The Place of Analytical and Critical Reviews in Any Growing Biological Science and the Service They May Render to Research

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> On my return home, it occurred to me, in 1837, that something might perhaps be made out of this question by patiently accumulating and reflecting on all sorts of facts which could possibly have any bearing on it. After five years' work I allowed myself to speculate on the subject,….—CHARLES DARWIN in the Introduction to *The Origin of Species,* 1859.

A review of literature has long been a conventional part of original scientific papers. Such a review is usually of immediately antecedent work. It is most often narrowly selective and descriptive only of results, conclusions, or opinions, chosen as closely related to the original work to be presented. It need not concern us further.

Reviews of literature, published as such, are now an established part of the information services offered to help scientific research and the application of its results in practice. The stated policy of the Commonwealth Agricultural Bureaux, planned as a comprehensive information service for agriculture, requires the production of reviews. Learned societies and associations of scientific workers produce periodical reviews in their own subjects. The type and quality of such reviews vary widely. Most of them are of the first or second type described below.

TYPES OF REVIEW CLASSIFIED AND BRIEFLY DESCRIBED

THE PERIODICAL REVIEW

Numerically, reviews of this type far exceed any other. Each is prepared by an expert and is concerned with one limited field of research and a limited

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time, most often the year just past. All work published in that time on that subject is to be included. The text consists of brief notes of findings or opinions, with little criticism and usually without analysis or synthesis. Many such reviews are no more than annotated bibliographies.

Even so, they save the time of the research worker who wishes to know what is going on in his own or other fields, and the text is usually sufficient to enable him to select what he wishes to read in the original.

THE OCCASIONAL REVIEW

This review too is usually prepared by an invited expert, but he is not expected to "cover the literature" of any defined period. He is given the opportunity to discuss a subject broadly and to comment on it. (See Information for Authors in *Physiological Reviews*.) He may be selective and critical. In these circumstances the value of an article will depend on the expertise of the writer and the validity of the point of view from which it is written. In practice value tends to vary inversely with the extent to which an article is a summary of opinions and directly with the extent to which it is a discussion of findings.

Physiological Reviews has produced many memorable reviews in this class, of which the following are particular examples which come to mind because they belong to our particular field of work: Henderson (1925) on acid-base balance, Adolph (1933) on water metabolism, Madden and Whipple (1940) on plasma proteins, Soskin (1941) on blood sugar, Kleiber (1947) on body size and metabolic rate, Granick (1951) on ferritin, and Manery (1954) on water and electrolyte metabolism.

THE ANALYTICAL AND CONSTRUCTIVE OR RESEARCH REVIEW

It is concerned directly with facts and findings, seldom with the opinions of the authors of papers from which data are taken. The facts may be of widely different kinds. They may be body measurements, the quantitative results of metabolism experiments, the results of analysis of body fluids or tissues or of food, records of birth and mortality, or, in fact, any biological observations that furnish numerical data which may be treated statistically. Again, the facts examined may themselves be concepts: the concept of being well grown or well nourished, that of optimum requirement for any of the separate constituents of food, of health and normality, all of which will be found to depend on the interpretation of measurements such as are enumerated above. The review of concepts is indeed a more advanced stage of the review of numbers. The two are never completely divorced, for the review of numbers may, and usually does, lead to some new interpretation or concept, and the review of concepts may have as its purpose to clarify issues and show where further

numerical information is most urgently required. The rest of this paper will be concerned with the nature of this type of review and its uses, and illustrative examples will be taken from our own publications.

The quotation from the Introduction to *The Origin of Species* which appears on the first page of this paper might have been written of the analytical and constructive review, for which it is difficult to find a short and adequately descriptive name. For brevity, and want of anything better, it may be called the research review, for it is both a review of research and an inquiry into the deductions that may be drawn from an accumulation of results treated as a new whole.

