefully behind in its role), and a major attempt should be made to distribute effort effectively, but large support programs and other than modest growth would be inappropriate.

We are perhaps fairly well equipped with a base from which to develop the strength we shall need in plant and animal physiology and biochemistry, though the university component of this activity is notably weak. Because of agricultural, fisheries and forestry activity, we have moved actively in applied aspects of these fields, and in at least some specializations, we have been of world class. With the distinguished leadership of federal research laboratories, Canada has an enviable research performance in these fields. Our record for applying our research findings has perhaps not been as notable, and for the future we should hope for better performance. Though the world's food problems would seem to ensure a market, history would suggest that the market will be intensely competitive. To survive as producers, Canadian food and fibre industries will have to keep well up with the times. In becoming "big business"[1], agriculture, forestry and fisheries will not only have problems, but will be in great need of new fundamental knowledge and new applied trade tricks which the physiologists and biochemists may provide. Genetics, of course, has immediate application in these pursuits and should equally be encouraged. The potentials for new pharmaceutical compounds from plants and animals are substantial and the development of appropriate biochemistry is desirable.

As a twin to these commercial considerations, the physiological sciences have much to contribute to the understanding of human and animal health and behaviour. Canadian efforts in this direction, roughly equally divided between medical and non-medical orientations, are notable for some conspicuous peaks of achievement and some surprising lacks in coverage. In the cardiovascular, neurophysiological and endocrine areas, Canadian achievements are, by any standard, developing well and of high quality, in large part because of work in the medical areas. Canadian work on non-medical physiology has tended to place greatest emphasis on domestic animals and fish. In the "bread and butter" areas of nutrition, milk and egg production, and so on, Canadian research has been and still is quite adequate and able to take advantage of new knowledge generated elsewhere.

But, to a substantial degree, human physiology is still the model from which most animal physiology is deduced. It is only in the past two decades that comparative physiology has begun to

[1]As an aside, the urbanization of our society ("5 supercities in the year 2000") makes us increasingly dependent on fewer people for food and fibre. If someone is not already doing it, we should give consideration to what this could mean in the case of a national emergency.

put a perspective on much of our understanding. In these more comprehensive pursuits, Canadian effort has been notably deficient. The physiology of most wild animals is imperfectly known. Both vertebrate and invertebrate physiology has direct relevance to the understanding of human health and function. Moreover, as has been brought to our attention so clearly in the past few years, animals are excellent indicators of stresses in the environment that may influence humans (DDT, lead, mercury and many other contaminants).

For the reasons of food and fibre production, understanding of human functions and protection of environments, the strong development of the physiological sciences seems desirable in the Canadian pattern of future development.

The story is somewhat the same in the behavioural sciences. Canadian effort has expanded rapidly in the past decade and provides a beginning for future growth although there is a great gulf between the ethologists, who study animal behaviour, and the psychologists, whose main thrust is toward man. A notably missing area is the study of non-human primates which has been much in vogue elsewhere in recent years. Canadians made little contribution to the research that preceded the current unveiling of man as an animal. This perhaps reflects in part that we were too busy at home, and in part that we are nationally deficient in zoos. But whatever the reason, it is doubtful that this kind of research should be developed in Canada in the future, even if in the hope that its further pursuit would show man to have more redeeming graces than are now apparent. The subject seems to have been well worked from a behaviourist's point of view and there is probably more to be gained from more comprehensive studies of comparative ethology.

Research in the behavioural sciences is thus modestly healthy, if fragmented, in Canada, and its development has wide application in many fields. Its further growth should be encouraged, particularly in the universities.

If the foregoing were all there was to biology, and if we lived in a world of our own, Canada could afford to continue its present pace in development of the biological sciences. Growth to date has probably been at an efficient and economic pace, and aside from the need to get cracking on Arctic biology and to tidy up on sadly deficient areas that relate to pollution research, we could afford to persist in our gradual catching up to maturity. But we do not live in a world of our own. Increasingly, we are having thrust upon us problems that arise as a consequence of knowledge and technologies generated elsewhere. Our questions, then, should not be "What should we do about the science of biology?" because that will largely be decided by others; rather, we should ask, "What are the penalties of not doing certain kinds of research?" and "What are the benefits of doing more work in particular fields?"

In the context of these questions, *the key areas for future development* can be placed in five groups: (1) microbiology; (2) genetics; (3) cell biology, molecular biology, virology and immunology; (4) systems and theoretical biology; and (5) new ecology and new systematics.

In the subject matter of microbiology, Canada has had a gathering record of achievement in agriculture and medicine, but it is only since 1950 that there has been any substantial development.[1] Canadian contributions have been notable in the determination of the structure of micro-organisms and the functions of the structure, and in the understanding and control of some mammal, fish, poultry and plant pathogens. The basic nutritional studies that made possible the cultivation of tissue cultures and the development of viral vaccines were done in Canada. The work on soil microbiology has been of outstanding quality.

[1]This section on microbiology is heavily indebted to a brief to the Science Council by the Canadian Society of Microbiologists.

All of this makes it seem as though microbiology is in healthy condition in Canada, but measured against the opportunities and problems of the future, our present level of effort is imprudently small.

There are the technological potentials for using micro-organisms as chemical converters, which make their present uses as fermenters look like "small beer". There are possibilities for production of pharmaceuticals and biochemicals. Aerobic autotroph bacteria are proving useful in recovery of uranium and copper, and there can be little doubt that Canada should invest in research on bacterial mining and smelting. Recycling of sewage wastes, of which we hear so much these days, is largely a problem in applied microbiology. Waste petroleum may be degraded by bacteria.

As a food producer and supplier, we obviously should invest in microbiological aspects of food preservation and distribution. Arising from microbiological research, there are possibilities for incorporation of the genetic determinants for symbiotic nitrogen fixation to plants other than legumes, thus reducing the need for nitrogen fertilizers.

On top of all this sort of thing, the greatest contribution of micro-organisms to human welfare is their decomposition of organic matter, which is a key link in the "life support system" of the planet. Though they are the vital "biodegraders", their roles are only broadly known. Much of our current concern about environmental quality should be directed to the effects of pollutants on micro-organisms.

For all these reasons, microbiology should be vigorously developed from its present nuclei of high quality in Canada. Additionally, attention should be given to ways of encouraging industry participation in this kind of work. At present, Canada is not exploiting the rich potential of microbiology, while envying Japan and the United States who do. Industrial research activity is our weak point.

Of all of the subject areas of biology, *genetics* seems the best candidate as a common denominator. As the science of heredity, it is concerned with the processes which make the living world distinguishable from the non-living. Our capacity to manipulate living material to our advantage will largely rest on our knowledge of genetics. A few Canadians were quick to realize this, and during the 1920s and 1930s they made discoveries that were directly responsible for our subsequent successes in agricultural production. Strength across the whole range of genetics developed less rapidly, though elsewhere new subject areas with great scientific significance were prompting serious concerns about society of the future. It is only recently that Canada has been making belated entry into the exciting and disturbing research that is so glibly rendered into our jargon as "genetic engineering".

Genetics is probably the most important subject in biology for which society of the future will require, as ingredients for its decisions, the sober judgements of its scientists. In an age that promises opportunities for selective breeding and control of the characteristics for every living thing, especially including man, failure to develop appropriate scientific strength could be tantamount to abdicating responsibilities. And yet the conclusion is inescapable that the particular kinds of research that have fundamental application to the problems of the future are generally not being carried forward in Canada.

Contemporary genetics is really a variety of subdisciplines that merge at the molecular level with molecular biology, immunology, virology and developmental biology, and at the population and species level with ecology and systematics. Strength in genetics is thus to some degree a cognate of strength in other fields. The vigorous development of genetics in Canada seems to be mandatory.

In the whole set of studies that centre around biology at the cellular and molecular level, Canada has had a conspicuously "latecomer" role. While present activity is by no means small or second rate, it is nevertheless small in relation to the development in other branches of biology and small in relation to the potentials and problems. Immunology, for example, which is concerned with the tissue reactions of organisms to foreign cells and substances, has wide application to diseases caused by bacteria and viruses, the problems of blood transfusion and organ transplants, allergies, and the diseases caused by the body's response against itself. Additionally, immunological techniques are widely applied as tools for measuring small quantities of proteins. The general picture of Canadian effort in immunology has been of fragmented effort, with a few distinguished activities. Until recently the overall pattern was one of weakness. Fortunately, in the past five years, growth of immunological research has been substantial and the present pace of activity should be maintained and enlarged.

Virology has similar direct application to the many plant and animal diseases that are virus-induced. The present emphasis on virus research as a whole is on biochemical and biophysical approaches, but these activities are not well developed in Canada. Although there are some very good centres of virus research, the subject is generally not well developed at Canadian universities.

Molecular biology is essentially a fusion of biochemistry, microbiology and genetics, which had its origin about the time of the Second World War. Its development has been noted by the contributions of chemists and physicists to the study of living processes, and its crowning achievement, the discovery of the genetic code. Ultimately, all living processes have explanation at the molecular level, and with this kind of explanation comes the ability to "create life" and to "direct" living processes. It is the extrapolations of molecular biology that excite the excitable to see that the knowledge of the genetic code has potentially more impact for mankind than the understanding of the atom.

To this most profound area of discovery, Canada's contribution has been very small. Though whole departments of biology in the United States switched into molecular biology in recent years, the Canadian reaction was much less responsive. For this we should perhaps be thankful, but the Canadian reticence in this case seems to have been overdone. We do not have the people we need in molecular biology to keep us informed and aware of opportunities.

Cell biology is in better shape in Canada than is molecular biology, but again, like the rest of the sciences in that group, the broad picture, particularly at universities, is one of weakness. Tissue culture is a basic tool, but our total effort is almost invisible. Organ culture is similarly neglected. Though there are many studies of cell membrane structure and function, there are few, if any, studies on biochemical composition and structure. Plant cell biology is more deficient than animal cell biology.[1]

The whole area of cell and molecular biological studies thus seems to have been slow in developing in Canada. Along with genetics, this is the part of biology that is creating our concern for the future. It will, without doubt, grow and proliferate in new directions as the science moves on. It is, then, an area to which we should direct major support in the next decade, even if only to stay in the same relatively weak position we now occupy.

Systems and theoretical biology is similarly new and dynamic. Our relative backwardness in these studies is probably related in part to the immense technological lead that has devolved from the "space and military" programs in the United States. In many of the relevant areas of applied mathematics, Canada is well behind. One has only to visit a large United States campus to realize that the presence and utilization of large computer facilities have spawned an intense interest in complex problems and analysis of many kinds of biological systems.

[1]This is perhaps true the world over.

The use of computers and mathematical techniques is generally weak in the biological sciences in Canada. Most of the panel reports are notable for their omissions in this regard. The panel report on biomathematics indicates that, in Canada, the ratio of scientists to statisticians is much higher than it is in the United States, the United Kingdom or Australia. In general, Canadian users of mathematics in biology are disturbingly few in relation to the opportunities. As in the case of cellular and molecular biology, we need specialists in the fields of mathematical biology, if only to keep abreast of the increasingly complex techniques and the intellectual depths of the science of the future.

For all of the current noise about ecology, ecologists still commonly persist in their syndromes of "one ecologist-one species" and "let's measure everything"– the first being characteristic of the autecologists who study the web of interrelations of a species, and the second of the synecologists who study the properties of plant and animal communities. As a result of the "one ecologist-one species" approach, some of the simplest points of descriptive natural history have been repeatedly rediscovered, as successive generations of field workers start from scratch in constructing an appreciation of an animal's biology. This type of study has been extremely valuable but its potential for developing new kinds of understanding is very limited. The synecologists have been more commonly accused of using the "let's measure everything" approach. In attempts to try to look at too many things at once and to deal exclusively in *a posteriori* hypotheses, they have substantially developed the basic description of the natural world, but have discovered remarkably few new principles since Clements and Shelford, and Tansley and Elton and Leopold first put fine language around the simple truths of the "balance of nature".

The new ecology, which deals more in processes and experiment, is now well under way and ecology is rapidly evolving into a science. In this transition, Canada is in relatively good shape. There is strong emphasis on ecology in Canada because of its relevance to so many resource use questions. To make our contribution to world knowledge and to keep abreast of the field, it is probably necessary only to hasten the process of change, to back the "new ecology" with the type of "big project" thinking that it requires, and to make special efforts to bring physical scientists into team approaches.

For the new systematics, which is a twin of the new ecology, we are less well endowed. Modern concepts of evolution centre about the dynamics of ecological systems (hence, "ecological genetics")– the ways in which natural selective processes preserve the moving equilibria of plant and animal associations. Every living organism is a package of adaptations that comprises its equipment for coping with the present and a number of possible futures. In various ways organisms interact with each other and the totality of their environment so that they evolve by "natural selection". Though this has been appreciated for several decades, the development of the subject has been largely theoretical. Recent work in the field has suggested that rates of natural evolution may be much higher than has been realized. In the fast changing world of today, an understanding of these processes has wide and basic application.

New kinds of research may pose needs for new kinds of collaboration among various kinds of scientists. Throughout the various panel reports, particularly those in the key fields for development, it is repeatedly stressed that the "big new gains" in understanding will come from "teams", and whether they are described as interdisciplinary or multidisciplinary, the message is always that one man rarely has the necessary total package of skills and perspectives. Investments that are aimed at producing true, world-class biological research must therefore be concentrated and appropriately integrated. It is a widespread view that modern biology is becoming more oriented to "problems" rather than disciplines. Research therefore proceeds in the direction that the problem suggests. If a biological problem poses a question in physics, then the investigator becomes a physicist for the occasion. If the problem then leads to a question of heredity, the investigation embarks on genetics. This kind of pattern of research is reinforced by the "team" approach. The one-time "titan of science" who mastered many disciplines is a thing of the past. Replacing him is a leader and a mixed group of people who can collectively master the various aspects of the "problem".

The foregoing discussion of the subject matter of Canadian biology is thus largely artificial. The very fact of the discussion by disciplines is indicative of one of our major tasks for the future–how to so improve the communications in our scientific community as a whole that we can talk of meaningful and major problems as well as, or even instead of, increasingly meaningless and minor disciplines.

This is true, not just within biology, but in the wider view of science. Many biologists are convinced that the pace of biological research will be greatly quickened by encouraging physical scientists to tackle appropriate facets of biological problems. Mathematicians can contribute in both the applied and theoretical spheres, and are currently active over a wide range of biological problems. In the opinion of the head of a large Canadian mathematics department, mathematics has made its contribution to the physical sciences; its future lies in the biological and social sciences. Physicists have made notable contributions to molecular biology and to physiology of cells and whole organisms. Chemists have substantial contributions to make to the whole range of biology–from the questions of molecular configuration to the complexities of processes in mud at the bottom of lakes and oceans.

The development of a new holism in Canadian science may thus be the most important step in keeping the country well ahead in the growth and application of science.

The Accoutrements of a "Mature Science"

When biological sciences are well developed, it would be expected that the national scene would include a substantial number of "accoutrements" of the science. For the biology of the last century, the appropriate requirements were a group of societies (with varying degrees of exclusiveness) and appropriate journals; museums; zoos and botanical gardens; excellent libraries; the prestige to attract and the facilities to host international congresses; field stations on the seashores, deserts or other major environmental sites; the occasional national expedition to God knows where; a few great names of the science, superbly provided with everything their patrons could endow; and, permeating all, a feeling of national identity within an international brotherhood.

Times have changed. Most of the Victorian accoutrements of biological science are as much needed as ever, but others are dinosaurs in the countries in which they developed and white elephants when recreated today in newer scientific communities. Also, in the past 50 years, and particularly in the last two decades, new kinds of biological science have generated needs for new kinds of equipment, and the increasing volume of scientific findings has generated new problems in communication. In planning for the future, the national investment in the accoutrements of science will have major significance.

