CANADIAN WILDLIFE SERVICE

A Wildlife Biologist Looks at *Sampling, Data Processing, and Computers*

by DENIS A. BENSON

OCCASIONAL PAPERS No. 6

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Canadian Wildlife Service
Occasional Papers Number 6

National Parks Branch
Northern Affairs and National Resources

74160-3—1

These papers were presented at meetings of the
Canadian Society of Wildlife and Fishery Biologists
held in Fredericton in November 1963,
and in Ottawa in January 1964.

Issued under the authority of the
HONOURABLE ARTHUR LAING, P.C., M.P., B.S.A.,
Minister of
Northern Affairs and National Resources

ROGER DUHAMEL, F.R.S.C., Queen's Printer and Controller of Stationery, Ottawa, 1964

Cat. No. R69-1/6

ABSTRACT — SOMMAIRE

This publication consists of two papers presented at meetings of the Canadian Society of Wildlife and Fishery Biologists.

The first paper, on the subject of statistical sampling, stresses the difficulties facing the field biologist who has, perforce, to sample highly heterogeneous populations. It is pointed out that much of the presently existing body of theory is based on the experimental type of sampling, in which environmental conditions may be more or less controlled, and that such theory may not be immediately applicable in the wildlife and fisheries field.

A number of elementary texts are quoted and discussed in an effort to orient the researcher who is a qualified biologist, but a neophyte in the field of statistical mathematics.

The second paper attempts to orient the field researcher with respect to the technological advances that have been made in electronic equipment used for recording, processing, and analyzing scientific data. It is written as an introduction for the researcher who is considering the use of electronic methods for the first time. The functions of data processing equipment and of computers are distinguished. Problems that are faced by the biologist are illustrated by means of a description of how the Canadian Wildlife Service is handling the problem. Examples are offered of both completed and current projects in which electronic aids play a part, both in the processing of data, and in the computations involved in a statistical analysis.

L'ouvrage comprend la reproduction de deux communications qui ont été présentées lors de réunions de le Société canadienne des biologistes de la faune.

La première communication, qui traite de l'échantillonnage statistique, met en relief les difficultés auxquelles est en butte le biologiste qui se trouve contraint de choisir des échantillons parmi des populations hétérogènes d'êtres vivants. L'auteur fair remarquer que la plupart des données théoriques dont on se sert de nos jours, se fondent sur l'échantillonnage expérimental, qui se fait dans des conditions qui échappent plus ou moins au contrôle du biologiste; il s'ensuit donc que ces données théoriques ne sont pas directement applicables dans le domaine faunique et ichtyologique.

L'auteur fait état de plusieurs ouvrages élémentaires et il en fait l'analyse à l'intention du chercheur qui, bien que biologiste compétent, est toutefois novice en matière de mathématiques statistiques.

La seconde communication s'adresse au chercheur en campagne qui désire se mettre au courant des progrès techniques réalisés dernièrement dans le domaine des machines électroniques qui servent à enregistrer, à classer et à analyser les données scientifiques. Elle est conçue à l'intention du chercheur qui projette de faire ses débuts dans le domaine de l'ordination. L'auteur établit la distinction entre l'ordination proprement dite et le calcul à l'aide d'une calculatrice électronique. Certaines difficultés qui confrontent le biologiste, sont mises en relief et l'auteur décrit comment le Service canadien de la faune les surmonte. Il offre des exemples de travaux menés à bien ou actuellement en cours, grâce à l'aide précieuse des machines électroniques, tant pour faire l'analyse des données que pour résoudre les calculs compliqués que nécessite l'établissement de tableaux statistiques analytiques.

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COMMENTS ON SAMPLING

When answering our program chairman's invitation to join the panel, I introduced the idea of sampling in the following way:

> ". . . *when the biologist does not, or cannot, make a total count, he takes a sample. At that point the mathematical laws of probability take over and the biometrician has work to do. In fact, he does little else except work with samples. As a result, the topic of sampling is almost synonymous with 'biometrics'.*"

Let us consider a few broad purposes for which we employ sampling procedures. The best known application is perhaps the "human response" or "public opinion" survey. These vary from mail or telephone surveys to questionnaires delivered by an enumerator, through to cases where the desired information is obtained by personal interview. The general category includes most of the fact-finding surveys of the Dominion Bureau of Statistics, and also includes the United States surveys of sports fishermen and hunters, and our own economic survey of sport fishermen and hunters in Canada. Waterfowl kill surveys in both countries are in the same general category.