The current short and mostly utilitarian examples have many noble fore-runners in report and book form. It is not possible to take *The Origin of Species* (1859) as the archetype because it was preceded by just over a century by Lind's treatise on scurvy (1753), of which the title page says: *"A Treatise of the Scurvy*. In three parts. Containing an inquiry into the Nature, Causes, and Cure, of that Disease. Together with a Critical and Chronological View of what has been published on the subject." Of about the same time as *The Origin of Species* there are many of Sir John Simon's reports on the public health when he was chief medical officer to the Privy Council; later came his *English Sanitary Institutions* (1897), Greenwood's *Epidemics and Crowd Diseases* (1935), and that learned and charming book *Ourselves Unborn* by Corner (1944) which offers the unexpected conclusion that "the human body is not notably endowed with specialised anatomical features of a kind that would fit us to perform limited activities supremely well, but on the contrary is built rather closely to the general mammalian pattern, and therefore can perform varied tasks under the guidance of a superior brain."

THE RESEARCH REVIEW

THE SUBJECT MATTER

The field of biology in general and of nutrition in particular offers plenty of material for treatment in analytical and constructive reviews. The technique can be used for any quantitative problem as soon as enough bits of information are available to provide a worth-while array of data. It may or may not require, or be suitable for, complex statistical treatment. There are two main points to be noticed: the difficulties of assembly because of the scatter of publications, and the complexity of the subject matter itself which, by its nature, accounts for a large part of the scatter and, at the same time, makes assembly and analysis of the composite a necessity.

Publication

A quick look at the number and sort of publications which may have to be consulted will show why assembly is usually a slow and laborious process. When *Nutrition Abstracts and Reviews* was first published in 1931 it contained in the first year titles, or titles and abstracts, of just over 3000 papers from about 400 journals and in about 20 languages. The last completed volume, No. 27, had over 6000 from nearly 600 journals in slightly more languages, and notes on many more papers in symposia or conference proceedings. These 600 journals are seen regularly in five different libraries in seven different places: the Reid Library at the Rowett Research Institute, which is devoted to the literature of animal nutrition, Aberdeen University Library with three branches, the library of the Ministry of Agriculture, Fisheries and Food, the library of the Royal Society of Medicine, and the library of the Lister Institute of Preventive Medicine, the last three in London. In addition, there are reprints from yet other journals and reports from research centres all over the world which are sent direct to the Commonwealth Bureau of Animal Nutrition or the Reid Library, and are not widely available in libraries.

To make an assembly for analytical review, all the available papers must be seen in the original, or photostat copy or other substitute for the original, so that the data if suitable for the purpose in mind may be transcribed. For instance, the 8600 individual observations used in the review of basal metabolism, which will be described in more detail below, were transcribed from roughly 100 papers in medical, physiological, chemical, and agricultural publications issued round the world from Japan, China, Malaya, and India via Europe, Africa, and North America to South America, Hawaii, Australia, and Indonesia. Three diligent young women devoting part of each working day to the task took six months to find, select, and transcribe the individual data. Unless such a team can be mustered, with guidance and linguistic help at need, such a task is beyond the likely powers of individual enterprise.

Complexity

A very large number of variables must be considered and either eliminated by matching or allowed for in the plan of any piece of research in nutrition. First the animals, including man: to be taken into account are breed, sex, age, size at birth and at completed growth, rate of growth or of production (milk, egg, meat), stage of reproductive life, previous dietary history, physical environment (e.g., temperature and humidity). Second, in diet there is a great complexity of nutrients. Known to be of importance are about 20 amino acids, 14 inorganic elements each in many different compounds, and 17 vitamins

of known structure; of carbohydrates there are 10 sugars and 8 groups of polysaccharides; 14 fatty acids, and as many triglycerides, innumerable pigments and aromatic substances, as well as many injurious and inert components, present in countless different foods. Add to which that a complete longitudinal study of human growth must take about 20 years, of growth in a pig at least 3 years and even in a rat 9 months; and that there is the reproductive span also, and old age beyond that.

It is obvious that the number of possible questions is enormous and that no one man or one team in the whole of a lifetime can hope to cover by original research more than a minute part of any nutritional field.

Further, nutrition is not so much a science or an art in its own right as a meeting place of many sciences and arts. Since the advent of isotopes in metabolic work, the shepherd and the medical specialist make direct contact with the atomic physicist; the biochemist and the psychiatrist hobnob over esoteric studies of the composition and metabolism of brain cells, and the cook and taste panel consult with big business and public health experts on “additives” to food.