Because far more research is done elsewhere than in Canada, *one of our best bargains is investments in foreign literature.* That which is in the traditional languages of science (English, French and German) is fairly readily available, but the Russian literature (and, increasingly, also the Japanese) is far less well known to us. High on our list of priorities should be the building of an excellent translation service that would complement those of other countries. The U.S.S.R. is virtually all at the same latitude as Canada. They have many of the same (or only slightly different) plants and animals. The U.S.S.R. and Canada are, together, virtually *the* boreal forest, taiga and tundra zones of the northern hemisphere. On all biology related to renewable resource management, we should obviously exploit what they know. In other areas of biology, the sheer mass of their effort must command our attention, even if, in some fields, we derogate its quality.[1] To a simple-minded biologist, a grasp of Russian is as important to our national scientific future as a grasp of both French and English is to our cultural future. Our present translation facilities are inadequate for the almost phenomenal job necessary.

Second among the priorities for good communication devices is a strong national science library with superlative services to universities and government agencies. While much of the literature awareness of "scientists" is a myth which they like to cultivate, there can be no question that the "information explosion" has reached such proportions that even the myth is dying. The most efficient solution for a small country like Canada seems to be to devise some form of integrated and co-ordinated service that ensures access to as much as possible of the world's literature, and a minimum of unnecessary duplication (see Science Council Report No. 6). Hopefully, in the next five years, we will witness a major revision of our passive concepts of libraries and move to a new age of selective information retrieval.

On the question of societies and their journals, which are the traditional media of scientific communication, there would seem to be two reasons for being nationalistically minded: (1) to have prestige; and (2) to publish things of essentially national interest. To date, our Canadian scientific societies have been weak. Our biologists have been much more likely to migrate south for conferences and north for research, than to go east or west for either. We have had fewer biological societies than medical societies, many of the biological societies were relative newcomers (Appendix IV), and if there was any doubt about their mediocrity, one had only to attend a few of their meetings in between a few visits to comparable conferences of their United States counterparts.

[1]For example, in genetics, until very recently.

There are 17 Canadian biological journals (Table 1). Of these, many of the more distinguished are supported wholly or in part by a government subsidy. Other Canadian journals in which biologists may publish are "in-house" journals of government research departments. True "society" journals, paid by memberships and subscriptions, are not particularly vigorous in Canada. Those society fees our scientists do pay are frequently used for foreign journals.

Canadian biologists tend to publish in other than Canadian journals. Applicants to the National Research Council list their publications for the last five years. In a sample of 308 applications from the 1176 submitted for 1970, there were listed 2140 publications, of which 1277 (or 60 per cent) were in other than Canadian journals (Table 2). Better than 35 per cent were published in the United States. Wide publication in the best foreign journals reflects credit on Canadian science, but is surely an indication of weakness of the national media when less than half (and perhaps not the best half) of our work is published at home.

Canadian biological societies and the government agencies should give high priority to the development of strong Canadian journals. Do we need some prizes, perhaps, or no page charges for Canadian contributors?

On the subject of zoos and botanical gardens, biological field stations and national expeditions, there are two contrasting sets of opinions. Some biologists feel that Canadian biology must develop these kinds of facilities as a necessary set of accoutrements to a mature science, and that our present pace is hampered by their virtual non-existence in Canada.[1]

[1]There is still no single marine station or zoo in Canada which is on a par with those of Europe and the United States.

Table 1–Number of Canadian Periodicals Indexed in Biological Abstracts, Wholly or Partly Supported by Government (Federal or Provincial) or Published Independently

	Published Regularly			Published Irregularly			Total
	Govt. Publs.[1]	Society & Univ. Publs.		Govt. Publs.[1]	Society & Univ. Publs.		
		Receiving Govt. Grant	No Grant		Receiving Govt. Grant	No Grant	
Agriculture and Food	0	0	7	2	0	0	9
Biology	4	2	8	1	0	2	17
Fisheries	3	0	1	6	0	0	10
Forestry	2	0	1	2	0	2	7
Natural Resources	1	0	4	3	0	0	8
Medicine	3	0	13	0	0	1	17
Physical Sciences	3	2	3	4	0	2	14
Miscellaneous[2]	0	1	1	0	0	2	4
Total	**16**	**5**	**38**	**18**	**0**	**9**	**86**

[1]Including NRC: *Canadian Journals of Research.*
[2]Including psychology and anthropolgy.
Source: Directory of Scientific and Technical Periodicals, National Science Library, 1969 (NRC-10889).

Table 2–Countries in which a Sample of Canadian Biologists Published during the period 1965-70

Division	Total NRC Appli-cations	Sample Size	Number of Articles Published					Subtotal Foreign Countries	Total
			Canada	U.K.[1]	U.S.A.	Europe	Other		
Animal Biology	278	71	171	117	162	42	6	327	498
Cell Biology	344	86	236	70	325	60	10	465	701
Plant Biology	234	69	184	60	117	32	3	212	396
Population Biology	320	82	272	66	162	41	4	273	545
Total	**1 176**	**308**	**863**	**313**	**766**	**175**	**23**	**1 277**	**2 140**
No. of Journals			118	104	238	90	20		570

[1]Includes Australia, New Zealand.

With considerable enthusiasm they are thus developing proposals for marine stations on both coasts, recommending expeditions to the more remote parts of the Canadian Arctic, and to other places that meet the requirements of being far away and inaccessible. The contrary opinion is that all these kinds of activities would only help to make us old before our time. Rather than doing all these "oh gee whiz" things, which are Victorian or "Teddy Roosevelt" in flavour, we should invest our limited funds in the kinds of facilities that will keep us abreast of the most modern trends in biological science. For example, it might be desirable to develop facilities of the kind that are usually described by the word "biotron"–a set of facilities providing controlled environments, intricate instrumentation, and a high degree of automation that can be used for sophisticated experimental studies in many of the functional aspects of biology. Similarly, modern genetics, tissue culture, and virtually all of the molecular and cell biology fields, require expensive precision equipment and quite superlative laboratory facilities.

The question of how best to invest in major facilities is very difficult to resolve and is much to the fore in the thinking of Canadian biologists. Several of the panel reports remark that, for many disciplines, only the federal government facilities are in the premium class[1], and that for the future, only the federal government will have the resources necessary to build some of the facilities required.

[1]Computing facilities are a conspicuous exception, federal services being notably deficient.

It must then be underlined that Canadian biology should be particularly marked by the communal use of major investments such as ships, biotrons, special regional facilities, and so on.

Among the specific suggestions of the panel reports, there are a few rather important general points that indicate that, in some measure, both traditional and avant-garde research may be served by common facilities. Thus, Canada urgently needs a set of regional laboratory facilities which provide excellent holding and controlled environment equipment for plants and particularly animals. For ecology and behaviour studies, these are particularly needed and would be highly useful for the complete spectrum of studies that have a bearing on questions of environmental effects. At present the marine and freshwater holding facilities in Canada are largely an appalling assemblage of Rube Goldberg contraptions; the few facilities for holding wild birds and mammals are even worse. Major research facilities, such as the controlled environment greenhouse at the University of Alberta and the Marine Sciences Research Laboratory at Logy Bay in Newfoundland (which were built with National Research Council major installation grants), are very desirable investments. Hopefully, many similar installations will develop in the future.

If we are going to strive for excellence in all branches of biology, we are obviously going to achieve excellence in none of them. Lacking the background and endowments of other places, it seems natural for us to try to speedily retrace their steps before emerging by the same route to glory. But in fulfilling the role of advisers to the nation on the impact of modern biology, we would be better advised to follow the course of developing accoutrements that will serve the newer trends of biological science. It is no easy matter to predict which directions the science of the future will go, either by its academic momentum or its social responsiveness. Faced with the necessity of choosing alternatives, we would do better to take some chances by investing in the future than to plod along in the hope of catching up. Accordingly, we should place less emphasis on a literal copying of the traditional accoutrements of biology and strike out for facilities and activities that will serve the biology of the future.

At the level of the individual laboratory, requirements for new and major equipment are increasingly to be expected. Automated analytical devices which feed results directly to computers can enable investigation at new levels of comprehensiveness, and at the best laboratories, much of the tedium and human error of biological research have been eliminated. Development of the application of radioactive tracer techniques to biology hinges upon good (and expensive) instrumentation. Telemetric devices, electronmicroscopes, amino acid analysers, infrared spectrometers, and the like, have taken the place of the rubber boots and tweezers of yesterday's biologists. The modern biologist needs much of the same equipment as those in the physical sciences, and he has the added problems of maintaining and studying perishable living materials.

To meet the need for ever more sophisticated and expensive equipment, biologists, and particularly their administrations, should be thinking in terms of a new scale of expenditure for the future.

The state of our National Museum deserves a particular comment because it is pathetic by old-world international standards. The apparent aspiration of the museum is to emulate the large institutions of a bygone day which were repositories of taxonomic material, and by virtue of the emphasis on morphology, the centres for systematics of their day. Most of them had sufficient patronage, prestige and income that they were able to carry on these kinds of activities, as well as to provide a show place where the marvels of the natural world could be exhibited to the general public.

It is no longer desirable for museums to serve this multiple role. Nowadays, if you want to run a show place, you have to be a showman. If you wish to be a systematist, you must be concerned with modern genetics, modern ethology and modern ecology. The new systematics takes the morphology in its stride as one of the essential components in investigation. It is very unlikely that rearrangement of biological material into new pigeonholes and explorations all over the place will result in any drastic revision in the major concepts of the theory of evolution, even though it may be responsible for taxonomic revision of groups and the provision of a sound base of systematics for work in other disciplines.

In consequence, it would probably be desirable to split the various roles of traditional museums and to have each performed in its most appropriate milieu. The public display and showmanship jobs should be turned over to the cultural agencies, perhaps some rearrangement of some of the present activities in the Secretary of State Department. Development of the activities of modern research systematics should be centred in universities.

The truly museum activities, those that centre around the bookkeeping of scientific material, classical systematics and the largely technical jobs of identification (a necessary service to many other branches of biology)[1], should be set up under a single administration (perhaps under the National Research Council) in a similar fashion to a national library service. There should be a large central repository and a network of national regional museums. This concept has wide acceptance among Canadian biologists. Development of the concept could proceed forthwith by suitable negotiations between the National Museum and various provincial museums that have the capacity for growth into national regional centres. Hopefully, each regional centre would act as a repository of material from the region, a "mail order" office for communication with all branches of the National Museum, and a focal point for identification services in the region.

Every encouragement should be given to eliminating the duplication of this kind of activity in different federal government agencies. Rather unrealistically, several agencies have embarked on a course that would only be appropriate if each were the only scientific agency in the country. Consequently, there are very substantial museum collections in several federal government departments and little bits and pieces of museum material in various university and government offices across the country. Some of these collections (the superb Canada Department of Agriculture material on insects, for example) are already assigned as being part of the National Museum. With the development of a strong national museum and identification service, it would be hoped that, by a rapid process of voluntary attrition, many bits and pieces in the country might coalesce into a useful, functional, national entity.

With all of these steps, the concept of a "British Museum" in Canada would die an appropriate natural death, and its parts would be salvaged for more modern enterprises.

The need for a feeling of a "national identity in an international brotherhood" is more valid today than ever before. There is no lack of imagination to suggest new lines of investigation, and there should be no limit to the kind of enterprise that should be supported. But the country cannot afford to support the kind of mediocrity that arises from fragmentation, duplication of hobby shop levels of effort and ignorance of what is being done elsewhere, or failure to exploit the critical evaluations of colleagues. Yet, for various reasons, largely historical, Canadian biology is not characterized by the freewheeling kind of communication and criticism that encourages quality.

Pompous as it may sound, it seems reasonable to say that Canadian biology has a national service to perform that must transcend the parochial chauvinisms of its subdisciplines and administra-

[1]For example, the Canadian Oceanographic Identification Service of the National Museum has been very useful to the Canadian marine IBP projects.

tive subdivisions. Machineries are needed that will provide the necessary forums for debate, and the committee structures for *ad hoc* or periodic assessments of the "state of the nation" with respect to particular problems or disciplines. The day is long since past when idiosyncratic reviews (such as this review) can adequately serve to provide judgements on the wide sweep of socially important subjects which comprise modern biology.

The one great contemporary need of Canadian biology is for devices that will give it more cohesion, more of a single voice, and more of the internal communication that is necessary if it is to serve society effectively. The recent emergence of the two biological parent organizations, the Canadian Federation of Biological Societies and the Biological Council of Canada, is highly encouraging. Providing a single forum for debate and vigorously engaged in a continuing assessment of progress and problems, they will do much for Canadian biology. They should be supported by all segments of the biological community. Enterprises of their kind are long overdue in Canada. It is a widespread belief that, for basic research, the system involving the scientists and their funding agencies should be, as nearly as possible, self governing. The learned societies thus have the challenge to rise to the occasion by attempting to give the self-guidance which the country expects of them.

The Administrative Deployment

There are almost 5800 "life scientists" in Canada (Table 3). Less than 10 per cent are in industry; the other 90 per cent is about equally divided between governments and universities. The federal government group outnumbers the other government life scientists by about 2 to 1. These divisions of manpower probably reflect history and a Canadian way of doing things. By comparison with other technologically advanced countries, the industry segment seems low, and was a matter of remark in several panel reports. The strong federal government representation is characteristic of many of our institutions. A greater provincial commitment to science would seem to be desirable for the future.

Classified by mission, the various groupings of life scientists suggest a strong applied emphasis in Canadian biology. The "biology" group as a core is only about one-ninth of the total, and is ostensibly less than one-half the group of federal government biologists or the group of agricultural life scientists, or about the same size as the forestry group or the fisheries and wildlife group. These are misleading comparisons, of course, because some of the 5800 are better described as professional practitioners rather than as research scientists. With all shades of grey being represented, and virtually all being potential research contributors, it is extremely difficult to estimate precisely the relative emphasis on various degrees of "fundamentality". By using rather arbitrary arithmetic, it might be estimated that roughly 40 per cent of the total manpower effort is directed toward basic areas (viz. put together most of the biology group, roughly one-half of the medical group, and one-quarter of the remainder).

It should be underlined, however, that, in the non-medical areas, university biologists are only half as numerous as government biologists, and that the total number of biologists in arts and science and science faculties is a small group in the overall total of life scientists in Canada. In developing Canadian biology for the future, it must be recognized that in the past there has been a substantial applied overtone to most of our activity. As well as a considerable involvement of university workers in applied work, there has been a substantial national investment in government scientific enterprises. The panel reports make frequent mention of federal laboratories as being the only real "centres of excellence" in various subject areas. This was perhaps appropriate in the circumstances of our development, but for the future, it could

Table 3–Number of Research Scientists Employed by Government, Industry, and Universities, related to Life Science Missions

Employer	Life Science Mission							Total
	Biology	Agriculture	Medical	Forestry	Fisheries Mgmt.	Wildlife Mgmt.	Other	
Industry (and Private):	–	184[1]	308[1]	42[1]	–	7[2]	8[1]	549
Government:								
Provincial	44[1]	167[1]	(307)[5]	46[2]	107[2]	117[2]	–	788
Federal, NRC	84[1]	–	–	–	–	–	–	84
Federal, Other	–	810[1]	117[1]	420[6]	170[6]	92[1]	73[1]	1 682
University:								
Arts/Science	512[4]	209[2]	–	45[2]	27[2]	45[2]	37[2]	875[4]
Forestry	–	–	–	83[4]	–	–	–	83
Medical	–	–	1 365[3]	–	–	–	–	1 365
Agriculture (incl. Vet. Med.)	–	346[2]	–	–	–	–	–	346
Other	–	–	–	–	–	–	19[2]	19
Total	**640**	**1 716**	**2 097**	**636**	**304**	**261**	**137**	**5 791**

[1]*Directory of Scientific R&D Establishments in Canada.* Dept. Industry, Trade and Commerce, 1969.
[2]Appropriate Science Council of Canada Special Studies of Agriculture, Forestry, Fisheries and Wildlife, Marine Sciences (in press).
[3]*Canadian Medical Research: Survey & Outlook.* MRC Report No. 2, includes dentistry, pharmacy, public health, and related medical fields to the extent reported.
[4]Based on count of Assistant Professors and higher, 1969-70 university calendars.
[5]Unpublished 1967 DBS estimate for Prov. Govt. Depts.; DBS publication 13-526 re: hospitals.
[6]Dept. of Fisheries and Forestry, and International Fisheries Commission (personal communication).
Note: ( )Estimate of full-time equivalents.
– Not within definition of "mission".

leave us short on scholarship, inspiration, originality and independence. If the shift is not toward the growth of academic science, we are much more likely to perpetuate our current weaknesses. While the *status quo* is perhaps adequate for the transition period, there can be no doubt that the long-term drift must be toward proportionately more university research that is "administratively uncommitted".