Sampling is the major problem encountered, as is made clear by the titles of books that have appeared on the subject, such as "Sampling theory of surveys with applications" (Sukhatme, 1954), and "Sampling methods for censuses and surveys" (Yates, 1960).

In practice, every large-scale survey tends to be unique. Subject matter, budget, accuracy desired, literacy of the human population being surveyed, socio-economic conditions, and many other factors vary so widely that each survey seems to develop as a different child of the same parents. All are fathered by the human urge to acquire knowledge, and all are mothered by mathematical statistics. The growth and maturation of the child is largely dependent upon the amount of care it receives from its mother in the days of its infancy.

More general applications of sampling theory are discussed by Cochran (1953) in his book "Sampling techniques". He says:

> "Until recent years, relatively little attention was given to the problem of how to draw a good sample. This does not matter so long as the material from which we are sampling is uniform, so that any kind of sample gives almost the same results. Laboratory diagnoses about the state of our health are made from a few drops of blood. This procedure is based on the assumption that the circulating blood is always well mixed and that one drop tells the same story as another—an assumption which we as laymen fervently hope is correct. But when the material is far from uniform, as is often the case, the method by which the sample is obtained is critical, and the study of techniques that ensure a trustworthy sample becomes important."

The use of mathematical statistics in biology started in agriculture, and has only recently spread into other branches. It is interesting to turn to the words with which Simpson and Roe introduced their now classical book "Quantitative Zoology" in 1939:

> "The exclusion of zoology from the roster of the exact sciences has usually been a subject of self-congratulation for zoologists and of reproach for their more mathematically inclined associates."

If those words could be written in 1939, it is not altogether surprising that those of us who took our university training soon thereafter were not introduced to the subject of statistics. Those of us who did get a course or two perhaps did not realize that elementary theory, tests of hypotheses, and some normal distribution theory is not enough to support us in the murky depths of the heterogeneous populations we encounter. So often there are no guideposts. Nobody has been there before.

Many of us who did get a course in statistics used that classic text "Statistical methods" by Geo. W. Snedecor. Its excellence is shown by the number of reprintings and editions that it has gone through. Yet how many of us have attempted to sample highly heterogeneous populations and then turned to Snedecor for methods of analysis? I wonder how many of us failed to find help, and failed also to read the statement on page one:

> "Most of this book, excepting a final chapter, is devoted to the experimental type of sampling, moderate in extent, where environmental conditions are more or less controlled."

That final chapter first appeared in the fifth edition of 1956, from which I am quoting.

Our problem seems to be that, in general, we are attempting to employ advanced statistical techniques without the experience to be gained from a tradition of study of laboratory populations or of the closely controlled field experiments that have contributed so much to the development of the presently existing body of theory. Fisheries biologists are far ahead of terrestrial workers, but they also have their problems in the development, testing, and application of techniques.

Certainly I have no quick or easy solution to the problem. At times I wonder whether we should look at it as a frustrating problem, or as a challenge. There is opening before us a new and wider opportunity to experiment, to adapt, to test and develop new and more powerful techniques in our own field. Nor need we fear

that the mathematical statistician is going to supplant the biologist. The relationship must always be symbiotic. For example, Cochran (1953) lists nine principal steps in a sample survey. He comments on them in the following way:

> "This list of the steps in a sample survey has been given in order to emphasize that sampling is a practical business, which calls for several different types of skill. In some of the steps—the definition of the population, the determination of the data to be collected and the methods of measurement, and the organization of the field work—sampling theory plays at most a minor role."

We, then, as biologists must do what we can to take advantage of new techniques and new methods.

The practicing biologist can turn to simple, non-technical manuals and to introductory texts. The number and quality of manuals is bound to increase. Fisheries workers are truly fortunate to have available such references as W. E. Ricker's (1958) "Handbook of computations for biological statistics of fish populations". The wildlife field has recently acquired a handbook of "Wildlife investigational techniques", now in its second edition (Mosby, 1963). It contains several useful, if somewhat elementary, chapters on methods that are basically statistical.