Hence, individual contributions to knowledge in nutrition, and in biology in general, are small and must continue to be so. The contributors are, and will be, scattered over many professions and places of work and their polyglot publications will be similarly spread. It is therefore not only useful, but necessary, that the fragments in a given subject should be brought together from time to time and amalgamated, if money and effort as well as time are to be used in the best possible way. In other words, the making of analytical and constructive reviews seems to us to be essential in biological research, and a very present aid in time of need when briefing is required in medicine, in farming, or in political and economic planning.

CONDITIONS UNDER WHICH ASSEMBLY AND ANALYSIS ARE PROFITABLE

The stimulus to produce a review of this sort comes sometimes from an urgent demand for guidance. For example, the economic depression of the 1930's in Britain, with its poverty and malnutrition while agriculture had surplusses of food it could not sell, called for information on diet in relation to health and the requirements of food and nutrients to maintain health. The prospect of food shortage in 1940 made it compulsory that agriculture in the United Kingdom should use land and stock and feedingstuffs to the best possible advantage, and gave rise to an estimate of the relative efficiencies of farm animals in the production of food for man (see under “Practical Problems, Substitution”). Sometimes a review is called forth by the need to examine an

apparently false conclusion in some published work, as, for example, our study of secular change in the height of British adults, and sometimes by mere curiosity, as our analysis of the relation between the weight of mothers and their young at birth. Other instances appear below where we discuss individual reviews.

Once the demand for a review has become apparent, or the necessary stimulus to produce it has been applied, the first question asked is whether enough information exists to provide a worth-while result. The answer to that question one either knows from handling the literature, or must discover by searching.

WASTAGE OF MATERIAL

In the course of assembling data, a certain amount of wastage will always be found, and that for two main reasons.

Faults of Technique

Where the data derive from *ad hoc* physiological or chemical investigation, not much has to be discarded on account of poor technique. Differences between methods are so often small in comparison with the variation between individuals in experiments on animals, or in comparison with what are physiologically significant amounts of the substances being estimated. Where clinical work is concerned it may be necessary to use data from routine clinical examinations, not from research investigations, and then selection may have to be more rigorous. The Medical Research Council Committee on Haemoglobin Surveys (1945) wrote:

There can be little doubt, therefore, that the errors detected in this experiment are smaller than those likely to occur when a relatively inexperienced technician, after forcing a drop of blood from a reluctant patient and using an unstandardised pipette, hurriedly matches the resultant (possibly undergassed) solution in an uncalibrated diluting tube with a colour standard of uncertain value.

That is, no doubt, an extreme indictment, but the investigators who waste time and money making diet surveys by questionnaire or "recall" methods deserve no less severe comment. "No conclusions can be more valid than the data upon which they are based" (Bean, 1948). Similar difficulties arise, of course, in the use of practical feeding experiments, as opposed to planned *ad hoc* research, in animal husbandry.

Faults of Presentation

In these fields, technical, clinical, and agricultural, some of the work and unfortunately an increasing proportion of it, is lost for purposes of resynthesis,

because of the mode of presentation. There is, for instance, the paper in which the results of a diet survey are presented, not in absolute terms but as percentages of attainment of some arbitrarily chosen standard. Nothing further can be done with such data.

More important is the overcondensation of reports. Gone are the days when the individual results in an experiment were reported in detail, as in the reports of The Carnegie Institution of Washington and many reports to learned societies. The entry of statistical experts into the biological world, to be welcomed in other ways, has had this effect that results may be given only as a few equations, coefficients, and measures of probability. That is possible because the statisticians have already made sure that the experiments are properly planned to give a statistically satisfactory answer to a defined question. However satisfactory that may be for the solution of the problem set, it is not wholly satisfactory because the work is potentially a small part of a much larger whole. Devices exist by which such results may be combined with similar and similarly planned work, but the data cannot be rebuilt piecemeal into a larger array to serve a different analysis. They are capable of the one interpretation only.

That being so, it is much to be desired that the individual results of biologically important experiments should be tabulated and made available to those who could make further use of them, perhaps through a scheme like that of Dr. Ralph Shaw (1955) for limited editions of highly specialised papers described to the First International Congress on Documentation of Applied Chemistry.