For the group of biologists to which this review is chiefly directed, it is useful to examine the applications to National Research Council biology grant selection committees. The applicants are a limited group of people whose research in whole or in part is ostensibly "administratively uncommitted". It includes most of the biologists of university arts and science or science faculties, some applicants from faculties of agriculture and forestry, and a few federal and provincial government scientists participating in university work.

Thirty-nine Canadian universities were represented in the applications during the years 1966 to 1969. In 1969 there were 1079 applicants, of whom 927 were successful; in 1970 there were 1173 applicants, 967 of whom were successful. More than one-half of the applicants (646) were at the nine "universities": Guelph, British Columbia, Toronto, Alberta, Manitoba, Saskatchewan (Saskatoon), Laval, McGill, and Macdonald (at McGill). Almost three-quarters (855) were in 17 institutions, the other 22 institutions contributing numerically to only a bit more than a quarter of the total. Canadian academic biology is apparently concentrated in a relatively small number of places, many of which have only recently emerged and are still potential rather than active centres of research.

The National Research Council (NRC)

The single administrative machinery most important to the future development of "core" biology at Canadian universities is the National Research Council. Operating under the term of reference "to undertake, assist or promote scientific and industrial research, including, without restricting the generality of the foregoing... (sic)", the Council has become the holder of a large handful of the keys to new prospects for biology. As we all know, every biologist in Canada learns his grantsmanship early in his career. The heads of Canadian biology departments know that one of the major lines of progress is the "landing" of an NRC negotiated development grant. The Council is also the biggest single source of scholarships and fellowships, the publisher of some major Canadian biological journals, the manager of the national science library, and an obvious place to go if you have any bright new idea to float that requires an agency with a liberal-mindedness, a big budget and flexible terms of reference.

Bearing in mind that it has had a very large responsibility in developing science in Canada, the National Research Council has done a remarkable job, particularly in ensuring a minimum of bureaucracy and in consistently encouraging the scientific community to share in deciding the course of its own future.

Awards to biology are roughly 23 per cent of the total in science, and biologists are roughly 25 per cent of the total number of applicants. In these circumstances, it is surprising that there is only one biologist on the 18-member Council. There are, of course, many desiderata in forming a Council and it may be difficult to solve them "orthogonally". Nevertheless, bearing in mind that biology shows signs of being the biggest science of the future, and that it already has great breadth and social importance, it is apparent that biology should be better represented. If you asked biologists, they would probably suggest that one-quarter of the Council's scientists should be biologists.

Coupled with its responsibilities so crucial to university research in biology, the Council also operates a biological research program of its own that ostensibly complements whatever else is going on anywhere in the country (in universities, other government departments or elsewhere). Their particular emphasis is on pathfinding in areas that show technological promise or social relevance[1], a somewhat more difficult "mission" to identify than that of other government agencies.

The two major functions of the Council–promoting university development and doing "in-house" research–theoretically could lead it to some difficult major decisions, i.e. whether to develop an NRC team or to encourage a university development. In practice the two budgets are separate items that are separately justified and presumably there is no real problem.

There remains the question of what should be done with the existing "in-house" biological research programs of NRC. The research activities in various "mission-oriented" departments and agencies of government have been treated extensively in other Science Council reviews. Suffice it to say that a strong case can be made for doing a modicum of basic work in government laboratories. First, it may not be easy to arrange to do it elsewhere (though there is real need for trying new administrative arrangements). Second, the presence of a group of "in-house" consultants provides an excellent and necessary source of internal criticism and judgement. Third, many contemporary problems require a degree of technical and critical ability that is only found in scientists who have opportunities to develop basic lines of work. Fourth, and most to the point, and returning to an earlier theme, when the orientation is to problems and the best ways of solving them, government research is bound to involve a basic component.

For the particular case of the present NRC "in-house" research in biology, it is

[1]The policies and practices of NRC are clearly stated in the document, *Support of Research in Canadian Universities by the National Research Council*, which was based on a brief submitted to the Study Group on support of research in universities. Similar statements of policy and practice are available in the *Report of the President, 1968-69*. The comments which follow should be considered in the general context of these various statements of NRC activity.

perhaps doubtful that it should grow rapidly in the present circumstances; but it is certainly not desirable that it should be cut down. A relatively small number of biologists is involved. Aside from the research they do, which is not to be dismissed lightly, they are a source of informed opinion which has potential for a particularly unprejudiced point of view. Like the NRC time signal, they have about the same neutrality to everybody. Organized to perform even more of the chores to the total community than they presently do, and given the time to do enough research so that their technical opinion is worth having, they have a role to perform in the future which, while perhaps slightly different in emphasis from that of the past, is one into which they can easily evolve.

The developing activity in the National Research Council of a clearinghouse and central repository of information on pollution seems a particularly appropriate role. Similarly, it is suggested, in a later part of this review, that NRC might provide the appropriate umbrella for organization of taxonomic identification services in Canada. These, and similar activities that serve a wide cross section of Canadian biology, can substantially assist the total development of the science for the future.

With respect to the particulars of their "in-house" research activity, it is essential that NRC duplicate neither the research in other government agencies nor that which is best developed at universities. Thus, where a problem requires a long-term commitment, it should be quite clear that, if NRC is to tackle it, the problem should be outside the purview of other branches of government, should be directed to a problem rather than a discipline, and should clearly require the setting up of an establishment. Similarly, for other government agencies, the creation of a new unit should proceed only after comprehensive assessment of the real requirement for "in-house" research.

The basic difficulty of this simple thinking is that, because of the many difficulties of biological research, it frequently gets lost along one or more of many side channels. When there are inadequate resources, there is a tendency to pursue what is soluble rather than what is difficult but most relevant. And since investigations and investigators gain a momentum on a particular line of research (whether in government or university), it may become necessary to make progressively more strained arguments about relevance. In some instances one may observe arguments for continuing or expanding a line of work that almost amount to self-fulfilling prophecies. Given a group that creates awareness, there is generated a concern for "problems" that are "pressing", for which more staff is necessary, creating new spheres of awareness, and so on. The eventual surgery that may be necessary to short circuit the "do loop" may thus be quite painful. Administrators of government laboratories continuously struggle with this major problem of research administration.

For the future it would seem desirable to explore ways of preventing these problems. A possible answer is for the National Research Council and other agencies to hire more of their staff on a contractual basis or to contract out research problems to commercial research firms. If the national picture calls for a short-term blitz on DDT research, the NRC might build its own staff, but alternatively might hire a team of researchers on premium salaries to do the work (whether basic or applied), giving each worker a clear guarantee of, say, five years' employment, with one year's notice of intent for renewal and no fringe benefits other than those carried on a day-to-day basis. A portable pension scheme would lower the salary commitments. Quite possibly, some research requirements could be advertised for tenders from commercial firms or opportunistic consortia of individuals.

To the degree that the problems in research of government agencies may be temporary or ephemeral, contractual procedures will substantially help in getting out of research activities which seem needed but then turn out to be trivial, or get done elsewhere, or whatever. At the same time, they enable quick response to new problems with the forming of new teams of fresh and suitable people, rather than trying to teach new tricks to old dogs or going through the meaningless rituals of putting new names to old research. For the future, when responsiveness and flexibility will be vital, the reactionary philosophy of making short-term deals for better or worse may be much the best way of handling a proportion of government "in-house" research.

Such arrangements might also do service to the relation between the National Research Council, other government agencies, and the universities. It seems that whenever a national scientific problem or social crisis of virtually any kind arises, universities may be quick to state that something they are doing is very important in solving said problem or said crisis. With great sincerity but short memory, they argue the merits of their particular campus as a place to do the "much needed research on subject X". They would perhaps do better to argue the merits of developing broad areas of study, and would be more likely to do so if the temptations were removed by placing short-term national problems clearly in the lap of government agencies or their contractual teams.

In many instances, there may be merit in putting contractual teams on university campuses where their work would be less susceptible to the introversion and xenophobia of isolation, and best placed to exploit existing facilities.

The Machineries of NRC Research Grants

Each year four biology grant selection committees of the National Research Council decide on the distribution o about $9 million among more than 1000 applicants (see Table 4 for details for 1969 and 1970).

The procedure of deciding on awards is basically similar in the four committees (cell biology, animal biology, plant biology and population biology). Seven or eight Canadian university scientists, representative of the various facets of the subject matter and of the various parts of the country, review in excess of 200 requests in no more than 2½ days. If 2½ days represents 20 working hours, no grant application receives more than six minutes consideration (three minutes would probably be closer to the norm). Each of the members has had about two weeks to look at all the applications before the committee meets, and each member has a responsibility to speak first on a share of the total number of applicants.[1]

The system relies heavily on committee members doing their homework, and on their familiarity with the work that is going on in the country. There can be little question that, despite every attempt to be completely fair, the committees may sometimes play favourites of one kind or another, and with respect to the people they know less well, may dispense some random justice. It is certainly not uncommon to hear complaints about the system from people who feel that they have not been fairly treated.

Some degree of discontent should be taken as a sign of good management–in a word, it is "music" to administrative ears. Moreover, it is the practice that members of grant selection committees should have only a three-year period of tenure. In consequence, there are opportunities for imbalances to be redressed, as each set of decision-makers operates from a slightly different base. All things considered, the present system of making awards, while casual in appearance, seems to provide a reliable but somewhat erratic system of judging on substance.

The real question is whether this system is a suitable base on which to

[1]The sessions are "convened" by NRC staff scientists who keep the books, and who also keep a scrupulously passive role in the granting procedure.

Table 4–Summary of National Research Council Operating and Equipment Grants ($5 000-$50 000), March 1969 and March 1970

Grant Selection Committees	March 1969								March 1970							
	Operating				Equipment				Operating				Equipment			
	Requests		Grants		Requests		Grants		Requests		Grants		Requests		Grants	
	$000	(No.)	$000	(No.)	$000	(No.)	$000	(No.)	$000	(No.)	$000	(No.)	$000	(No.)	$000	(No.)
Biology:																
animal	3 658	(254)	1 816	(238)	700	(52)	192	(16)	4 030	(276)	1 878	(234)	963	(62)	218	(20)
cell	5 020	(304)	2 252	(252)	2 039	(115)	663	(51)	5 436	(345)	2 461	(277)	1 453	(94)	680	(55)
plant	2 707	(207)	1 509	(176)	642	(43)	141	(12)	2 979	(234)	1 660	(191)	615	(49)	133	(13)
population	4 188	(314)	1 920	(261)	452	(35)	185	(15)	4 231	(318)	1 990	(265)	548	(39)	132	(11)
Psychology	2 240	(238)	1 550	(194)	163	(10)	58	(4)	2 432	(255)	1 683	(211)	290	(18)	12	(2)
Chemistry	10 031	(594)	5 903	(569)	3 305	(172)	392	(28)	11 152	(644)	6 193	(593)	3 408	(177)	275	(12)
Physics	5 844	(406)	3 052	(367)	1 737	(99)	602	(47)	6 633	(436)	3 268	(387)	1 897	(114)	513	(44)
Engineering:																
chem. & met.	4 212	(278)	2 295	(254)	1 330	(88)	298	(27)	4 532	(294)	2 469	(270)	1 758	(100)	225	(16)
civil	2 165	(176)	1 194	(158)	610	(31)	208	(13)	2 868	(193)	1 317	(170)	742	(40)	173	(15)
electrical	3 638	(252)	2 055	(227)	1 439	(71)	289	(23)	4 545	(270)	2 261	(259)	1 720	(95)	214	(24)
mechanical	3 262	(238)	1 792	(220)	657	(38)	219	(23)	4 046	(279)	2 035	(254)	1 017	(56)	322	(23)
Earth Sciences	5 231	(421)	2 889	(397)	1 453	(91)	335	(30)	5 660	(433)	2 902	(403)	1 473	(96)	388	(36)
Space & Astronomy	2 579	(122)	1 397	(114)	681	(34)	173	(15)	2 929	(140)	1 485	(129)	702	(37)	165	(14)
Mathematics	4 427	(450)	2 009	(433)	6	(1)	—	—	4 922	(533)	2 072	(505)	—	—	—	—
Comp. & Info. Sci.	1 007	(90)	521	(81)	74	(4)	24	(3)	1 878	(134)	776	(113)	183	(11)	21	(2)
Totals	**60 209**	**(4 344)**	**32 154**	**(3 941)**	**15 288**	**(884)**	**3 779**	**(307)**	**68 273**	**(4 784)**	**34 450**	**(4 261)**	**16 769**	**(988)**	**3 471**	**(287)**

build for more onerous tasks. At one time there were two grant selection committees–a General Biology Committee and a Prairie Regional Committee. This pair was then replaced by two committees, one for the universities that began with the letters "A to McG", and the other from "McG to Z" (good grief!). Still later a third committee was added for agriculture and forestry grants. Finally, in recent years, the present logical arrangement of committees related to subject matter was devised. There are three possible needs for the future–a greater number of committees, more rigorous review procedures, and a parent committee to consider matters of policy. The group of four now does a good job of reviewing applications, but there is only the legwork of *the* biologist on the Council to thread common themes through the whole pattern of activity. Consequently, biology as a whole is not served cohesively and, in fact, co-ordination of the work of the four committees is minimal. It would be desirable to strike a parent committee, perhaps one comprising the chairmen of the various grant selection committees and *several* of the biologists on the Council (the NRC Advisory Committee on Biology has had this type of role in the past).

A further split into more selection committees would seem to be indicated within another three to five years, as the work load increases.[1] Alternatively, committees could meet for a longer period. The use of outside referees could strengthen the selection procedures, and NRC could here follow the lead of the Medical Research Council. Where government scientists have particular expert knowledge to contribute, they should be added to selection committees as advisers.[2]

[1]The three-year grants which started in 1970 may provide opportunity for better evaluations, for there will be only a third as many applicants to review each year. On-site visits are much to be encouraged for this new scheme.

[2]This has been made possible by a recent change in policy.

As a final point, it would be desirable if some way could be found of providing applicants (especially new applicants from smaller institutions) with good advice about the form research proposals should take. Although all applicants have a good booklet of instructions available to them, some personal advice from an NRC officer would probably help to remove some of the inequities that arise from misunderstanding or ignorance on the part of the applicant. A technical officer who visited campuses and met with applicants to discuss their problems might be a good investment.

The technique of granting awards proceeds on the policy of assessing the man rather than his research proposal. As for any meritocracy, the ostensible long-term result will certainly be that the rich will get richer, while the poor get poorer. For example, the present average grant at the larger and better-established universities tends to be greater than at the smaller and newer universities (Table 5). This difference is even more apparent when the number of zero awards is included in the comparison. The top 15 universities have 52 per cent of the biologists and get 60 per cent of the funds. The top 20 have 70 per cent of the biologists and get 80 per cent of the funds. And all this is perfectly understandable. The good researchers will be attracted to better research environments.