There are many "non-mathematical" paperbacks and manuals available. They can be valuable, but many are misleading, not so much by what they say, but by what they leave unsaid. For example, some of them seem to imply that *all* biological data are distributed normally, and can be summarized statistically by methods based on normal distribution theory. Personally, I have a strong aversion to "simple" little books whose authors "simplify" mathematical terminology and do not use the standardized symbols of mathematics and statistics. An understanding of the language of statistics is a sound beginning. As with any other language, much can be learned by using a dictionary when you read. There is a good dictionary of statistical terms available (Kendall and Buckland, 1957).

There are many introductory texts on the market. They are an essential step on the road, but we must always watch for the oversimplification that is used for the purpose of teaching principles. A good choice in our field is a recent text, "Principles and procedures of statistics with special reference to the biological sciences" by Steel and Torrie (1960). It includes many of the more recently developed statistical techniques. Being a new text, it also contains a number of typographical errors.

The biologist can turn to the statistician, provided (a) he can find one, and (b) the statistician has the desire and opportunity to assist. However, it has been said that to contribute fully, one statistician should not be involved in more than four or five projects at any one time, and should immerse himself thoroughly from the early planning to the final publication of results. It is understandably difficult to obtain

assistance from busy men who tend to feel that they cannot do much good by a casual approach. Many of them believe that they should either go into the problem deeply, or not at all.

The team approach is becoming more and more a part of scientific work. When disciplines overlap there is no more promising approach. In his text, "Statistical analysis in biology", Mather (1947) says:

> "Statistics is the concern of two different groups of scientists. The first group, of mathematical statisticians, is interested in developing the theory and extending the applicability of their subject, while the second group, which consists of non-mathematicians, is concerned largely with using the methods already available as tools in their own researches. Among this latter group biologists are forced by the peculiarities of their experimental material to occupy a leading position; for it is very rarely that the full value of a biological experiment can be realized before the observations have been subjected to a suitable statistical analysis.
>
> "This separation into two groups, which might be termed respectively the makers of statistics and the users of statistics, is not, of course, complete. The mathematician must be able to appreciate the problems met by the users of his product, or his work will be sterile. Similarly, the biologist must have a sufficient knowledge of statistical theory to know how far present-day methods will take him and at what point he must turn to the statistician for help and advice."

It is a logical result of biologists delving into statistical theory that occasionally one of them will emerge as an accomplished mathematical statistician, and a leader in his original biological discipline. We have a few brilliant men in Canada who have done so in our own specialties. Most of us, however, are not of their calibre—we do not achieve real competency in mathematical statistics, but we do learn a number of statistical techniques. I count myself as one of those who are neither field biologist nor statistician.

Biologists, such as myself, who are working in the field of biometrics are, I believe, a temporary phenomenon. We attempt to fill a need that will continue to exist until biology students are exposed to more of the fundamentals of statistics in our universities. Biologists working from one direction will be met by mathematical statisticians working from the other.

To end on the original topic of sampling, I would like to turn to an excellent paperback book that is to be highly recommended. M. J. Moroney in his "Facts from figures" (1962) has produced one of the clearest expositions of the ideas of statistics, and has done so in a manner that makes easy and amusing reading—a rarity indeed amongst books on statistics. His chapter, "What happens when we take samples" starts out as follows:

"The statistician's job is to draw general conclusions from fragmentary data. Too often the data supplied to him for analysis are not only fragmentary but positively incoherent, so that he can do next to nothing with them. Even the most kindly statistician swears heartily under his breath whenever this happens. Before he looks at it he knows just what the position is going to be. It is a common pastime in many organizations, and even laboratories, to collect vast quantities of data on a routine basis, using apprentice labour, with the vague intention of submitting them to analysis 'one day when things are not so busy'. Of course things are never slack, so the 'piles of useful stuff in the files' get more comprehensive—and out of date—as the years go by. Pious intentions to analyse some day are of little value. If data are not worth analysis at a suitable near date they are rarely worth the labour of collection. Less time collecting and more time analysing would be a valuable aim in many laboratories.