There is wastage also from failure to report all the simple details which must be known or ascertainable in any experiment. For instance, in our assembly of papers on basal metabolism a number could not be used because basal metabolic rate was stated only in relation to surface area, without information about either height or weight; or because age was not stated. The same sort of thing is common in experiments on animals; indeed, in our experience failure to report is the commonest cause of wastage. We suggest that, if experimenters were made familiar with the idea that their results would, in due course, become part of a larger array of data, they would possibly take more thought to describe their material fully.

TYPES OF RESEARCH REVIEW

At opposite extremes in this class are the review which is a purely statistical analysis of assembled data, and that which is a review of concepts, not of primary data.

THE STATISTICAL REVIEW

Basal Metabolism

One example is our study of Basal Metabolism related to Sex, Stature, Age, Climate, and Race (Quenouille *et al.,* 1951). It arose from the request of the Director of the Nutrition Division of FAO to his Standing Advisory Committee at its meeting in Geneva in 1947 for advice on the formulation of energy requirements of different populations for use in relation to estimates of food supplies, actual and desirable. In particular, information was wanted on possible differences with race, size, climate, and the age constitution of populations. There was no review from which guidance on all points could be got, and little information on energy expenditures other than basal that was likely to bear directly on the several questions asked. It was decided therefore to collect information on basal metabolism. A team of three young university graduates searched out and examined papers and, when all the descriptive details required were given, transcribed the data for each individual subject to a prepared form.

Data about climate were provided by Dr. W.B.Fisher, then lecturer in Geography at Aberdeen University, who had been a meteorological officer with the Royal Air Force during World War II, and who still had access to the records of the Air Ministry. The statisticians who made the analysis were Mr. Maurice Quenouille, then lecturer in statistics at Aberdeen University and Mr. A.W.Boyne, statistician to the Rowett Research Institute. They were given no "opinions" about racial or other differences. The inferences are purely statistical.

The points of general biological interest which emerged are: the basal metabolism of a woman is almost exactly seven-eighths of that of a man of the same height and weight; two main racial groups were distinguished, each with two sub-groups; climate produces its maximum effect in hot dry and cold wet areas. Basal metabolism falls at the rate of 3 per cent per decade from age 3 to ages over 80.

It was planned to follow this review with one on the cost of measured amounts of work on the ergometer, of exercise, and then of occupational work, but the results were found to be too scanty and too variable to be of much use. We plan to publish in the autumn a short note, chiefly on the cost of walking.

None of the conclusions about basal metabolism is entirely new, but each is based on a sample so much larger than any used before that it is not surprising that they differ in detail from earlier conclusions, and are more precise. The rate of decline with age is midway between earlier estimates of 2 per cent and

4 per cent derived from small samples. The difference between men and women of the same height and weight is 12.5 per cent; an earlier estimate from a small sample was of a difference of the order of from 5 to 9 per cent. The systematic relation of basal metabolic rate to the climate in which the subject lived is new.

Stature and Growth

Reference has been made above to the apparently false interpretation as immediate stimulus to produce a review. Our study (Boyne and Leitch, 1954) of secular change in the height of British adults was undertaken because Morant's (1950) conclusions on that subject appeared to us untenable chiefly because he treated adult heights as if they derived from a homogeneous population and not from a cohort of survivors over a century in which major changes had taken place in standards of living, public health, and mortality rates. Our reanalysis showed that the British data, on account of limitations of sampling and imperfections of reporting, were in fact inadequate to decide whether a net increase in mean height at completion of growth had taken place or not. It was possible to give clear evidence of an increase of mean height of young adults in Denmark from records of measurements of recruits taken from official statistics and supplied to us by the Director of the Institute of Human Genetics in Copenhagen.

The review of data on adult stature was followed by one on secular change in the height and weight of English elementary school children (Boyne, Aitken, and Leitch, 1957). The data were supplied by School Medical Officers in response to a direct request from us, and a sample of measurements of 1,180,000 children aged 5, 8, and 12 years was built up. Not only did this review put on record for wide circulation important measurements that would otherwise have remained hidden in local medical reports with an exceedingly limited circulation, but, because of the size of the combined sample, deductions could be drawn that would have been impossible from inspection of the individual reports.