A further raising of standards and adequate assessment of the real degree of spread in research ability of the applicants, both of which appear desirable, would presumably make the differences even greater. But there is more to the granting procedure than meets the eye. A large proportion of the applicants are perhaps not distinguished, but they are competent. The investment of relatively modest amounts of money in the researches of several of these people may well pay more dividends than massive investments in very few people. Moreover, there are always many new applicants whose research potential can

Table 5–Average, for the years 1966-67 to 1969-70, of Annual National Research Council Grants in Biology to those who Applied for Operating Grants for 1970-71, Classified by University

University	Animal Biology			Cell Biology			Plant Biology			Population Biology			Refusals up to 1969	Total, All Divisions	Total Appli-cations	Average Grant/ Appl.	Rank
	No.	Total	Av.	No.	Total	Av.	No.	Total	Av.	No.	Total	Av.					
Alberta	18	114 500	6 360	22	181 100	8 230	19	108 400	5 700	20	120 100	6 000	7	524 100	86	6 090	11
Acadia	1	5 500	5 500	—	—	—	—	—	—	4	14 100	3 520	2	19 600	7	2 800	
Bishop's (Lennoxville, P.Q.)	—	—	—	2	8 900	4 450	—	—	—	1	4 100	4 100	2	13 000	5	2 600	
British Columbia	23	197 400	8 580	27	296 400	10 980	20	129 300	6 460	29	255 600	8 810	8	878 700	107	8 210	2
Brock (St. Catharines, Ont.)	1	5 300	5 300	4	32 400	8 100	2	9 100	4 550	—	—	—	0	46 800	7	6 690	8
Calgary	7	37 100	5 300	13	78 100	6 010	3	28 500	9 500	11	67 600	6 140	1	211 300	35	6 040	13
Carleton	2	12 000	6 000	6	58 200	9 700	5	31 400	6 280	5	20 700	4 140	1	122 300	19	6 440	9
Dalhousie	2	13 500	6 750	4	21 300	5 320	2	20 900	10 450	8	66 400	8 300	1	122 100	17	7 180	7
Guelph (+O.A.C.)	43	238 700	5 550	30	134 800	4 490	30	182 000	6 070	20	88 700	4 430	20	644 200	143	4 500	
Lakehead (Port Arthur, Ont.)	1	3 000	3 000	—	—	—	1	4 800	4 800	1	3 500	3 500	4	11 300	7	1 610	
Laurentian (North Bay-Sudbury)	2	8 600	4 300	—	—	—	1	4 000	4 000	4	11 800	2 950	0	24 400	7	3 490	
Laval	12	67 300	5 610	13	92 000	7 080	10	52 900	5 290	13	56 500	4 340	4	268 700	52	5 170	
Lethbridge	2	6 000	3 000	1	7 400	7 400	1	7 000	7 000	—	—	—	0	20 400	4	5 100	
Macdonald (at McGill)	14	134 200	9 590	8	85 300	10 660	7	49 800	7 110	5	26 900	5 380	3	296 200	37	8 010	3
McGill	7	48 200	6 890	19	180 700	9 510	6	38 200	6 370	13	102 500	7 880	4	369 600	49	7 540	6
McMaster (Hamilton)	3	26 200	8 730	15	149 300	9 950	1	14 100	14 100	2	9 000	4 500	1	198 600	22	9 030	1
Mt. Allison (Sackville, N.B.)	1	3 300	3 300	2	12 700	6 330	—	—	—	—	—	—	1	16 000	4	4 000	
Manitoba	15	92 300	6 150	21	145 000	6 900	28	203 400	7 260	15	78 500	5 230	10	519 200	89	5 830	16
New Brunswick	6	35 200	5 870	5	21 200	4 240	1	4 400	4 400	5	19 000	3 800	6	79 800	23	3 470	
Memorial	3	29 100	9 700	4	17 700	4 420	2	7 400	3 700	15	96 800	6 450	2	151 000	26	5 810	
Moncton	—	—	—	—	—	—	—	—	—	3	10 200	3 400	3	10 200	6	1 700	
Montreal	8	70 500	8 810	7	71 500	10 210	4	30 000	7 500	6	40 400	6 730	3	212 400	28	7 590	5
Ottawa	2	17 200	8 600	5	56 800	11 360	2	11 200	5 600	4	37 000	9 250	3	122 200	16	7 640	4
Prince Edward Island	—	—	—	1	3 000	3 000	—	—	—	—	—	—	0	3 000	1	3 000	
Queen's (Kingston)	6	50 900	4 420	11	67 500	6 040	3	25 900	8 630	6	33 200	5 570	2	177 500	28	6 340	10
Saskatchewan (Regina)	2	8 500	4 200	4	28 900	7 220	2	12 800	6 400	6	27 000	4 500	1	77 200	15	5 150	
Saskatchewan (Saskatoon)	15	101 000	6 730	9	50 400	5 600	19	124 100	6 530	12	69 900	5 820	9	345 400	64	5 400	
St. Mary's (Halifax)	2	8 700	4 350	—	—	—	1	4 500	4 500	—	—	—	0	13 200	3	4 400	
Sherbrooke	3	23 100	7 700	2	7 700	3 850	—	—	—	5	24 100	4 820	0	54 900	10	5 490	
Sir George Williams	1	5 000	5 000	2	6 900	3 450	2	9 000	4 500	1	6 900	6 900	3	27 800	9	3 090	
Simon Fraser	6	35 700	5 950	8	47 700	5 960	3	22 800	7 600	12	81 200	6 770	2	187 400	31	6 050	12
St. Francis Xavier (Antigonish)	—	—	—	1	2 500	2 500	1	8 000	8 000	—	—	—	2	10 500	4	2 620	
Toronto	19	131 900	6 940	20	127 400	6 370	13	86 600	6 660	32	213 100	6 660	10	559 000	94	5 950	15
Trent (Peterborough, Ont.)	2	20 300	10 150	2	9 100	4 550	1	3 500	3 500	4	18 900	4 720	1	51 800	10	5 180	
Victoria	10	65 700	6 570	2	6 300	3 150	2	12 900	6 450	7	31 500	4 500	4	116 400	25	4 660	
Waterloo	4	20 900	5 230	8	38 000	4 750	2	20 200	10 100	6	48 100	6 020	3	127 200	23	5 530	
Windsor	1	4 300	4 300	6	27 900	4 650	2	12 600	6 300	2	11 900	5 650	2	56 700	13	4 360	
Western Ontario (London, Ont.)	6	32 700	5 450	7	36 300	5 180	6	66 600	11 100	10	56 900	5 690	3	192 500	32	6 020	14
York (Toronto)	4	18 800	4 700	9	68 600	7 620	2	7 100	3 550	1	7 300	7 300	3	101 800	19	5 360	

scarcely be assessed without a few years of "seed" grants. Also, too rapid a response to an apparent "comer" may prove unwise, and being too quick with the axe on fading productivity may reflect lack of appreciation of circumstances of the individual or the particular stage of his work. These are the facts of life that make decisions of grant selection committees difficult and for which statistical analyses of applications and awards are likely to be unrevealing.

The present procedures of peer judgement seem the only safe guide in the subjective circumstances. To the degree that they err because of ignorance, they are more likely to favour charity, giving the benefit of doubt to the applicant. There is thus a good argument for better review procedures.

The question continues to arise, "Who will support the person of very limited competence whose application is rejected by NRC but whose participation in research is deemed desirable as an aid to good teaching?" The answer seems to be that the universities should provide this support, doing so to the degree that they believe in what they so frequently say on the subject (and doing so with funds other than those for "overhead" from NRC).

It is to be underlined that regional or subject matter preferences, and especially the degree of "mission orientation", should be vigorously excluded from the considerations of the grant selection committees. To load them with such a responsibility would be quite unfair, especially when their value as adjudicators is premised on their knowledge of the specialty rather than their grasp of the national need. More to the point, if they were to judge on any other basis than merit, they would lose all credibility in the eyes of their colleagues.

Lack of strong support for individuals of outstanding merit is another sore point in the total granting picture. The panel reports make frequent lament about the absence of "schools" in Canadian biological research. In some measure, this may be a sentimental attachment to the erstwhile traditions of European science which, in its heyday, was built around the few and glorious. Today, the paternalistic pattern of such an establishment is considered passé, partly for reasons of democratization, and partly because the pace has so quickened that few stay in the limelight long enough to warrant lifetime heroship. The requirement, then, is to devise a machinery which is quick to detect brilliance and equally quick to detect its fade. The National Research Council in particular, and the other granting agencies in general, need special funds for five-year massive support of particular research people with particularly good ideas. For example, grant selection committees of NRC might each choose one applicant each year for maximal five-year support, not only giving him what he asked for, but encouraging him to ask for as much as he can efficiently digest. This could mean that four people a year might each get as much as \$100 000. With the expectation of dropping a "set" every five years, the total annual expenditure would be no more than \$2 million. The payoff would be in the leadership of 20 top biologists in Canada.

Additionally, the National Research Council should provide encouragement for proposals to form teams. The Medical Research Council (MRC) is currently doing this. The NRC block-term grants of some years ago were perhaps conceived as a device for this among other purposes, and should perhaps be revived for just this purpose. The NRC grant selection committees, with awareness of the usefulness of group activity in their own disciplines, could perhaps be given the additional responsibility for reviewing "team" applications, striking special review committees for on-site visits and discussion prior to awarding of a grant.

A particularly timely matter for discussion is the pattern for supporting graduate students. Like the fixed-income groups in our society, graduate students find their years of apprenticeship a financial strain in these days of inflation. Many of the students are married and even an NRC scholarship ($3 600) is a bare living. Those who are not on scholarships may be hired as student research assistants, receiving either $3 000 a year *from their supervisor's operating research grant*, or a $1 000 summer stipend plus a winter teaching assistantship of $2 000 to $2 500.

Aside from the size of these stipends, which should be a matter of major concern, there is the issue of the way in which they are administered. Except for the undue emphasis on third-year performance, the scholarship awards are done on a basis which seems eminently fair. Given a scholarship, a student can shop for the institution and supervisor he is attracted to. By contrast, the non-scholarship student must shop for an institution and a supervisor who can support him. From the student's point of view, this may mean that he cannot get into graduate work unless he finds support for himself, or that he must work in a subject area which is not his first choice. The professors with the larger grants have more funds to spend on graduate student assistants and, consequently, they are generally well loaded with students.

In recent years the proposal has been debated that graduate student support should be separated from operating grant requests, federal funds for student support going to universities to administer. Some professors see this proposal as a useful device that would bring greater equity to the students of various leanings and "fairer" distribution of students to professors. The good graduate supervisor, it is argued, may not necessarily be a productive researcher himself. Others view the scheme with hostility because they feel that good researchers are the best tutors of research students and that university-administered schemes would be much weaker in ensuring quality.[1]

A group of graduate students at the University of British Columbia strongly favoured a plan of supporting all "good" applicants by a uniform amount in their first year, requiring all to undertake some teaching or other responsibilities to earn it, and awarding of continuing scholarships to some fraction of the group on the basis of this first year of performance *as graduate students*. It has also been suggested that grant selection committee review panels might comment on the suitability of proposed research projects as vehicles for graduate teaching. If a project was found to merit support but was not suitable for graduate teaching, grants might be given with the appropriate proviso that funds should not be used for student support.

The question of how to support graduate students is evidently complex and many-sided. The present system is a patchwork of improvisation. Practices vary within and among universities. A national conference, involving many representatives of the graduate student body, would seem to be a very desirable way of starting a review that would lead to any needed reform.

The foregoing are facets of the NRC granting procedure that are widely appreciated and widely debated perennially across the country. It should be clearly appreciated that, if it is the object of the National Research Council to support excellence, then there should be fewer grants and bigger grants mostly to people in the bigger institutions. Whether policy should be so single-minded is another question. It could be argued that NRC policy might be to support excellence in major centres and to support mediocrity up to a point elsewhere in the hope that the caterpillar of mediocrity, given time, may metamorphose into the butterfly of distinction. Unfortunately, it may only produce bigger caterpillars.

[1]This topic is discussed in the Special Study No. 7 of the Science Council, *The Role of the Federal Government in Support of Research in Canadian Universities*. It is there argued that the present system should be discontinued because it tends to support students under the auspices of research programs of questionable quality! If this were true, the problem would seem to be more with the mechanisms of reviewing applications than with the way of supporting students.

The other major instrument of National Research Council granting procedures, the negotiated development grant, seems a much better device with which the NRC and an institution may jointly try to build competence by a substantial boost for a few years from the NRC. These grants provide the best route by which a smaller institution can hope to make a big jump in a particular field. One could make the argument that you are likely to get more for a research dollar by developing something that already exists, rather than trying to start from scratch. In the context of the international competition in science, this is a fairly forceful argument and should be the reason for some of these grants. But, from the point of view of the development of the total university community in Canada, it may well be better to focus attention on the small institutions. To an administrator there is nothing so welcome as a newcomer with the freshness and innocence that does not know yet why things cannot be done. And this is precisely the role of the new institutions. The better-established universities have had more opportunity to gain the merit and equipment that can attract excellence. The newcomers need major assistance to reach the same plateau.

There is thus reason for concentrating negotiated development grants in the two areas: building on an existing strength or starting a venture at a newer institution. Falling between these two alternatives can obviously amount to a general purpose grant without focus or impact, and can greatly increase the likelihood of preserving mediocrity.

To date there have been seven negotiated development grants in biology: Simon Fraser (pestology), Calgary (environmental science), Manitoba (wheat genetics), Montreal (molecular biology), Laval (nutrition), Guelph (migration and behaviour). Ostensibly each of these grants has been made with an assessment of relevance, national need and regional considerations.

The Other Granting Agencies

The whole picture of granting is, of course, considerably more complicated than is indicated by NRC policies and procedures. Operating grants are made to biologists by the Medical Research Council (MRC) and as well by the resource-oriented government agencies (Fisheries Research Board, Canada Department of Agriculture, Department of Energy, Mines and Resources, Canadian Wildlife Service and others).

Rather surprisingly, *grants to* NRC *applicants from agencies other than* NRC totalled almost $4 million in 1969 (about 45 per cent of what they got from NRC). Their distribution to universities (Table 7) was sharply different from that of NRC funds, only 7 of the top-rated for NRC being in the top 15 for outside grants. The combined grant to NRC applicants from both NRC and outside sources yields the ranking of universities in Table 6.

It seems that there are some substantial mechanisms for compensating the effects of NRC granting procedures, though they mostly result in rearrangement of the order of the established institutions rather than assisting the new and small universities. In some cases, substantial grants from the Canada Department of Agriculture for studies in agricultural science are involved; in others, grants from the Fisheries Research Board for studies relevant to fisheries. Grants from NRC to some individuals in cell biology may be substantially augmented by National Cancer Institute or Medical Research Council grants (or vice versa, depending on your point of view). In broadest terms, the total research support system seems equipped to ensure some measure of applied work at universities and some measure of special nourishment for beginners.

It would be "nice" to be able to say that this is a system with "built in checks and balances" and it is "healthy to have such diversity". To a degree these platitudes are appropriate, but they cover a number of irregularities, and disguise the fact that each biologist in the country has

Table 6–Average Grant per NRC Applicant from National Research Council and from other Sources, for the Fifteen Universities Receiving Largest per Applicant Grants from each Source

University	NRC Average Grant/ Applicant		Average Outside Grant/NRC Applicant		Total NRC and Outside Average	
	$	Rank	$	Rank	$	Rank
McMaster	9 030	1	3 710	8	12 740	3
British Columbia	8 210	2	4 520	5	12 730	4
Macdonald (at McGill)	8 010	3	7 640	1	15 650	1
Ottawa	7 640	4	1 880	–	9 520	10
Montreal	7 590	5	5 230	3	12 820	2
McGill	7 540	6	1 490	–	9 030	14
Dalhousie	7 180	7	1 880	–	9 060	13
Brock	6 690	8	0	–	6 690	–
Carleton	6 440	9	330	–	6 770	–
Queen's	6 340	10	4 640	4	10 980	6
Alberta	6 090	11	3 690	10	9 780	8
Simon Fraser	6 050	12	1 500	–	7 550	–
Calgary	6 040	13	2 130	–	8 170	–
Western Ontario	6 020	14	2 100	–	8 120	–
Toronto	5 950	15	3 560	11	9 510	11
Laval	5 170	–	7 010	2	12 180	5
York	5 360	–	4 320	6	9 680	9
Manitoba	5 830	–	4 200	7	10 030	7
Waterloo	5 530	–	3 710	9	9 240	12
St. Mary's	4 400	–	3 550	12	7 950	–
Saskatchewan (Saskatoon)	5 400	–	3 050	13	8 450	15
Guelph	4 500	–	2 870	14	7 370	–
Victoria	4 660	–	2 190	15	6 850	–

a potential shopping list for support. Fortunately, there seems to be a gaining liaison developing among the various federal granting agencies at the working level. Duplications in MRC/NRC support have been largely removed. The communication between NRC, MRC and the Canada Council (Tri Council Co-ordinating Committee) is said to be good, and it will need to be to sort out the procedures for the expanding group of social scientists whose work overlaps many disciplines. Liaison with the Canada Department of Agriculture and the Fisheries Research Board is also said to be good, but judging from the lack of information provided by applicants to the NRC, it would appear that there is room for considerable improvement in procedures.