"But it is not simply because the road to hell is paved with good intentions that the miserly acquisition of data is to be deplored. There is a more serious reason. Data should be collected with a clear purpose in mind. Not only a clear purpose, but a clear idea as to the precise way in which they will be analysed so as to yield the desired information . . . . It is astonishing that men, who in other respects are clear-sighted, will collect absolute hotch-potches of data in the blithe and uncritical belief that analysis can get something useful out of it all—especially if a statistician once starts to juggle with it."

DATA PROCESSING AND COMPUTERS

The planning of this paper was made relatively painless by the use of an outline provided by our program chairman. I have followed his outline with one exception.

The subject given me was "Data Processing". I have assumed that both mechanical data processing and the use of electronic computers were included.

There is a distiction not too often made in popular writing that is important to us. "Data Processing" is a term that is restricted to the rapid mechanical handling of large volumes of data that require a minimum of mathematical calculation. Computers, on the other hand, are designed for the purpose of carrying out mathematical computations that are too time-consuming for manual methods. Data processing installations and computer installations may be, and often are, separate entities even though they may in some cases, be physically adjacent to one another.

How rapidly is the field advancing?

There is no standard of comparison by which the question may be answered. The rate of development of mechanical and electrical "hardware" and the rate at which it is being installed and applied are both accelerating in a fashion reminiscent of the early stages of a biological growth curve, logistic in nature. A great deal of the development of the field is taking place in the military services and in industry. In our own line of work we have available the resulting machinery and techniques.

Computers are becoming available at many universities, where they are employed for training personnel, and in various types of research. Use of electronic aids is standard practice in many governmental agencies. Applications vary from scientific research to equipment inventory and the administration of motor vehicle registration, and from the handling of vital statistics to the issue of pay cheques.

Data processing equipment is used so widely today that opportunities are available now to almost all of us. In this paper, I am attempting to outline very briefly what those opportunities are, and how we may take advantage of them.

The level at which electronic aids become feasible

The researcher usually starts to use plain 3″ × 5″ cards to build an author-subject index for his reprints before he leaves university. The habit, once acquired, grows to include creel census, post-mortem records, phenological data, morphological measurements, parasite counts or what have you. When those decks of cards become too unwieldy—when the process of data retrieval becomes a tedious and time-consuming

chore—then a level has been reached where it becomes feasible to move into the "needle-sort" type of card. They are usually printed to order, and punched entirely manually, or by a combination of "gang-punching" and manual work. Sorting is done with a needle in most cases, and the decks of cards are maintained conveniently by the researcher in his office or laboratory for quick and easy access.

When the volume of records continues to increase the cycle is repeated. The advantages of quick access and complete control of the records are outweighed by the time and work required to manipulate the cards. At that time, mechanical data processing of machine punched cards is indicated.

A slight variation on the same theme takes place when the biologist starts to apply a few simple statistical tests to his data. At first he works with pencil and paper. Then, due either to increasing volume, or increasing complexity of the mathematics to be applied, the individual, or more usually the office or laboratory, acquires an electric desk calculator.

Eventually, the time arrives when the field researcher turns to his head office with one of two problems. The first is that the sheer volume of computation is reducing his time in the field. The second problem is one of complexity. More advanced analyses are called for. In either case, the question asked is: Can head office (a) do the work, or (b) supply a machine operator?

At that level, we define the job as a "computer application".

There are many definitions of the word "feasible". In terms of the economics of scientific man-power, time, and money, electronic methods usually replace others when (a) the volume of work exceeds available man-power, (b) the cost of the time spent by the researcher exceeds the cost of electronic methods, or (c) the complexity of the computation exceeds the mathematical experience and training of the researcher.

The type of planning required

The type of planning that is required in any research project that involves either mechanical data processing or the use of computers differs not at all in principle from that of a project that does not employ those aids.

However, there are two practical differences. Far larger quantities of data may be handled in a far more complex manner than was once possible, and the data must be precisely prepared for analyses that will be carried out by persons to whom the data may be meaningless outside the context and format of prescribed source documents. By "source documents" we mean the punch cards, data sheets, or other means of presenting data in a form acceptable to the processing agency.

The planning of research projects is a subject worth a few moments of our time. Questions to be asked of the data must be defined, and the relevant form of analysis decided upon. Then, and only then, is it appropriate or even useful to start the field work.