Birth Weight

A review of a different type and from a more general biological sphere is of the relation of birth weight of the mother to that of her young (Hytten and Leitch, 1957). The stimulus to produce it came from the suggestion of Dr. R.M.Laws (1956) that the large aquatic mammals, seals in particular, are able to carry relatively heavy young because of the anti-gravity effect of water. He based his obvious misconception on the table on p. 117 of D'Arcy Thompson's (1942) book *On Growth and Form*. D'Arcy Thompson was concerned not with

the weight of the young carried, but with the weight at birth in relation to weight to be attained at completed growth. His figures for young born in multiple birth, for instance the bear and the lion, refer therefore to the single members of a litter. Since neither D'Arcy Thompson nor Laws had produced a true picture of the relation of birth weight of young to weight of mother, we decided to look for information about different species. After a search of the immediately accessible journals and monographs we retrieved data for 70 species, and the information was condensed into a graph (Fig. 1).

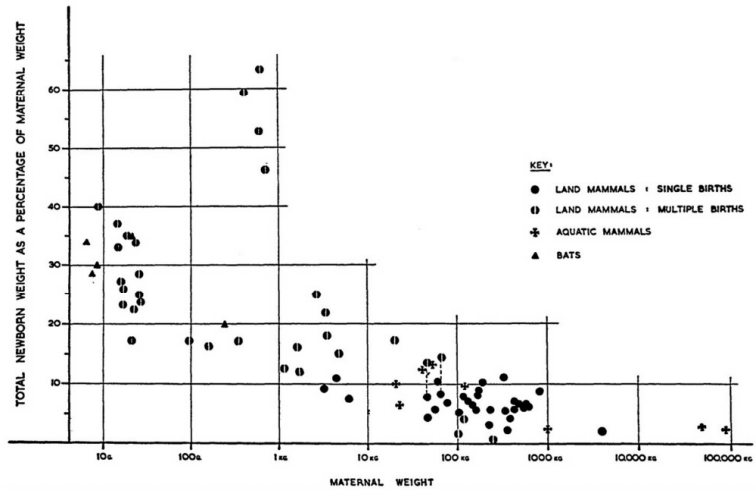

FIGURE 1. The relationship between maternal weight and total weight of the newborn young in 70 mammalian species.

With reference to the aquatic mammals, in the ratio of weight of young to weight of mother they do not differ from large land mammals, including man. The main differences in ratio between animals of the same or similar adult weight are attributable to differences in maturity at birth and to the number of young born at a birth, two or more weighing more than one, but less than would be in proportion to number. This law appears to be valid in general from the bat that weighs 6 g. to the whale that weighs 100,000 kg.

Guineapigs with litters are outside the general picture. We suggest that the domestic guineapig, possibly a descendant of the South American Restless Cavy *(Cavia porcellus),* which produces one, or at most two, at a birth, occupies its strange position as the result of selection for superovulation, and because litters of four have been obtained without much, or any, sacrifice of individual size or maturity at birth.

THE REVIEW OF CONCEPTS

An example of this type of review is that of Thomson and Duncan (1954) on the diagnosis of malnutrition in man. It surveys concepts and definitions, the accepted or proposed criteria of specific deficiency states, the clinical pictures of the well fed and the ill fed, and finally suggests the overriding importance of somatometric studies in which attained dimensions of the body are compared with primary patterns of growth and development. The idea of an inherent pattern in human growth and its importance for health is of recent development (cf. Leitch, 1951), but Hammond and his disciples McMeekan and Pallsson had earlier shown the importance in pigs and sheep of the full development of the "growth potential."

Other examples from our own publications in which the discussion is chiefly of concepts are the reviews on The Evolution of Dietary Standards (Leitch, 1942), The Calorie Requirement of Adult Man (Keys, 1949), Energy Feeding Standards for Dairy Cattle (Blaxter, 1950), and Iron-Deficiency Anaemia in the Pregnant Woman and Its Relation to Normal Physiological Changes (Hytten and Duncan, 1956).