For example, the typical agricultural scientist may well find that his research proposal may be written up in a way that appeals to both the Canada Department of Agriculture and the National Research Council, or perhaps to neither. The interdigitation of NRC and CDA grant selection committees would accordingly seem desirable. The same is true for the "fisheries" biologists who are supported by the Fisheries Research Board, largely by a system of major grants to institutions (something like negotiated development grants). These grants are commonly divided up by university departments in a quasi-NRC way once they are received. Many other granting agencies are also involved in somewhat similar arrangements. With the more than 40 granting agencies in the federal government alone, there is an urgent need for tidiness at a time when most science is talking about and may be moving into multidisciplinary pursuits.

Taken as a whole, the statistics of Table 7 strongly suggest that, for all of the coordinating at high levels, there is still a lot going on at the grass roots level that reflects confusion. The consequence may well be that the present distribution is desirable, but it would be reassuring if it were reached in a more orderly manner.

In addition to the duplications of grants, there are the questions of the differential

Table 7–Average Grant, for the years 1966-67 to 1969-70, from Sources other than the National Research Council, for Applicants to NRC in 1970-71, Classified by University

University	Animal			Cell			Plant			Population						
	No. grant holders	No. grants held	Total amount held	No. grant holders	No. grants held	Total amount held	No. grant holders	No. grants held	Total amount held	No. grant holders	No. grants held	Total amount held	Total all divisions	No. of NRC applications	Average outside grant per NRC applicant	Rank
Alberta	14	25	155 150	7	10	34 580	11	19	80 745	10	15	47 056	317 531	86	3 690	10
Acadia										3	5	11 150	11 150	7	1 590	
Bishop's										1	3	3 025	3 025	7	430	
British Columbia	15	23	150 850	13	17	99 400	22	33	115 050	19	26	118 300	483 600	107	4 520	5
Brock														7	0	
Calgary				3	3	32 590	2	4	24 130	3	4	17 750	74 470	35	2 130	
Carleton	1	1	1 550				1	1	1 550	2	2	3 100	6 200	19	330	
Dalhousie	1	2	6 000	2	2	2 900				2	4	23 000	31 900	17	1 880	
Guelph	25	40	151 010	19	25	123 788	24	32	88 850	14	15	47 200	410 848	143	2 870	14
Lakehead										3	5	7 170	7 170	7	1 020	
Laurentian	1	2	6 000							1	1	7 550	7 550	7	1 080	
Laval	7	14	79 750	6	10	74 000	4	4	16 700	5	8	194 000	364 450	52	7 010	2
Lethbridge	1	2	1 600	1	1	3 000	1	1	4 000				8 600	4	2 150	
Macdonald	11	25	125 140	6	10	59 100	6	12	52 800	2	9	45 750	282 790	37	7 640	1
McGill	2	2	13 500	4	5	49 370				1	1	10 000	72 870	49	1 490	
McMaster	2	4	15 500	7	7	66 165							81 665	22	3 710	9
Mount Allison	1	1	1 000	1	1	4 000							5 000	4	1 250	
Manitoba	8	13	57 905	11	18	87 600	13	27	128 859	13	18	99 024	373 388	89	4 200	7
New Brunswick				1	1	4 000				3	3	10 450	14 450	23	630	
Memorial										4	8	35 250	35 250	26	1 360	
Moncton							1	1	4 000				4 000	6	670	
Montreal	3	6	61 283	4	4	68 200				1	2	17 000	146 483	28	5 230	3
Ottawa				1	1	17 000	1	2	13 000				30 000	16	1 880	
Queen's	4	12	42 870	7	14	77 916				3	4	9 200	129 986	28	4 610	4

Table 7—Continued

University	Animal			Cell			Plant			Population						
	No. grant holders	No. grants held	Total amount held	No. grant holders	No. grants held	Total amount held	No. grant holders	No. grants held	Total amount held	No. grant holders	No. grants held	Total amount held	Total all divisions	No. of NRC applications	Average outside grant per NRC applicant	Rank
Saskatchewan (R)	1	1	2 500	1	1	1 400	1	1	2 600	3	3	6 625	13 125	15	880	
Saskatchewan (S)	9	16	69 075	4	5	30 100	12	17	64 630	7	12	31 225	195 030	64	3 050	13
St. Mary's	2	2	8 000				1	1	2 650				10 650	3	3 550	12
Sherbrooke	1	4	14 275										14 275	10	1 430	
Sir George Williams				1	1	1 000							1 000	9	110	
Simon Fraser	2	2	4 300	2	2	8 650	1	1	9 667	6	6	23 850	46 467	31	1 500	
St. Francis Xavier							1	1	825				825	4	210	
Toronto	9	10	26 830	13	18	82 450	6	7	14 890	16	24	210 703	334 873	94	3 560	11
Trent				2	3	10 900	1	1	1 000	3	4	4 550	16 450	10	1 640	
Victoria	7	8	22 100	3	3	18 500	2	3	4 315	5	5	9 800	54 715	25	2 190	15
Waterloo	2	4	5 800	5	8	19 250				7	9	60 350	85 400	23	3 710	8
Windsor	1	1	1 550	1	1	1 550							3 100	13	240	
Western Ontario				4	7	34 500	2	2	3 100	5	10	29 650	67 250	32	2 100	
York				6	7	73 700	1	1	3 200	1	1	5 200	82 100	19	4 320	6
Prince Edward Island														1	0	
Totals			**1 049 538**			**1 097 109**			**636 561**			**1 084 928**	**3 868 136**		**3 280**	

treatment that may be given to similar applications to different agencies. Separating the real disparities from the tangled circumstances of ability and opportunity may be difficult, but it should nevertheless be attempted.

The "MRC/NRC differential" is a much talked of case in point which warrants comment, because it appears to some that, for a proposal for the same work, an applicant to MRC gets more than one to NRC. Certainly the MRC has a different granting policy. Its rejection rate over the past several years has been higher (about 20 per cent on operating grants and about 30 per cent in the grants-in-aid program as a whole). The rate for support of applicants at the level of funds requested is much higher (about 40 per cent), although the ratio of dollars asked for to dollars awarded is about the same for NRC and MRC. The average grant per applicant and per successful applicant is substantially higher (Table 8).

Precise comparison of the relative treatment of NRC and MRC applicants is made difficult by differences in the granting philosophy and procedures but, nevertheless, these statistics boil down to the fact that the Medical Research Council provides larger operating grants, on the average, to a smaller fraction of its applicants than does the National Research Council.

Many justifications could be given for this differential, such as that the better medical researchers have more time to devote to their research than their counterparts in arts and science faculties, the medically oriented have greater needs for sophisticated instrumentation, medical science elsewhere is well supported and we must keep up with the others, and so on. What they all boil down to is that, in our society, respect for skilled medical research is well developed. Basically, the taxpayers would be reassured to know that good medical researchers are well supported. In a manner of speaking, those kinds of research expenditures are close to the bone.

The lessons to be learned, then, are twofold. First, rather than fret about the

Table 8–Applications and Awards for Operating Grants from Medical Research Council and National Research Council in 1968-69

Grant Range	MRC	%	Total NRC	%	Biology	%
$1 - $2 000	43	4	319	8	36	4
2 001 - 4 000	73	6	875	22	223	23
4 001 - 6 000	111	9	892	22	248	25
6 001 - 8 000	169	14	689	17	179	18
8 001 - 10 000	180	15	432	11	112	11
10 001 - 12 000	133	11	249	6	54	5
12 001 - 14 000	79	7	154	4	35	4
14 001 - 16 000	101	8	115	3	30	3
16 001 - 18 000	69	6	81	2	15	2
18 001 - 20 000	59	5	84	2	20	2
20 001 - 25 000	66	6	87	2	19	2
25 001 - 30 000	46	4	35	1	5	1
30 001 - 35 000	24	2	18	1	5	1
35 001 - 40 000	14	1	9	1	1	1
40 001 and over	37	3	19		1	1
Total Awards	**1 204**[1]		**4 058**		**983**	
Effective[2] Applications	1 610		4 266		1 072	
Total Operating Grants	16 619 363		31 054 000		7 416 581	
Meant Grant per Applicant	10 323		7 348		6 918	
Mean Grant per Sucessful Applicant	13 803		7 653		7 545	

[1]Includes 370 awards previously committed for renewal.
[2]Fresh applications plus renewals.
Sources: MRC–personal communication; NRC–University Research Assistance Branch, personal communication.

differential, NRC applicants in research areas with medical relevance should press for more vigorous grant selection procedures, and maximal support of the "few" best who, by virtue of their brilliance and opportunities for research, warrant support at the same level as the best of those who are funded from MRC. Second, universities should actively seek to eliminate their own internal medical and other differentials, rearranging duties and attitudes so that their best scholars in pure science have abundant opportunity to develop strong research potentials.

In Search of Balance, Excellence and an International Role

The patterns of major policy in science administration in Canada must surely include attempts to achieve a balance that ensures diversity and growth, an excellence that ensures major advances in some fields, and an international role that reflects awareness of the broadest contexts. Many discussions and decisions of the last two decades have been aimed at these objectives and, currently, the introspections of a number of reviews show promise of generating some new ventures in the search for improvement. The following comments may be added to these considerations.

One way of achieving at least an apparent balance is to so diversify the scientific structures that "need" is judged from a wide variety of angles. Thus, Canadian government agencies provide a set of semi-autonomous administrations with partially overlapping scientific programs, in which some measure of duplication may be judged as a necessary evil. At Canadian universities, faculty and department activities are similarly overlapped, giving rise to the common debates of their senates about who should do what. Finally, behind much of the granting activity are the desires of various sector interests to push universities into particular configurations that would make them good training grounds for particular kinds of recruits, and centres for developing kinds of activities that are geared to the nation's needs as seen through the various particular pairs of eyes. The J.B. Macdonald Report on the role of the federal government in support of research in Canadian universities makes no bones about advocating a pluralistic structure of government research support.

While it ensures some measure of balance, one of the consequences of this total pattern of activity is a fragmentation of effort and a frequent confusion about the appropriateness of various arrangements. Thus, for example, an activity that one government agency chooses to try to develop on a campus, another tries to develop in its "in-house" program. Additionally, because universities have large teaching loads and government agencies have pressures to solve immediate problems, both tend to do basic biological research as a sideline, rather than as a full-time preoccupation. There are thus few examples of a well-focussed national effort on a particular discipline or scientific problem. The balance of diversification may sacrifice opportunities for major scientific development and quick response to a national need for a particular kind of knowledge.

One way of helping to meet this problem is to further augment the granting picture with something special–grants to cure national shortcomings. The new "strategic research grant" of the National Research Council, which is aimed at stimulating growth of an activity which seems to be lacking in the total national picture, seems just such an attempt. Thus, the NRC might assume a more active policy than in the past. Its grant machinery would graduate from being a servant to being more of a manager. Words such as these could raise the hackles of many biologists because they convey a whiff of government tinkering in academic freedom. But consider what happens at present. By virtue of being participants in the machinery of NRC decisions and that of other granting agencies, many people in the academic community grow into a position to encourage well-informed and timely applications for major kinds of support. This kind of activity, which is not undesirable nor fraught with the patronage and nepotism that the paranoic imagine, should be made more regular and more overt. The National Research Council has consistently encouraged participation and criticism in its affairs and has an enviable reputation for fairness and honest judgement. By encouraging open and wide debate, and broad participation in the major grant decision-making, it will continue to serve as well as to manage. Accordingly, the strong development of appropriate short-term committees of the NRC, which advise on strategic research grants and are closely tied in their work with the other federal granting agencies, is to be encouraged.

A second way of overcoming some of the shortcomings of a pluralistic granting structure is to guard vigorously against the very human tendencies to build fences and imagined spheres of activity, which eventually results in much duplication of mediocre and feeble levels of effort. The essential orientations should be to the problems that need to be solved rather than to the niceties of clean administrative structure. At the moment, Canadian institutions offer a set of overlapping policies that, collectively, could provide abundant latitude for new kinds of arrangements. At universities, both the pure and pragmatic work in a good atmosphere for research, but they need devices by which they can do things on a bigger and long-term scale. Government scientists have opportunities to do the big things, but, in general, the atmosphere for basic work in government agencies, particularly provincial but also federal, is inclined to be cramped and overly fussy about imagined restrictions in terms of reference. The more that university and government groups can be assisted in obtaining what the other has to offer, the more likely it is that each will perform better. And hopefully, we may be nearing the day when the "applied" and "basic" extremists will realize that they have more in common than in dispute, and will more readily exploit each other's particular potentials without trying to do each other's jobs.

For the future it will be desirable to consider a variety of institutional arrangements that emphasize the flexibility that could cope with the varied requirements for specified problems. For example, why should a university not ask for funds to do work on a very specific mission-oriented problem, perhaps negotiating with government an "extramural research agreement" that perhaps could require a collaboration with government scientists and the use of government facilities. Why should a government laboratory not make an arrangement to give graduate instruction in a particular specialty?

With a limited scientific community, our emphasis should be on getting the most out of what we can afford. In many areas of research, the greatest obstacles to future efficiency are likely to be the too rigid definitions of duties, the too defensive reactions of empires, and the too fussy attentions to administrative rituals. The free flow of scientists from government to university via portable pension and secondment schemes should be vigorously encouraged. Promotability might even be related to diversification of experience. The psychological barriers to free flow should be eliminated by provision of incentives and penalties. Much wider use should be made of contractual devices. The emphasis should be on making a more holistic community of the total group of biologists in the country.

The inclusion of university scientists in advisory boards for government "in-house" activities (and vice versa for that matter) is a particularly useful way of making the various groups more aware of and more sympathetic to the problems and practices of the other. Advisory boards must involve work on the part of their members if they are to be useful rather than emasculated, or worse, mischievous. Where advisory boards presently exist, they should be broadly encouraged; where there are opportunities for creating them, they should be established.[1]

More generally, it needs emphasizing that the association of institutional affiliations with approaches to research is something of an optical illusion. The topic of research may well be circumscribed by administrative considerations, but whether it is done in an applied or basic state of mind is quite likely to reflect the characteristics of the individual scientist, and his judgement of what knowledge is needed at the present juncture. It would perhaps be more rewarding to list the kinds of problems that face the country and to consider the best institutional arrangements for tackling them. It might then become apparent that some of our present arrangements and, hopefully, those of the future, may defy the logic of "mission orientation" or "academic purity", but are responsive ways for getting on with a job.

None of the present machineries of granting seem geared to solve the critical problem of how to achieve "peaks of excellence" in at least some of our Canadian biology. Several of the panel reports develop the theme of how to achieve excellence. Common to most proposals are the ideas: (1) a number of workers must be involved as a group or team; (2) there must be heavy support in the form of facilities and technical staff; (3) there must be a virtual preoccupation with research; and (4) funds must be "guaranteed" for a number of years. Underlying most of the proposals is the assumption, largely fostered by years of frustration, that if scientists could only get away from the multitude of daily digressions, they would really be able to "get down to work".

Certainly, to the cynical, it sounds very much like the "Big Rock Candy Mountains", but there is no doubt at all that biologists are convinced that this is the direction in which we should go if we are to make significant steps in the directions of national need and scientific accomplishment. Lacking a sufficient history to have acquired a large group of patrons of science, Canada must deal with the conundrum of how to use public funds in the types of enterprises that are usually associated with the liberal-mindedness of private endowment. Essentially, of course, it is a matter of confidence: we must become nationally convinced of the values to society of uninhibited scholarship. Given this conviction, the arguments about what to do, where to do it, and who is to have the opportunity, will flow with a healthy vigour.

This is one of the biggest challenges to those who will shape the future of biology in Canada. Some tentative steps have already been taken. In a running controversy about "mission orientation", federal government agencies have sheltered some of their budding prospective groups so that there are now, in a few subjects, overt government "centres of excellence". The National Cancer Institute research units in Canada are widely cited as successful centres. The Medical Research Council is encouraging the formation of "Groups" and with scrupulous attention, both to the quality of research and the administrative environment in which it is to be done, seem well away on a tack that should produce the desired results. By imaginative and selective backing of their winning horses, some universities have achieved distinction in particular fields of biology. All these kinds of enterprises should be given the most vigorous encouragement.