If electronic equipment is to be used for analysis the project plan must name the necessary equipment and the agency that has that equipment. Data processing methods must be laid down, and computers chosen in consultation with that agency. If appropriate computer programs are not available, they must be obtained or written. Only then is it possible to describe the requirements for the source documents.

If, for example, a machine accepts input in the form of standard 80-column punch cards, then raw data could be recorded either in the field or in camp on 80-column sheets using the format and coding required for punch cards. It might be preferable to punch the cards in the field office using a small, manually operated punch. It might be practical in some cases for an observer to carry a plastic card-holder and to record observations by punching cards with prearranged codes, whereupon the raw data immediately become input data for a machine. The so-called "mark sensing" card achieves the same end. It can be marked with a graphite pencil to indicate the punching pattern that is to be followed by an automatic punch. In any case, input material should be prepared with as few operations as possible between the original observation and the data processing agency.

If you have decided that what I have said about planning is equally relevant to any research project, whether or not electronic aids are to be used for analysis, then I have made my point. The logical processes of inanimate machinery compel us to exercise the logical approach to a problem that we, as scientists, ought to employ in all our work.

Advantages and disadvantages of electronic methods

It is necessary and profitable to give careful consideration to a choice of one of two or more comparable items or courses of action. Before buying a motor vehicle, the family discusses the advantages and disadvantages of two doors or four doors, sedan or station wagon. Engine size is given consideration, as is the argument of automatic transmission versus manual.

Our generation may forget, or be unaware of the fact that not too long ago the discussion was about the automobile versus the horse and buggy. That was not so much an argument about advantages and disadvantages as it was a discussion of whether or not to make use of a new technology. The "advantages" to be derived were not to be obtained elsewhere. The discussion of advantages and disadvantages became a discussion of benefit versus cost.

In order to place our discussion in perspective, let us think of the individual researcher who is considering the use of a computer for the first time. He faces a number of costs, problems, amd difficulties. However, when he decides that he has reached a stage where the use of electronic aids has become feasible, he is, in effect, saying that the benefits are wanted, and are financially achievable. What of the difficulties?

The researcher must know exactly what he wants. I have spoken already of the planning of a project, from objective to ways and means, and from computer programs back to the collection of data. All that is no more than an application of the scientific method.

The one and only new element is the division of labour that arises between the researcher and the machine installation. The problems generated are those of communication and interpretation.

In the Canadian Wildlife Service I am attempting to solve that problem by acting as an intermediary—a connecting link. It is, or should be eventually, a self-liquidating assignment.

Our experience so far indicates that the intermediary might do the following:

1) Learn the problem from the researcher.
2) Interpret the problem to the statistician.
3) Ensure that the solution proposed by the statistician is biologically valid.
4) Locate an appropriate installation.
5) Locate appropriate computer programs and procedures in consultation with the statistician and with officers of the computer installation.
6) Learn to understand the characteristics of the various possible forms of source documents and input, and choose those best suited to the project.
7) Interpret the format of the source document to the researcher.
8) Handle the administrative details of obtaining time on the machinery.
9) Act as liaison man with the machine installation staff during the machine operation.
10) Interpret the resulting output format to the researcher.

The intermediary must know something of biological research, but need not be a researcher—in fact, he will not have time for research. He must have some knowledge of mathematical statistics, but a qualified statistician would be wasted on the job. He must know something about the scheduling of data processing operations and of the programming of computers. He should know something of the "languages" used by programmers to communicate with their computers, but he need not be a programmer. He should have a general knowledge of the available "hardware", where it is, and what it does best. The intermediary needs a smattering of several disciplines.

It will be obvious that a researcher who is geographically close to a machine installation and who can be available whenever his data are scheduled for analysis, and who is willing to take the time to learn the ropes, can take over any or all of the functions of the intermediary. If the results of his research are not improved thereby, and if he does not save time and money, then his problem was not a "computer application" in the first place!

It is only when an application can be handled manually at a comparative cost that there is any meaning to a discussion of advantages and disadvantages of electronic aids. To use, or not to use them, is a decision to be made on a cost-benefit basis.

Use of data processing machinery and computers by the Canadian Wildlife Service

The earliest association the Canadian Wildlife Service had with data processing was through our responsibility for migratory birds, and the handling of data arising from the banding of birds. For a decade The United States Fish and Wildlife Service banding office has employed data processing equipment and more recently has moved into the computer field.