THE SERVICE OR INTERPRETIVE REVIEW

An early and most distinguished review in this group came from the Rowett Research Institute before there was a Bureau of Animal Nutrition, namely Orr's book on *Minerals in Pasture* (1929). It was the first review to demonstrate the importance of pasture as a crop and the disastrous effect on the health of the grazing animal of lack in the pasture of certain inorganic elements. It was the stimulus to a world-wide programme of analysis and experiment on deficiency of trace elements, which still continues. The review has twice been brought up to date, in 1944 (Russell) and in 1956 (Russell and Duncan).

In this group may be included most of the reviews, other than those listed as reviews of concepts, prepared in or for the Bureau and published in *Nutrition Abstracts and Reviews* or as *Technical Communications*. They include all our earlier reviews of requirements. One on the riboflavin requirement of man by Finn Bro-Rasmussen (1958) of the State Vitamin Laboratory, Copenhagen, has the true pattern of assembly, analysis and reinterpretation. Table 1 of Part II of Bro-Rasmussen's review is reproduced here to show how, by tabulating data from a number of sources, he has been able to establish beyond reasonable doubt that the riboflavin requirement of species ranging in size from the horse to the mouse, and of a microorganism, may be expressed as a function of the energy turnover, but not, as was previously believed, of the protein intake.

There are also collections of data on vitamins in food and one on the water

TABLE 1[a] *Riboflavin requirement of different species related to optimum protein intake and energy intake.*

Species	Riboflavin requirement			Authority[c]
	μg. per 100 g. food[b]	*μg. per 100 g. protein*[b]	*μg. per 1000 cal.*	
Horse	about 350	about 3500	about 850	Pearson, Sheybani, and Schmidt (1944 *a*, *b*)
Man (adult)	—	2000–2500	500–600	Average from values in Table 4.
Calf	about 300	1000–1300	600–800	Brisson and Sutton (1951)
Pig	275–300	900–1000	650–750	Krider, Terrill, and Van Poucke (1949); Miller, Ellis, Stevenson, and Davey (1953); Miller, Johnston, Hoefer, and Luecke (1954)
	130–200	450–650	250–380	Forbes and Haines (1952)
Child	—	about 1800	about 700	Snyderman *et al.* (1949)
Dog	200–400	1000–2000	500–1000	Axelrod, Lipton, and Elvehjem (1940; 1941)
	250	1300	600	Potter, Axelrod, and Elvehjem (1942)
Fox	250–400	1300–2000	600–1000	Schaefer, Whitehair, and Elvehjem (1947)
Hen	300–350	about 2000	700–850	Hill, Norris, and Scott (1954); Jackson *et al.* (1946); Petersen, Lampman, and Stamberg (1947 *a*, *b*)
Turkey poult	270–350	about 1500	650–850	Bird, Asmundson, Kratzer, and Lepkovsky (1946); Boucher, Patrick, and Knandel (1942); Jukes (1938); Patrick, Darrow, and Morgan (1944)
Chick	275–325	about 1500	650–850	Bethke and Record (1942); Bird *et al.* (1946); Bolton (1944; 1947); Norris *et al.* (1936); Stokstad and Manning (1938)
Duckling	about 300	about 1500	about 750	Fritz, Archer, and Barker (1939)
Rat	about 300	about 1500	about 750	Burch, Bessey, and Lowry (1948); Mills (1943); Nieman and Jansen (1955); Sure (1940); Wagner, Axelrod, Lipton, and Elvehjem (1940)
Mouse (C_{57})	about 400	about 1600	900–950	Fenton and Cowgill (1947)
Lactobacillus casei	250–320	500–550	650–750	Bro-Rasmussen (1955)

[a] From Part II of "The riboflavin requirement of animals and man and associated metabolic relations," by Finn Bro-Rasmussen (1958).
[b] Here and elsewhere in this review when quantities of riboflavin (or protein) are expressed as "per 100 g. feed," the feed is a ration of artificial type containing a sugar, starch, or air-dry cereal, a protein, most often purified casein, oil, minerals, and vitamins, or is a simple pig or poultry ration of much the same sort.
[c] The authorities listed are as given in Bro-Rasmussen (1958).

metabolism of farm animals and, as *Technical Communications,* a review on the feeding of camels, one on amino acids in foods and feedingstuffs and, to be published shortly, reviews of diet in relation to reproduction in sheep and pigs. One or two illustrative points may be described.