The next steps in a logical evolution seem clear–more of the same in the wider spectrum of biological studies. Curiously, many of the most vigorous objections may come from those in the existing community of scientists (whether in government or university) who fear that "centres of excellence" may grow at the expense of other activities, or from administrations for whom supervision of "two breeds of cats" poses knotty problems. The obvious answer would seem to be to set up special funds for the es-

[1]See the Study Group Report on Fisheries and Wildlife Science in Canada for a full discussion of this viewpoint.

tablishment of institutes and to place their administration in the hands of specially constructed committees. This seems the only way of giving excellence the best of both university and government worlds.[1]

Particular attention should be given to the problem of what to do about terminating special kinds of support for excellence. It is probably much easier to generate enthusiasm for starting a venture into excellence than to generate ruthlessness for terminating it if it fades.

To allay some of these concerns, and perhaps to inspire some quite new concepts in research administration, it would be useful to try out some new things (that may lead to some original mistakes) and to invest in some research on research. One reaction to the prolonged debate on these issues is the nagging suspicion that we may be less than scientific about our science. The lack of this kind of professional guidance (if indeed it at present exists as an orderly discipline) is a conspicuous feature of Canadian scientific administration.

The last two decades have seen the growth of new kinds of international scientific projects and associations and agencies which are variously named for convenience by short bursts of capital letters (for example, IBP, IGY, IHD, GARP–projects; ICSU, INTECOL–associations; WHO, FAO, UNESCO–agencies). All have facilitated a greater catholicism in science, but their proliferation has caused some confusions, and their shortcomings have aroused some cynicism. Though Canada seems committed to the good works of international collaboration, it is apparent that, from the viewpoint of biology, there is no clear policy nor machinery for directing our scientific work in relation to internationally conceived programs. Insofar as the essentially missionary, contractual, or touristic enterprises of individual scientists are concerned, this is of course desirable. But when national participation in a program may imply a cut from the funds available for national research, there is clear need for policy and machinery.

The International Biological Program (IBP) is an excellent example. The IBP was conceived as an effort to increase understanding of the processes influencing biological productivity. Because of the many ways in which different scientists view this question, the program became diffuse and has even been referred to on occasion as "a collection of projects in search of an organization". Be that as it may, Canadian participation in IBP, which has slowly gained a considerable momentum, has made an impression on Canadian ecology, and is an object lesson in what to do in the future when this kind of program comes along.

First, the National Research Council should strike *ad hoc* committees to assess the extent to which requirements for new international proposals may already be met in the Canadian scene. Where our total national effort on a particular subject is deemed sufficient for the purpose, it can be brought to a focus for easy packaging and transmittal to an international pool by any convenient administrative device. The meteorologists and oceanographers seem adept at this sort of thing and their example might be followed. Where a particular research effort is required, there are the alternatives of setting up a special fund (as for IBP) or including requests in operating grant proposals, perhaps for preferential review by grant selection committees (as perhaps for GARP). Regardless of what the procedure is, it should be clear from the outset and administered in a consistent way over the years. Present practices show evidence of being improvised and sloppy.

Second, when a group of projects is set in motion as Canada's contribution to an international program, special effort should be made to ensure communication between the parts. If this is not done, even good "programs" can degenerate into thinly disguised con games that provide

[1]The concept of Medical Research Units and Agricultural Research Units in the United Kingdom should be carefully examined as a pattern we could follow in Canada.

a convenient way of diverting more dollars into doing more of the same under the aegis of internationality. For truly co-ordinated programs, the inherent centrifugal forces of scientific investigation must be countered (but not stifled) by liaison. This criticism fits the early stages of IBP, but has recently been substantially rectified.

Third, the date at which programs end (or their duration) should be even more clearly defined than the dates at which they start. There is current discussion of a successor organization to IBP ("the son of IBP" as someone said). This is "great" because it can only mean that IBP is worthwhile. But to the extent that the sequel(s) involve research expenditures, IBP should be placed on an equal footing with several other potential alternatives, national or international. Otherwise, like many other of our scientific enterprises, IBP could become in essence a "named investigation" persisting beyond its productive years.

Fourth, and final, Canadian biologists might give thought to initiating their own international ventures. While we are in many ways pipsqueak, we have a useful reputation for sober judgement and detached interest which might make it relatively easy for us to help steer the direction of world research as well as to participate in it. Surely Canadians can see and promote some new international enterprises. The Biological Council of Canada and the Canadian Federation of Biological Societies should provide initiatives in this regard.

No discussion of the international aspects of modern biological science would be complete without reference to the necessity for an adequate machinery for making effective use of the scientific community in overseas aid and development programs. For more than 20 years Canadian scientists have been used in aid programs as part-time recruits, and their activity has been organized in a way that has not altogether reflected with credit on the "External Aid Office" (now the Canadian International Development Agency). Apparently, only an occasional individual has the combination of personality, vitality, experience and expert knowledge that can make much of an impression in a foreign country. And where the impact of such an individual is great, it may lead to a development which is lopsided in a more general context.[1] Thus, while our biologists who have gone overseas may have been much admired as individuals, their impact on foreign development has not perhaps been great. Because of the complexities of development, the new line might be that we should aim to do a few things and to do them well by sending substantial teams that contain the several kinds of talents involved in resource use and health problems with a substantial sociological and economic content.

There may thus be considerable merit in the developing plan for an agency of the Department of External Affairs (the International Development Research Centre) that could put together the necessary personnel for effective large-scale development programs abroad. The new agency could recruit widely and could dispatch teams that might even be able to do abroad what we find difficult to do at home. It would be most unfortunate if the Institute were to build its own substantial permanent staff of scientific specialists. A contractual approach that draws on the strengths of the various experts who are best informed would seem to have the greater promise. It is thus necessary that it be made easy for trained people to move freely and with encouragement, from government and university positions to short-term international assignments.

Education, Professors and Manpower

The problem of modern training in biology (as with several other sciences) is simply stated as the conundrum of how to teach a person to recognize patterns in

[1]This can especially be true in resource fields. For instance, the technique of catching fish may be out of step with the capacity for distributing and marketing.

a kaleidoscope. The subject matter is less important than the intellectual discipline because, long before the student becomes a teacher, the rug of substance will have been pulled from under his feet, and he will be left with only his well-trained wits to adjust to a new set of "so-called" facts. As never before, the new generation needs the professional skills of problem solving. They need powers of analysis, intellectual flexibility and the entrepreneurial abilities that enable them to range across disciplines with enthusiasm, hoping that at each stopping point an expert (or the literature) will bail them out of their lack of particular background or specialized technique. They must know how to use machines and they must have the rigorous background in "pure science" so appropriate to producing a research-mindedness.

The older generation is commonly caricatured as professional scholars, masters of their field of literature, experts at a small set of techniques, and addicts of a specialty of increasing narrowness. It has been jokingly remarked that they favour producing scientists in their own image, and their concept of a good student is one who shares their prejudices except on a sufficient number of trivial points to warrant saying in a letter of reference that "he has a mind of his own".

In appreciation of these and other circumstances, the academic community is in a state of confused transition to something. Everyone agrees that students must gain insights into the sciences of deduction and induction. Virtually all agree that the first two years of university training requires formal indoctrination in the essentials of contemporary mathematics, physics, chemistry, biology, and for the sake of the rest of the world, English.

Beyond the second year, there are the alternatives of a general "biological" training or specialization in one of the branches of biology. The former alternative is typical of the smaller institutions which do not have enough specialization in any direction to have much choice about a philosophy. Specializations of various kinds are most pronounced in the larger universities, where the student has more opportunity to put on various kinds of blinkers at an early stage of his career. Of 41 Canadian universities, 33 have "all-purpose" biology or biological science departments (Table 9) and most of these are small as departments go. The other 8 (Alberta, Brandon, British Columbia, Guelph, McGill, Manitoba, Toronto and Western Ontario) each have departments of botany and zoology; 5 of them have non-medical departments of microbiology, 2 have departments of entomology, and 2 have departments of genetics. There are 13 non-medical biochemistry departments.

Within the last few years, several of the larger universities, recognizing the dangers of overspecialization, have developed, or are developing, "biology programs" which, by one device or another, contrive to recapture some of the lost comprehensiveness of undergraduate training.[1] This is a very desirable trend for, while on the one hand the specialists are necessary, the more broadly trained are less susceptible to rapid obsolescence and are better able to synthesize the several components in many real-life problems.

It is for these reasons, too, that the development of generalists of even wider scope is being encouraged, although at the undergraduate level there is the risk of going too far in the direction of superficiality. The "environmental science" and "general science" programs (and, in some places, departments) are in this category, and their graduates may well find that, while everyone admires the gentleman scholar, nobody wishes to hire him.

A better route to a more synthetic approach is the growing tendency to mix an undergraduate training in one branch of biology (or a general biology course)

[1]For example, University of British Columbia, University of Alberta, McGill University, University of Manitoba, all have formative or developed biology programs. McGill has very recently set up an all-encompassing "biology department".

Table 9–Biological Sciences Departments in forty-one Canadian Universities, as indicated in University Calendars for 1970-71

University	Biology	Biological Sciences	Bio-Chemistry	Botany	Biological Programs	Entomology	Genetics	Microbiology	Zoology
Alberta			x[2]	x	x	x[1]	x	x	x
Acadia	x								
Bishop's	x								
Brandon				x					x
British Columbia			x[2]	x	x			x	x
Brock		x							
Calgary	x		x[2]						
Carleton	x								
Dalhousie	x		x[2]					x[2]	
Guelph				x				xx[3]	x
Lakehead	x								
Laurentian	x								
Laval	x		xx[2]					x[2]	
Lethbridge		x							
McGill			x[2]	x	x	x[1]	x	x[1]x[2]	x
McMaster	x		x						
Mount Allison	x								
Manitoba			x[2]	x	x	x[1]		xx[2]	x
Memorial	x		x						
Moncton	x								
New Brunswick	x								
Montreal		x	x[2]					x[2]	
Ottawa	x		x[2]					x[2]	
Prince Edward Island	x								
Queen's	x		x[2]					x[2]	
Saskatchewan (R)	x								
Saskatchewan (S)	x		x					x	
St. Joseph's	x								
St. Mary's	x								
St. Francis Xavier	x								
Sherbrooke	x		x[2]					x[2]	
Sir George Williams		x							
Simon Fraser		x							
Toronto			x[2]	x					x
Trent	x								
Victoria	x		x					x	
Waterloo	x								
Winnipeg	x								
Windsor	x								
Western Ontario			x[2]	x				x	x
York	x								

x Administratively affiliated in faculty of arts and sciences or faculty of science.
x[1] Administratively affiliated in faculty of agriculture.
x[2] Administratively affiliated in faculty of medicine.
x[3] Administratively affiliated in faculty of veterinary science.

with graduate training in another; or an undergraduate training in one science with graduate training in another. Increasingly, the instincts of students are leading them to interdisciplinary and multidisciplinary patterns which make them biochemists, biophysicists or biomathematicians, by developing a major and a minor as undergraduates and (or) requesting a pattern of graduate work for which their undergraduate work is incomplete. To the extent that this is a disorderly process, it may create products with curious gaps in their backgrounds[1], but even this is preferable to an education which has no gaps only because of its narrowly defined limits.

While the universities struggle with their "rules and regulations" to bring new order to the current transitions, it is to be hoped the flexibility will be retained and eventually preserved. The biology of the future will need both specialists and generalists, and with the uncertainties ahead, it would be dangerous to opt exclusively for either philosophy of training.

A special plea must be made for the university professors, at present a much-harassed and misunderstood segment of society. They live in a world which is more competitive and objectively ruthless than is imagined by the layman. Characteristically, they achieve their training in a prolonged competition which is only a prelude to more of the same. They achieve success by drive as much as by inspiration, and they commonly have temperaments that cannot abide lack of recognition. They most certainly do not, as is often supposed by people who should know better, spend eight months teaching and four months aestivating. Rather, they work hard year round to fit research and training into a total activity. This has become increasingly impossible as enrolments go up and as the literature in their specialities blossoms prodigiously in volume, in new techniques, in new sophistication.

[1]In the words of one of our colleagues, "He was a good cell biologist but he didn't know a bull's foot from water cress."

Few graduating Ph.D.'s are good for more than a decade of good research before they feel the need for retraining, even though it may have taken until they were thirty to get trained. The regular granting of sabbatical years has only recently become practice in some Canadian universities, and it is apparent that leave every seven years may be, in present circumstances, a superstitious error in judgement. To this question we should direct close attention because it has bearing on our success in biology in the future. Society might get the most from its investment in academic biology if "study leave" were on the basis of every fourth or fifth year, or if investment were made in special retraining "schools", perhaps scheduling, especially for professors, short courses on the use of new instruments or on new developments in particular fields. The Canadian Association of University Teachers should spearhead a thorough study of the retraining problem and the devices by which it might best be achieved.

The discontinuation of the Senior Research Fellowships program of the National Research Council seems to have been a particularly backward step because it means that many Canadians will not be able to afford a sabbatical leave unless they get support from foreign sources. In consequence, the opportunities for senior researchers to get their batteries recharged have dwindled at a time when they should be expanded.

These matters have bearing on the subject of manpower resources. There is considerable discussion about the current overproduction of Ph.D.s. This concern is legitimate when voiced by the "unemployed" because the advice they have received about job opportunities may have been misleading. Additionally, there may be some concern by governments that the investment in education will not pay immediate dividends. Otherwise, the production of a small surplus seems very desirable. After more than 20 years, Canadian institutions will have the hope of having more choice about who they hire, rather than gobbling up all available Canadians (except those that went elsewhere) and turning to the residues of the U.S.A. and U.K. markets. At long last there may be well-trained people available for employment for a multitude of jobs which heretofore have been filled by the underqualified. And, of course, a Ph.D. education does not evaporate if its recipient does not find a job that does not exploit all of his specialist's potential. Any investment in education pays many indirect dividends to society, as well as personal and cultural dividends to the individual.

The concern then should focus on the recent graduate who has made a personal sacrifice that is not being rewarded with the role that he and his patrons thought was planned for him in society. Undoubtedly he is better equipped for such a role than many who already have positions in university and government, and he deserves a chance to show it. The logical thing to do, then, is to hasten the process of retirement, preferably of those who have reached their "level of incompetence", or to provide far more flexible procedures for transferring to other functions those whose "IQ plus effort" makes them better suited to another job. While these sound like glib and even facetious suggestions, they contain the kernels of sound management practice and are extensively developed in the literature of management.

In any event, looking to the longer term, the current small surplus production in the biological sciences presumed by some to exist seems scarcely worth overriding concern. The ten-year outlook is for a demand that could readily accommodate the present surplus plus all of the members of larger cohorts than are presently being produced. To be confident that no excessive surplus will be produced, an effort should be made to improve our predicting powers, so that the emphasis is on time-led planning rather than time-lagged response. For example, it should be realized now that there is a danger of over-responding to the present surplus in a way that would leave us short on new Ph.D. graduates five years hence. The lack, for several years, of an adequate statistical machinery for documenting supply and demand means that present efforts have potential for being amateurish. The development of the federal government scientific manpower placement service should be encouraged and particular investment should be made now in improvement of prediction.

Summation

Most of the foregoing report deals with features of the future of biology in Canada that are so simple that it may not seem necessary to point them out or to write of them at length. We are living at a time when our understanding of the world of plants and animals, including ourselves, is expanding explosively. The potentials for the engineering of the biological world are large and are increasingly at hand.

To meet the challenge of constructive use of biological knowledge of the future, Canada is only partially equipped. Our biologists have performed an important job in contributing to the development of the country. To date they have been largely harnessed to chores that related to the development of our impressive scientific activity in natural resource sciences and the health sciences. Our fisheries biology is world class; our agricultural scientists have done a distinguished scientific job; our forest biologists have international reputations. The health sciences of the country are certainly distinguished. For all of these areas of activity, basic biology at university biology departments can lay claim to some share of the credit and the same kind of contribution will, no doubt, continue well into the future.