Our Service administers and coordinates all Canadian activity, and prepares records on forms that become source documents for the data processing unit. All routine records are returned to us in the form of machine tabulations. Our banding office stands in the position of an intermediary between the Canadian bander and the data processing agency.

When summaries of specific banding and recovery data are required, they are supplied at our request from the central agency. For larger jobs it is sometimes desirable that the researcher for whom the work is being done should be present.

As a federal agency we have no experience with data processing as it might be employed by a provincial agency, so I am taking the liberty of describing an application that I initiated while with the Department of Lands and Forests of Nova Scotia.

We had a system of compulsory hunter reports that ordinarily achieved about a 99 per cent return. The hunters' report cards were used as source documents. We rented a punch. Purchase of a filing cabinet suitable for punch cards and purchase of one control board completed our overhead.

Each punch card received coded data from a single report card, made up of the following items:

License number
Name and address of hunter
County of residence of hunter
Sex of first deer killed
Date of kill of first deer
County of kill of first deer
Sex of second deer killed
Date of kill of second deer
County of kill of second deer
Date of receipt of return (by the Department)

The deck of punched cards would eventually exceed 50,000 for any one year. Machine sorting and tabulating were carried out on an installation operated by another governmental agency.

Examination of the data punched on the cards shows what can be done merely by sorting and tabulating various totals. The job was designed primarily to obtain data for administrative purposes (mailing lists of non-respondents to receive reminders), publicity (kill reported to date), and game management (sex ratios, regional kill, mobility of hunters, etc.). However, there were overtones of research. For example, when sorted by date of receipt, a tabulation could be prepared for a graph of hunter success against promptness of reporting.

A data processing application, the results of which many of this audience will have seen, was our recent survey of sport fishing and hunting in Canada. In that case the data processing was carried out by machine. The final computation of confidence limits was done manually, but was based on data summaries prepared by machine. We did not employ a computer on that job.

Much the same type of data processing is coming into use with us for our waterfowl kill surveys. Needle-sort cards provided an entirely satisfactory technique for smaller surveys, but with increasing volume, we have reached a stage at which routine mechanical data processing is indicated.

Turning now from data processing to computing, we give up sorting cards and start doing arithmetic.

Even the simplest of computations becomes tedious if it must be repeated many times or if it involves a large number of data. The Service has had prepared a small program that computes, for normally distributed data, the following statistics:

Number of observations
Range
Mean
Variance
Standard deviation
Standard error of the standard deviation
Coefficient of variation
Standard error of the coefficient of variation

The suitability of the program for analysis of taxonomic data will be immediately evident. We have one researcher who is now in the process of copying ten years of observations onto data sheets designed as source documents. Since the program became available only recently, the data were not originally prepared in a suitable form.

I am told that it will take about a month of working days to copy the data onto source documents. Time required for analysis on a desk calculator is roughly

estimated at two and one-half months. We have asked for three hours time on the computer for the same analysis, and expect to have some of that time left over for other projects.

The same program is to be used to produce statistics that may in turn be used to test for the need of, and type of transformations required to produce approximate normality in data to be subjected to an analysis of covariance. The analysis of covariance will also be carried out on the computer.

In the near future, we expect to make use of a stepwise multiple regression analysis program.

The Canadian Wildlife Service has a broad interest in data processing and in computing. Over the past few years we have had an increasing number of projects that have benefited from those aids. Nevertheless, the volume of work we have is relatively minute. Our requirements have been widely divergent, and have called for various types of equipment. We have made use of installations operated by the United States Fish and Wildlife Service, The National Research Council of Canada, The Dominion Bureau of Statistics, and the Departments of Forestry and Agriculture.

Installations that are designed for peak loads are often available during slack periods. There has grown up a close co-ordination and excellent co-operation among those agencies that operate installations in order that all government agencies may obtain the maximum possible benefit from the equipment. The Canadian Wildlife Service has been the recipient of much generous advice and assistance, and has been able to purchase time on various machines and installations.

At our present stage of development, and, I suspect, for many years to come, the head office of our Service will continue to supply an intermediary and liaison function between our biologists all over Canada, and many of the varied machine installations that are available to us here in Ottawa.

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