The reviews of requirements of man for calcium (Leitch, 1937) and nitrogen (Leitch and Duckworth, 1937) were built to the same pattern: assembly of data from metabolism experiments, classification by age and sex, and elementary statistical analysis to show how retention was related to intake. For calcium there were about 400 studies of adults and about the same number of children. The analysis of the adult material was made on the assumption that no adult ought to retain or lose calcium or nitrogen continuously, and that the amount required for maintenance would be the amount that would give equal chances of gain or loss. The concept seemed, and is, both simple and logical, but was not at first well received in some quarters. Mitchell (1938) condemned the material as a hodge-podge of experiments and the method as "unique" but, as far as calcium was concerned, he could quote estimates in agreement and a year later (Mitchell, 1939) produced confirmation from an assembly of calcium balances analysed by a similar method. Data on nitrogen balance are under review now in the light of modern concepts of biological value.

The Technical Communication on the feeding of camels (Leitch, 1940) arose from a request from an officer of the Somaliland Camel Corps for advice about certain disorders in camels which, he thought, might be due to faulty feeding. Since little had been written about the feeding of camels, an enquiry was sent to correspondents in those parts of the Commonwealth in which camels were still used. From the replies received and what publications could be found on the diet and physiology of camels, a summary was made and a comparison of diets on which camels were said to do well, or not to do well. On analogy with the feed requirements of cattle, about which there was plenty of information, it was at once clear that camels were often underfed, or ill fed, or both. It was then a simple matter to draw up plans for diets adequate by standards for cattle, made up of the feeds commonly given to camels. It was also clear that the camel has a peculiar requirement for salt, which is related to its capacity to withstand deprivation of water; deprivation of salt may cause serious disorder.

This report was received with gratitude by the officer who asked for advice, and, he said, with amusement by his camelmen who thought it funny that advice should come from a remote armchair in a country where camels exist only in zoological gardens. The conditions for being able to make this particular armchair study of a distant field problem (and for giving advice on many

equally remote problems that have arisen since) are: (i) the overseas contacts which made the questionnaire a success, and which all Commonwealth Agricultural Bureaux have, and (ii) knowledge of the requirements of cattle and the composition of feedingstuffs, which is part of the everyday stock-in-trade of the bureau, and is kept alive and meaningful by constant contact with the research and farm work of the Rowett Research Institute. The necessary basic information about camel feeding was "retrieved" by questionnaire; interpreta tion and deductions were tested against a large body of related knowledge.

THE CREATIVE REVIEW

So far we have described reviews which assemble, analyse and discuss material mostly from one field of research. But there is another type, the highest and rarest, which takes data from more than one field and shows that they are related and what the relation is. From our own experience we can describe only one, *Food Health and Income* (Orr, 1936). *Food Health and Income* took shape against a background of poverty and food shortage in the house-holds of low-paid workers and the unemployed in the midst of apparent surplusses of agricultural produce. The Ministry of Agriculture and Committees associated with it, economists, and statisticians provided estimates of food supplies and the distribution of the national income, and an assembly of family budgets, woefully small and poorly representative of the population but all that there was at the time. The Bureau had for some time been collecting data on heights and weights of school children from reports of School Medical Officers, and more general information showing, or suggesting, a relation of ill health and high mortality to poverty and poor diet. A preliminary report was prepared, of which the essence was embodied in *Food Health and Income*.

The book condensed and focussed a great deal of thought about agriculture on the one hand and health on the other. Taken along with the researches into diets and requirements in the United States which came from the Bureau of Home Economics of the United States Department of Agriculture under Dr. Hazel K.Stiebeling, it helped to convince agriculture that an apparent surplus of food was in truth a deficit. That conviction led straight on to the proposal of the League of Nations in 1935 to marry health and agriculture, and so to FAO.

Not only so, but there is now in most countries a steady stream of work on the economics of diet, and the survey of supplies and consumption of food has become a national service in many. The World Health Organization and a very large number of students of social medicine are occupied, in parallel, with the economics of health and its relation to diet.