The challenges of the future, however, are much more profound. Our understanding of life has proceeded to the point where we can deeply affect the nature of human society. There are tremendous sociological and moral implications to this new power of manipulation. Even brushing these considerations aside with the argument that we can somehow muddle through, there remains a residue of terrifying prospects for destroying all of mankind, for which we must muster a technological defence; and the quite clear alternative that, by the careful control of the application of knowledge, we may help society progress into new eras of material and spiritual prosperity. It is equally clear that, in the next few decades, biology will be faced with the host of problems entrained in the increasing number of people.

Against this background and with an assessment of Canadian biology today, this review suggests that far more emphasis should be given to developing the strength of biology in the faculties of science in Canadian universities, and suggests the following for the future.

1. In the subject matter of biology, Canada has the problem of catching up in the traditional disciplines, at the same time as the new areas of biological science are developed. In building for the future, the various individuals and institutions should consider the following:

a) The total investment in systematics and descriptive natural history is probably adequate, but the distribution of effort among various plant and animal groups is uneven. Attempts should be made to reorient work in these disciplines to studies of the smaller organisms of soil, freshwater and marine environments, and micro-organisms generally. Large support programs and other than modest growth of this total group of activity would be inappropriate. (page 21)

b) The physiology and biochemistry of plants and animals should continue to develop in response to increasing pressures for greater food production and maintenance of environmental quality. Attempts should be made to develop work on physiology of wild animals, particularly from the comparative point of view. The university sector is weak in the total national picture and should be enlarged. (page 22)

c) The behavioural aspects of biology have a fair start in Canada but are fragmented. There is a particular gap between ethologists and psychologists. Growth of ethology should be encouraged and particular emphasis should be directed to comparative studies of behaviour. (page 23)

d) Microbiology should be vigorously developed from its present nuclei of high quality in Canada. Attention should be given to ways of encouraging industry participation in microbiological research. (page 23)

e) Canadian contributions to genetics have been distinguished but few in number and confined to relatively few fields. The particular kinds of research in genetics that have fundamental application to the problems of the future are generally not being carried forward in Canada. The vigorous development of genetics in Canada is strongly recommended. (page 24)

f) In the whole set of studies that centre around biology at the cellular and molecular level, Canada has had a conspicuously "latecomer" role. Immunology, virology, molecular biology and cell biology all exhibit a pattern of local strengths but overall weakness. Plant cell biology is more deficient than animal cell biology. In the next decade, major support should be given to biology at the molecular and cellular level, even if we are only to stay in the same relatively weak position we now occupy. (page 24)

g) In part, perhaps because of the "space and military" programs in the United States, many areas of applied mathematics have developed vigorously. As one of the consequences, there have been strong recent developments in systems and theoretical biology. Canada has fallen behind in these new areas. Because of the wide application in virtually all branches of biology, special effort should be made to encourage their development. (page 25)

h) Canada has given strong emphasis to ecology. To keep abreast of the field, it will be necessary to hasten the process of change to a new ecology which is process and experiment oriented, and which requires large-scale field experimentation. Emphasis should also be given to studies concerned with the processes of natural selection as they occur naturally. The development of ecological genetics should be encouraged. (page 26)

i) For many of the deficient areas of biological research, it will be important for the future to develop team approaches with multidisciplinary participation. (page 26)

j) Mathematicians, physicists and chemists should be encouraged to do research on life science problems. The development of a holism in Canadian science could be an important factor in future growth and world leadership. (page 27)

2. The accoutrements of a mature science of biology are not well developed in Canada. Among the more important requirements are the following:

a) High priority should be given to the development of communication devices for biology in Canada:

i) An excellent national translation service complementing that of other countries;

ii) A strong national science library, characterized by superlative service to universities and government agencies, developed from a major revision of present passive concepts of libraries;

iii) Strong Canadian journals, developed by biological societies and government agencies and supported by Canadian biologists by submissions of their best work. (page 27)

b) Canada has conspicuously few major facilities for biology. The communal use by government and universities of major facilities is particularly to be encouraged. A set of regional communal use laboratories with excellent holding facilities and controlled environment equipment should be particularly useful to a wide spectrum of Canadian biologists. In making major national investments in facilities, it will be preferable to place emphasis on development of equipment that is useful in the newer areas of biology rather than on a literal copying of traditional accoutrements. (page 28)

c) The traditional roles of museums should be split and each should be performed in its appropriate milieu. Public education and display functions should be done by a branch of the Secretary of State Department; modern research systematics should be done at universities; museum activities, curatorial and identification services should be placed under a single administration (perhaps the National Research Council) and should be built on a regional network of repositories. (page 30)

d) The Canadian Federation of Biological Societies and the Biological Council of Canada should be supported with vigour by all segments of the biological community. The two organizations should strive to provide a single forum for debate, and should be vigorously engaged in continuing assessment of progress and problems in Canadian biology. (page 31)

3. There are almost 5 800 "life scientists" in Canada, of whom only about 500 are in arts and science or science faculties of universities. This proportion of "basic biology" effort was perhaps appropriate in the circumstances of Canadian development, but for the future, could leave our national biology deficient in scholarship, inspiration, originality and independence. (page 32)

4. The National Research Council should have a greater representation of biologists on its 18-member Council. (page 34)

5. The "in-house" research activities in biology of the National Research Council are desirable but should not be substantially enlarged, except in response to problems that are clearly outside the purview of other branches of government and clearly require the setting up of an establishment. The developing activity in the NRC of a clearinghouse and central repository of information on pollution seems particularly appropriate. More attention should be given to the possibilities of contractual research arrangements as alternatives to building "in-house" research establishments. In many instances, there may be merit in putting contractual teams on university campuses. (page 34)

6. The operating grant selection procedures of the National Research Council are in general a good base from which to develop for the future. Improvements would be:

a) A parent committee on biology, particularly to co-ordinate the four selection committees; more rigorous review procedures and perhaps an increased number of selection committees within another three to five years. (page 38)

b) Further raising of standards and more rigorous assessment of the real degree of spread in research ability of the applicants. (page 38)

c) A system for giving strong support to individuals of outstanding merit. For example, the four grant selection committees of NRC might each choose one applicant each year for maximal five-year support. (page 40)

d) Encouragement to scientists to form small groups or teams by reviving the old "block-term grants" which would be awarded by review committees of the selection committee. (page 40)

e) A review of the present pattern for supporting graduate students, preferably a national conference involving representatives of the graduate student body. (page 40)

7. Negotiated development grants of the National Research Council should aim either to build on an existing strength or to start ventures at new institutions. Falling between these two alternatives can result in general purpose grants without focus or impact. (page 42)

8. Grants to NRC applicants from agencies other than NRC amount to almost 45 per cent of NRC grants. There is room for considerable improvement in liaison amongst the various granting agencies of government that are concerned with support of biological research. Particular efforts should be made to co-ordinate activities of federal granting agencies. While this seems to be provided by various committees, there is still a lot going on at the grass roots level that reflects confusion and results in possible duplication. (page 42)

9. The liaisons between granting agencies that are designed to prevent duplication and differential treatment of research applications should be continued and strengthened. In those areas of biology for which applications might

go to either of two agencies, it would be desirable that there be similar awards for similar research proposals. Universities should seek to eliminate their medical and other differentials, rearranging duties and attitudes so that their best scholars in pure science have opportunity to develop strong research potentials. (page 43)

10. Balance in the total federal granting picture is at present left to the complexities of the operations of a pluralistic structure. To fill gaps that might be formed and to respond to new situations, the new "strategic research grants" of NRC may help in achieving total national balance. Encouragement should be given to the formation of appropriate short-term committees of NRC that advise on strategic research grants and that are closely tied in their work with other federal granting agencies. (page 47)

11. Balance can be further ensured by institutional arrangements that emphasize flexibility. The consistent habit of associating institutional affiliations with approaches to research is misleading. For the future it will be more rewarding to think in terms of the problems that face Canada, and then to develop the best institutional arrangements for the jobs. It will be necessary to emphasize a flexibility in administration that will be able to cope with the varied requirements for different problems. In many areas of research, the greatest obstacles to future efficiency are likely to be the too rigid definitions of duties, the too defensive reactions of empires, and the too fussy attentions to administrative rituals. The free flow of scientists from government to university (and industry) should be vigorously encouraged. Collaborative activity between university and government scientists should be encouraged so that each group can exploit what the other has to offer. The inclusion of university scientists in advisory boards to government agencies is strongly endorsed where it is present practice, and is recommended in those situations where it is not presently done. (page 48)

12. The recipe for developing excellence has not yet been found in Canadian granting structures. Common to most proposals are the ideas of a number of workers, heavy support in facilities and technical staff, a preoccupation with research, and "guaranteed" funding for several years. Building this kind of activity is a major challenge for the future, and every encouragement should be given to growth of some major foci of biological research. Particular thought should be given to the techniques of terminating support of faded excellence. It may be desirable to conduct some research on research. The concept of Medical Research Units and Agricultural Research Units in the United Kingdom should be examined as a pattern for Canadian ventures. (page 49)

13. Canadian participation in proposed international programs of research should be reviewed by NRC *ad hoc* committees. The procedures of Canadian involvement should be regularized; special attention should be given to communication among national projects; the duration of projects should be clearly defined. The Biological Council of Canada and the Canadian Federation of Biological Societies should give leadership in promoting Canadian-inspired international research programs. (page 50)

14. Biologists should be encouraged to participate in overseas aid programs. It is necessary to make it easy for trained people to move freely from government and university positions to short-term international assignments. The Canadian International Development Agency should strive to remove impediments and develop incentives to this end. (page 51)

15. Most Canadian university departments of biology are small and unspecialized. Seven larger universities offer training in specialized departments. The development of general biology programs at these major universities is a desirable trend that will tend to give the subject a new holism. For the future, both gener-

alists and specialists will be required and flexibility to produce both should be preserved. Particular efforts should be made to provide flexibility that encourages interdisciplinary patterns of study. (page 52)

16. University professors need frequent opportunities for leave and retraining if they are to keep up with the times. Canadian universities should consider policies that provide study leave more frequently than once in seven years. The senior research fellowships program of NRC should be reinstated. The Canadian Association of University Teachers should initiate a study of retraining requirements and devices by which they might best be met. (page 54)

17. The present possibility of overproduction of Ph.D. graduates in biology should not be viewed with undue concern. The long-term demand is good; if large surpluses occur, thought should be given to early retirement and job transfer schemes. The lack of statistics on production of graduates and on demand for them should be rectified by improvement of the scientific manpower services of the federal government. (page 54)

Epilogue on Expenditures

The expenditure on basic biology in Canada will be larger in the future than it has been in the past if we respond to what seem to be the potentials and problems ahead. The present expenditure of about $9 million per year by the National Research Council, augmented by about $3.5 million by grants to NRC applicants from other sources, is not a large sum by comparison with other national expenditures on research and development. Viewed in relation to the problems of the day, it is far from adequate to enable us both to catch up and keep abreast of the times. A fivefold increase in research fund allocations to basic biology by 1980 does not seem an unduly ambitious or imprudent forecast. To date, Canada has developed biological research at a rate that is between the extremes of parasitism on the world literature and philanthropy to the causes of international science. For the future, there will be hard competitive business reasons, convincing philanthropic reasons, and compelling national social reasons for raising our sights to new levels of investment in all of the life sciences. It is important that this long-term prospect be clearly envisioned now. Of all branches of natural science, biology is one of the least responsive to the massive very short-term blitz.

In the total pattern of investment in life science research, it is urgently necessary to reinforce the basic component, which serves the applied fields, and which provides a national investment in scholarship.

Our first step into the future should be the realization that the changes of the future will come and will affect us, almost regardless of what we, as a nation, choose to do about it. If all of Canadian biology were to cease tomorrow, it would scarcely affect the future of the science, but it would drastically influence the future of the country. Most of the research that may affect our future will be done outside of Canada; much of what is applied in Canada will depend on our awareness of what is being done in the world.

Accordingly, one of the great roles of our community of basic biologists is to serve as reliable pipelines and interpreters of the scientific discoveries elsewhere. This role will only be achieved if they participate with great vigour in the frontier activities of world science. Our biologists will then bring authority and fact to discussion of issues that are perforce intensely charged with emotion; they will demonstrate, by their scholarship and teaching, the complexity of the natural world and the discipline that is necessary to understand it; and, by their example and service, they may help guide the national activity into directions of national need. They need not be organized for performance of any other roles than these to warrant a rapidly increasing support.

Appendices

Appendix I

Terms of Reference Consultant in "Basic Biology"

1. Preamble
This study is primarily concerned with the work of scientists interested in living organisms or their parts or systems of organisms in their environment, and whose efforts are not focussed on a particular set of social or economic goals, and will be referred to as "Basic Biology". Biological research provides foundations on which, to a large extent, advances in medicine, agriculture, forestry, fisheries, wildlife management and conservation of environment depend. Persons concerned with one or more of those "missions" support or perform appropriate biological research including the most fundamental; however, their objectives are expected to be clearly related to the "mission", and are therefore not part of this study but are included in other Science Council studies.

2. Terms of Reference
The consultant will conduct a study of the future of "basic biological" research in Canada. The study should:

a) identify the direction current basic biological research appears to be taking in Canada for the next 20 years;

b) identify the main biological questions that appear exciting in the next 20 years;

c) identify the main biological questions that appear exciting to Canadian scientists over the next 20 years;

d) determine whether Canada has the expertise and administrative mechanisms, or opportunities arising from geography, etc., to seek answers to the questions identified;

e) estimate the scale of approach needed to do meaningful work on the questions identified in b) and c) over the next 20 years;

f) draw any further appropriate conclusions.

3. Source of Information
The consultant will use all *available* sources of information including data and reports obtained in the Special Study of Basic Biology as directed by Dr. K.C. Fisher on behalf of the Canadian Federation of Biological Societies and the Biological Council of Canada.

4. It is hoped that the consultant will produce a report which can be published under his own name by the Science Council as a companion to an inventory study on "Basic Biology" derived from the Fisher study, and will be the "Future Look at Basic Biology".

Appendix II

Synopsis of Coverage of Life Scientists in other Science Council Studies

1. Study Group Report on Forest Resources Research

A primary source of information for the Forestry Study was the questionnaire sent to all biologists to obtain data initially for Science Council studies in Agriculture and Biology. There were 501 respondents to this questionnaire who considered their work to be primarily oriented towards problem areas in forestry. Of these, 128 were in universities (departmental names were not specified in tables).

The 1969-70 calendars of various Canadian universities list 84 staff members with the rank of Assistant Professor or higher in faculties and departments of forestry (U.B.C., 24; Lakehead, 3; Laval, 30; Memorial, 1; N.B., 14; Toronto, 12). Apparently, at least 44 researchers in other departments are foresters.

Realizing the limitations and weaknesses of the questionnaire (at least for their purposes), the study group on Forest Resources Research relied heavily on other sources, such as direct interviews with scientists and the publications of various governmental and academic bodies, to supplement, verify, and correct the questionnaire data. The coverage of forestry scientists in this report, then, seems quite complete.

2. Special Study on Agricultural Research and Development

The Agriculture Study relied very heavily on a questionnaire to assemble its data. Most of the conclusions were drawn from responses to the questionnaire by 1 869 scientists who considered their work to be oriented towards problem areas in agriculture.

Of these 1 869 researchers, 658 were in universities–554 in life science activity, 38 in agricultural engineering, 39 in agricultural economics and 27 in rural sociology. Of the 554 in life sciences, 349 were in faculties of agriculture and 209 were in other university faculties. The authors of the Agriculture Study felt that they had response from more than 80 per cent of all agricultural scientists.

3. Special Study on Fisheries and Wildlife Resources

The authors of the Fisheries and Wildlife Study relied on a variety of techniques to assemble information. They used the Agriculture-Biology questionnaire series as one tool, but augmented the data in it with information obtained during a six-week "brain-storming" tour of cities considered to be centres of fisheries and wildlife scientific activity. Also, many letters were written to appropriate scientists to explore various problems, and tables are cited from numerous diverse sources. Consequently, it is difficult to list the persons contacted or to count them, but there is little doubt that the universe of fisheries and wildlife scientists was covered quite thoroughly. Of those scientists involved in such problems, less than 10 per cent were in universities (72 out of 827). Most activity was in the government sectors of performance.

4. Study on Marine Science and Technology

Most of the scientists reviewed by this group were federal government employees.

The report on these biological areas covered the work of only 56 university scientists–37 in marine biology and 19 in biological oceanography and fisheries–at 8 institutions. Many researchers doing related work in numerous biology departments across Canada were not included.

5. Study on Physics in Canada (1967)

The biophysical committee for this report defined biophysics as "the study of biological or medical problems using the methods and concepts of physics". Biophysicists from all faculties in at least 25 different universities were included. With regard to university departments, the following numbers of biophysical scientists (i.e. professional staff with Ph.D. or equivalent) were surveyed: physics, 11; biophysics, 40; biomedical engineering, 10; chemistry, 6; *biology, 10;* physiology and other medical departments, 47.

It would appear that the universe of biophysicists was covered quite completely. The number of biophysicists in biology departments does not seem large, although it is possible that certain smaller biology departments were not included.

6. Study on Chemistry and Chemical Engineering

The Chemistry Study was handled mainly by the Chemical Institute of Canada which used a broad definition of chemistry and purported to cover such fields as biochemistry, agricultural chemistry, and food chemistry (nutrition).

For the section on biochemistry in universities, reliance was heavily on data collected by the Medical Research Council. The MRC study covered 160 biochemistry departmental members, all in medical faculties. Consequently, biochemical researchers in other university faculties do not seem to have been covered adequately. According to the Association of University and Colleges of Canada, there are ten universities without medical faculties capable of granting graduate degrees in biochemistry. Many of these universities have researchers in biochemistry located in biology, biochemistry, or chemistry departments.

One committee of the Chemical Institute of Canada studied the areas of agricultural and food chemistry. This group apparently encountered difficulty in securing statistical data on its field using the questionnaire designed for the Chemistry Study. Consequently, they studied data from Dominion Bureau of Statistics, Chemical Institute of Canada, Canadian Agricultural Services Co-ordinating Committee and the Ontario Research Index.

7. Study on Psychology in Canada
The Psychology Study, undertaken by the Canadian Psychological Association, attempted to cover all members of the psychological community with a series of questionnaires. The questionnaires provided data on a total of 656 "Research-Involved Psychologists", including 250 "Principal Research Investigators" who were in charge of independent research projects.

To complete their study of "Psychology in Canadian Universities", the Canadian Psychological Association obtained data directly from the chairmen of the 33 departments of Canadian universities that offered undergraduate or graduate psychology programs in 1966. At that time, there were 195 psychology departmental faculty members with the rank of Associate Professor or higher and 222 below this rank. Any psychologically oriented work being done within biology or medical departments was not covered.

8. Report on Research in Engineering
This report covers applied science. Information was obtained by sending questionnaires to heads of engineering departments at 23 universities. The study shows 14 engineering department staff members having research activity in biochemical engineering and food processing, 43 in biomedical engineering, 19 in "environmental control". Biophysical engineers were not separated out in the study.

Table 1–Number of Biologists and Para-biologists included in Science Council Studies other than Basic Biology

	Federal	Provincial	University		Industry	Total
			Fac. A&S	Other		
Agriculture	(935)	(204)	(209)	(449)	(60)	(1869?)
Forestry	(374)	(105)	(210)	(100)	(510)	(1089)
Fish & Wildlife	(514)	(217)	72	–	(17)	(827)
Marine Science	(121)	N.A.	56[1]	–	N.A.	–
Engineering (bio-engineering)	N.A.	N.A.	0	76	1	–
Chemistry (biochemists)	N.A.	N.A.	0	160	N.A.	–
Physics (biophysics)	37	N.A.	10	114	4	165
Psychology	–	–	0	0	–	–

Note: N.A. not available; – not applicable; ( ) includes some engineers, chemists, economists, statisticians.
[1]Includes some tallied in fisheries and wildlife report, particularly the marine ecologists at coastal institutions.

Appendix III

List of Panel Participants in the Study of Basic Biology in Canada

The 68 Canadian experts in biology who prepared reports for this study are listed below: those marked with an asterisk were the chairmen of the panels.

1. Structural Biology	
a) Animal Morphology	J.W.P. Gilman, University of Guelph
b) Plant Morphology	T.W. Steeves*, University of Saskatchewan K.E. von Maltzahn, Dalhousie University
c) Animal Systematics (other than insects)	C.C. Lindsey*, University of Manitoba E.L. Bousfield, National Museum of Natural Sciences I.A. McLaren, Dalhousie University
d) Insect Systematics	C.E. Atwood*, University of Toronto H. F. Howden, Carleton University G.G.E. Scudder, University of British Columbia
e) Paleontology	F.L. Staplin*, Imperial Oil Ltd., Calgary Jaan Terasmae, Brock University L.S. Russel, Royal Ontario Museum, Toronto
f) Plant Systematics	J.H. Soper*, National Museum of Natural Sciences J.B. Phipps, University of Western Ontario D.B.O. Savile, Plant Research Institute, CDA
2. Ecology	
a) Vertebrate Ecology	P.A. Larkin*, University of British Columbia D. Pimlott, University of Toronto E.W. Ricker, Fisheries Research Board
b) Invertebrate Ecology (other than insects) Parasitology, Limnology and Biological Oceanography	F.H. Rigler*, University of Toronto L.M. Dickie, Fisheries Research Board, Bedford Institute R.S. Freeman, University of Toronto
c) Insect Ecology	E.J. LeRoux*, Research Branch, CDA C.S. Holling, University of British Columbia K.E.F. Watt, University of California at Davis W.G. Wellington, University of Toronto
d) Plant Ecology	J.C. Ritchie*, Dalhousie University J.S. Rowe, University of Saskatchewan G.A. Yarranton, University of Toronto
3. Physiological Sciences	
a) Vertebrate Physiology	D.W. Clarke*, University of Toronto W.S. Hoar, University of British Columbia J.A. Stevenson, University of Western Ontario

b) Invertebrate Physiology	A.S. West*, Queen's University G.O. Mackie, University of Victoria J.L. Auclair, University of Montreal
c) Plant Physiology	A.C. Neish*, NRC Atlantic Regional Laboratory D.R. McCalla, McMaster University E.R. Waygood, University of Manitoba
d) Behavioural Biology	J.B. Falls*, University of Toronto P.H.R. James, Dalhousie University M.H.A. Keenleyside, University of Western Ontario.
4. Molecular and Cellular Biology	
a) Biochemistry	D.S. Layne*, University of Ottawa S.H. Zbarsky, University of British Columbia
b) Genetics	C.O. Person*, University of British Columbia H.B. Newcombe, Atomic Energy of Canada J.W. Boyes, McGill University
c) Molecular Genetics	L. Siminovitch*, University of Toronto D. Suzuki, University of British Columbia S.F. Threlkeld, McMaster University
d) Cell Biology	J.F. Morgan*, University of Saskatchewan R.M. Hochster, Canada Department of Agriculture, Ottawa
e) Microbiology	A.C. Blackwood*, MacDonald College, McGill University J. de Repentigny, University of Montreal R. Knowles, MacDonald College, McGill University
f) Virology	V. Pavilanis, University of Montreal
g) Immunology	B. Cinader*, Ontario Cancer Institute A. Sehon, McGill University A.C. Wardlaw, University of Toronto
5.	
a) Pharmacology	W.C. Stewart*, Defence Research Establishment, Suffield J.D. McColl, F.W. Horner Ltd., Montreal J.M. Parker, University of Western Ontario
b) Nutrition	L.E. Lloyd, University of Manitoba
c) Plant Pathology	B.H. MacNeill*, University of Guelph W.B. Mountain, Canada Department of Agriculture, Vineland, Ontario
d) Animal Pathology	R.J. Avery, Animal Disease Research Institute, Canada Department of Agriculture
6. Biomathematics	P. Robinson*, Canada Department of Agriculture J.W. Hopkins, National Research Council J.E. Paloheimo, University of Toronto

Appendix IV

National Life Science Societies in Canada

Societies with Health Science Orientation	Founded
Canadian Medical Association	1867
Defence Medical Association of Canada	1892
Canadian Tuberculosis & Respiratory Disease Association	1900
Canadian Dental Association	1902
Assoc. Médecins de Lang. Française de Canada	1902
Canadian Pharmaceutical Association Inc.	1907
Canadian Public Health Association	1912
Canadian Paediatric Association	1922
Canadian Institute of Public Health Inspectors	1923
Canadian Paediatry Association	1924
Canadian Dermotological Association	1926
Royal College of Physicians & Surgeons, Canada	1929
Canadian Physiological Society	1935
Canadian Rheumatism Association	1936
Canadian Association of Radiologists	1937
Canadian Opthalmological Society	1937
Canadian Anaesthetists Society	1943
Canadian Urological Association	1944
Society of Obstetrics and Gynecologists, Canada	1945
Canadian Association of Pathologists	1945
Canadian Cardiovascular Society	1947
Canadian Society of Hospital Pharmacists	1947
Canadian Society of Plastic Surgeons	1947
Canadian Veterinary Medical Association	1948
Canadian Orthopaedic Association	1948
Canadian Academy of Allergy	late1940s
Canadian Psychiatric Association	1951
Canadian Association of Phys. Med. and Rehabilitation	1952
Canadian Psychoanalytic Society	1952
College of Family Physicians of Canada	1954
Canadian Association of Anatomists	1956
Pharmacological Society of Canada	1956
Canadian Association of Medical Bacteriologists	1961
Canadian Society for Clinical Investigation	inc. 1961
Canadian Medical and Biological Engineering Society	1965
Canadian Society for Immunology	1966

Societies Not Principally Oriented Towards Health Science	Founded
Royal Society of Canada	1882
Alpine Club of Canada	1906
Canadian Institute of Forestry	1908
Agricultural Institute of Canada	1920
Assoc. Can.-Française pour l'Avance des Sciences	1923
Canadian Phytopathological Society	1929
Canadian Society of Soil Science	1931
Canadian Psychological Association	1939
Arctic Institute of North America	1944
Entomological Society of Canada	1950
Canadian Institute of Food Technology	1951
Canadian Society of Animal Production	1951
Canadian Society of Microbiologists	1951
Agricultural Pesticide Technical Society	1953
Canadian Society of Agronomy	1954
Genetics Society of Canada	1955
Canadian Society for Horticultural Science	1956
Canadian Biochemical Society	1957
Canadian Federation of Biological Societies*	1957
Nutrition Society of Canada	1957
Canadian Society of Plant Physiologists	1958
Canadian Society of Wildlife and Fisheries Biologists	1958
Canadian Society of Zoologists	1961
Canadian Botanical Association	1963
Canadian Society of Cell Biology	1966

*Includes only members of other national societies.

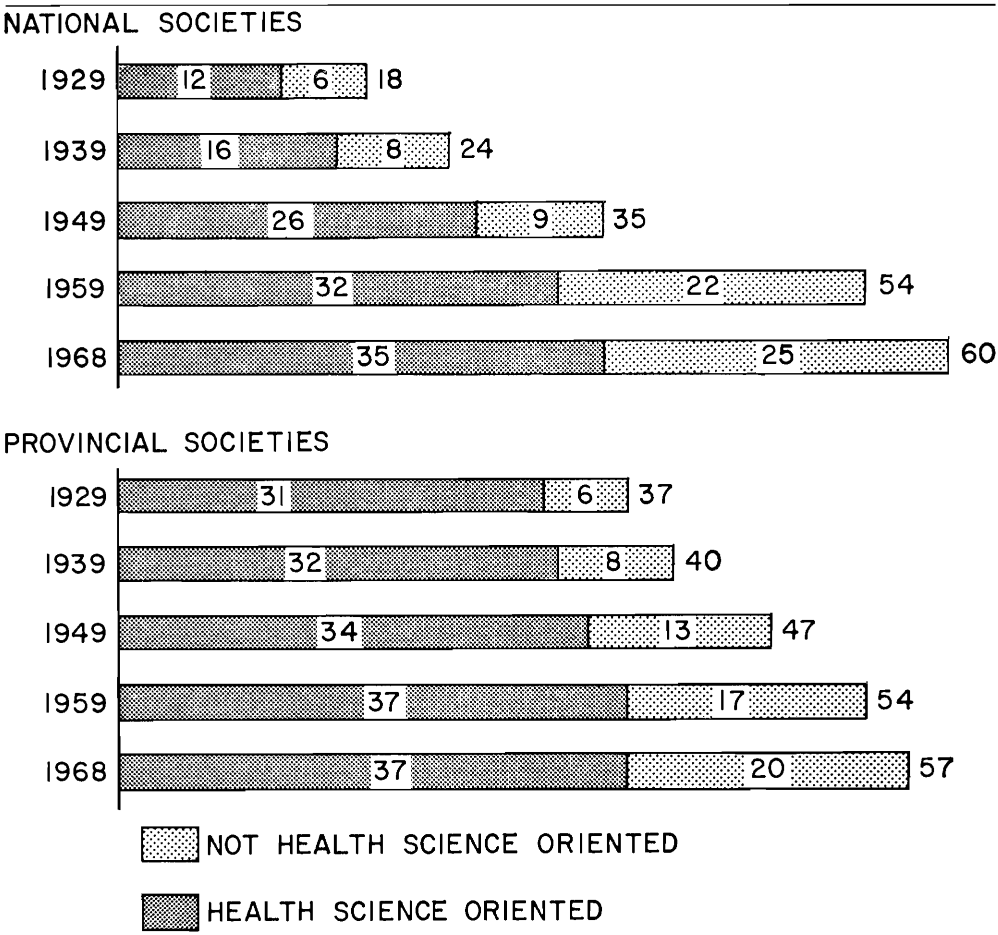
Provincial or Regional Life Science Societies in Canada

Name	Founded
Medical Society of Nova Scotia	1854
Nova Scotia Institute of Science	1862
Entomological Society of Ontario	1863
Ontario Dental Association	1867
Collège des Pharmaciens de Québec	1870
Ontario Veterinary Association	1874
Manitoba Pharmaceutical Association	1878
Ontario Medical Association	1880
New Brunswick Medical Society	1880
Manitoba Veterinary Medical Association	1881
New Brunswick Pharmaceutical Society	1884
Manitoba Dental Association	1885
New Brunswick Dental Society	1890
Dental Association of Prince Edward Island	1891
Saskatchewan Pharmaceutical Association	1892
Nova Scotia Dental Association	1893
Canadian Medical Association, British Columbia Division	1900
Collège des Meds. Vet. de Québec	1902
Entomological Society of British Columbia	1902
Alberta Dental Association	1905
Alberta Veterinary Medical Association	1905
College of Dental Surgeons of Saskatchewan	1906
British Columbia Veterinary Medical Association	1907
Manitoba Medical Association	1908
Société de Protection des Plantes du Québec	1908
British Columbia Dental Association	1909
Alberta Pharmaceutical Association	1911
Nova Scotia Veterinary Medical Association	1913
Acadian Entomological Society	1915
Newfoundland Dental Association	1915
New Brunswick Veterinary Medical Association	1919
Prince Edward Island Veterinary Medical Association	1920

Corp. des Ingénieurs Forestières de Québec	1921
Quebec Medical Association	1922
Newfoundland Medical Association	1924
Canadian Public Health Association, Saskatchewan Branch	1926
Medical Society of Prince Edward Island	before 1929
Ontario Association of Pathologists	1938
British Columbia Psychological Association	1938
Association Forestière Québeçoise	1939
Entomological Society of Manitoba	1945
Association des Médecins de Lab. du Québec	1946
Saskatchewan Institute of Agrologists	1946
British Columbia Institute of Agrologists	1947
Alberta Institute of Agrologists	1947
Ontario Psychological Association Inc.	1947
Ontario Public Health Association	1949
Alberta Society of Pathologists	1950
Société Entomologique du Québec	1950
Entomological Society of Alberta	1952
Entomological Society of Saskatchewan	1952
Saskatchewan Association of Pathologists	1955
Corp. des Psychologues de Québec	1956
New Brunswick Association of Pathologists	1959
Ontario Institute of Professional Agrologists	1960
New Brunswick Psychological Association	1962
Psychological Society of Saskatchewan	1967

Source: Scientific and Technical Societies In Canada, National Science Library, 1968. (NRC-10625).

Figure 1–Growth in Number of Life Science Societies in Canada



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