SOME PRACTICAL PROBLEMS

FACILITIES FOR WORK

In order that research reviews may be produced there must, of course, be access to libraries, adequate in their holdings and liberal in the privileges they grant, so that the literature required may be found and borrowed. It must be possible to command a team of skilled or semi-skilled labour to collect and transcribe. There must be expertise in many languages. There must be someone in charge.

The reviews to which reference has been made in this paper involve a knowledge of chemistry, physiology, clinical medicine, embryology, zoology, economics, statistics, animal husbandry, and field work of several kinds. Clearly, the setting up of a centre in which research reviews in biology are to be produced would require either a team of experts or a superior jack-of-all-trades with access to theoretical and practical help from experts. Since whole-time occupation of a team of high-power experts would be extremely expensive, and the work of writing reviews seems not to appeal to many of them, the jack-of-all-trades offers the more likely solution. Such a jack-of-all-trades need not of course be “master of none,” but must be sufficiently knowledgeable about all, not only to be quite sure when and where expertise is needed, but also to put a problem to, and discuss it with, the expert.

It seems likely that such a person, in addition to a natural inclination to such analytical and philosophic reasoning, must have a very broad university education and a number of years spent in at least one branch of biological research. Further, the place where he is to work should be such that he can have day-by-day contact with active research. In that way ideas conceived in academic contemplation may be trimmed and shaped in relation to actual problems.

AWKWARD QUESTIONS

Not only should the centre with its consultant experts be equipped to deal with straightforward assembly and analysis of data, but it may need a sort of corporate imagination to devise methods to deal with awkward questions. There is the problem of providing an approximation when data to give a precise answer do not exist; and that of giving a quick answer when there is not time for the laborious collection of existing data. The following are examples.

Approximation

It is often argued that the cross-sectional picture of growth derived from routine measurements at school of children of different ages is of little value,

and the only worth-while study is the longitudinal, measurement of the same children at different ages. There is of course a confusion of ideas there, but ignoring it, a device which was used in our study of secular change in the height and weight of school children goes some way to provide a substitute for a mass longitudinal study. It is, briefly, to compare at successive ages children born in the same year. They are not the same identical children. As records are, they provide at the best groups in which part replacement has occurred; but they have at least lived under the same general conditions of economic life and welfare services. Further study will be required to show in what ways the composite picture may differ from a limited, true longitudinal study.

Substitution

Early in World War II, the question of the policy to be adopted in respect of stock farming, which had been heavily dependent on imported concentrates, called urgently for information on the relative efficiencies with which animals convert feed to food for man. There were a few *ad hoc* classical studies of the feed cost of beef production and some records of milk produced and feed eaten by prize cows at dairy shows, but little else in readily usable form. There were very large numbers of experiments in feeding cattle, pigs and poultry, but to collect and analyse them then would have taken far more time than could be given. A short cut had to be devised. Instead of the results of actual experiments we used the standards on which countless experiments had been based and the amounts of the products budgetted for, and so compared feed costs of the products (Leitch and Godden, 1941). The results were checked against those in the few major studies, and with a small amendment where a standard was revised, proved acceptable and useful in practice.

EPILOGUE

Each of the types of research review discussed above has a part to play in furthering biological thought and investigation. The statistical review and the service review gather together scattered numerical data in logical order, and by so doing open new prospects to theory and practice. The review of concepts helps to dissipate too rigid interpretations of physiological or biological “laws” which may be hindering the formulation of new ideas; it discusses and disposes of sham concepts which merely confuse. The better examples of all kinds of research review are creative by suggesting new hypotheses or converting hypothesis to “law.” The Creative Review, so described, is the highest manifestation of such endeavour because it deliberately sets out to effect a synthesis between phenomena previously unrelated.

Most of the examples chosen to illustrate the argument have arisen in response to a need, more or less urgent, for information that could not be reliably obtained from a superficial survey of the literature. Needs and applications have been in political, social, medical, nutritional, and agricultural fields. Each review can claim to have retrieved and made use of knowledge in danger of disappearance and loss, or to have clarified issues and cleared the way to further research. Indeed, the technique of the research review, by virtue of the assembly and use of scattered records, appears to be unequalled as an instrument for retrieval of buried work. It gives a new value to the small experiment and the single biological observation, and in the analysis may reveal truths which might not be reached in a lifetime of direct investigation.

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