METHODS OF ESTIMATING THE CONTENTS OF BIRD STOMACHS.

BY W. L. MC ATEE.

IN his report on "The Food of Birds in India," C. W. Mason expresses decided opinions on the merits of the numerical and the percentage-by-bulk methods of estimating the contents of bird stomachs. Regarding his own work, Mason says: "I have made no statements in a general way as to the relative bulks of the food taken. We see it stated repeatedly that relative bulks of food taken by birds are very important in any conclusion that we may wish to draw from economic entomology. [ornithology?]..... Our only method for obtaining this end practically consists of a complete study of the food of the birds, from specimens obtained throughout the year under all climatic, physical and seasonal conditions and even at different times during the day (this latter point is certainly one of importance in some birds and possibly therefore in most)....Comparative bulks of foods, if expressed merely as percentages, are of absolutely no value whatever, and cannot give any idea as to the true economic ratio of the food of the bird in question. What we want to know is the exact number of grains of corn, the number of insects, etc., taken, and we must not draw our conclusions from a small number of records nor from a mass of records that have been accumulated at one season of the year only. We must take a fair average." (pp. 18–19.)

As these dicta regarding the percentage valuation of the elements of bird food reflect upon the methods in continuous use by the Biological Survey, U. S. Department of Agriculture, since 1895, a defense of those methods is in order. Arguments similar to those of Mason have been made before, but always it appears by those having a relatively small amount of experience in the actual examination of the contents of birds' stomachs. In fact Mason's arguments are not so strongly opposed to estimation of percentages by bulk, as some of his sentences by themselves seem to imply. For instance he admits that the bulk method would be satisfactory if a large number of stomachs, representing all localities and seasons, be examined. Later he states that conclusions must not be drawn from a small number of records, we must take a fair average. These things are exactly what every economic investigation, worthy of the name, strives to do, and what has been done with great success in the case of numerous species of birds in the United States. The final percentages of food obtained for some species are not changed by 1 per cent, by the addition of 100 stomachs taken in a restricted area in a single season.

The numerical system (which Mason prefers) of denoting the contents of bird stomachs in contrast to the percentage-by-volume system, has assumed a number of different forms. The modifications we are acquainted with are as follows:

1. Gives total numbers of various groups of insects, seeds, etc., taken by the whole collection of birds examined.
2. States the total number of birds, taking certain items of food, or in other words, the number of times a certain food is taken.
3. States the number of birds eating certain articles of food and the number of specimens taken.
4. The proportion of the number of times a certain food is taken to the total number of times all foods are taken, is considered the percentage of that food in the diet.
5. Estimates the proportions of food items according to their numerical representation among the total of all specimens eaten.

No. 1 is used by Mason (l. c.), No. 2 by Fisher.[1] No. 3 by King [2] and Newstead,[3] No. 4 by Gilmour,[4] and No. 5, for the estimation of animal food only, by Wilcox.[5] The last named estimates the percentages of vegetable food by bulk.

Thus 6 investigators who have tried to present the results of stomach examinations by a numerical system, have adopted at least 5 very distinct methods. This indicates that no very satisfactory numerical system has thus far been proposed, a fact which has not however prevented 3 of these men, viz: Mason, King, and Wilcox, from severely criticising the percentage-by-volume method.

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[1] [Fisher, A. K.] Bul. 1, Biol. Survey, 1889, pp. 133–143, and Bul. 3, Biol. Survey, 1893.

[2] King, F. H. Trans. Wis. State Agr. Soc., Vol. XXIV. 1886.

[3] Newstead, R. Suppl. Journ. Bd. Agr. [London], XV, No. 9, Dec., 1908.

[4] Gilmour, John. Trans. Highland and Agr. Soc. Scotland, 1896, pp. 1–93.

[5] Wilcox, E. V. Bul. 43, Ohio Agr. Exp. Sta., Sept., 1892, pp. 115–131.

In striking contrast to the diversity of opinion about a numerical system is the consistent application of the volumetric method, by at least 9 American food analysts. Dr. G. Rörig of Germany prefers the related but more technical and difficult method of ascertaining proportions by weight.

Some of Wilcox's objections to the percentage-by-bulk system are stated in the following quotation.[1]

"How to estimate the relative proportions of the various food matters found in the stomachs examined is a very important but rather difficult question. Upon a slight consideration it becomes evident that we cannot base our proportions upon the relative bulk of different materials. To illustrate, suppose we place on one side of the equation a blackberry and on the other enough chinch bugs to equal the bulk of the berry. It would obviously be very absurd to assume that the one counterbalances the other. Mr. King. . . .has considered this difficulty in the following words:

"If we compare the corn plant-louse, the gall stage of the grape phylloxera, the plum curculio, the small parasitic military microgaster, which lay its eggs in several kinds of cutworms, the potato beetle and the chinch bug with the large coral-winged grasshopper bulk for bulk, the ratios will appear about as follows:

1 Coral-winged grasshopper			=	12,000 military microgasters.
1	"	"	=	3,000 phylloxera.
1	"	"	=	1,500 corn plant-lice.
1	"	"	=	750 chinch bugs.
1	"	"	=	60 plum curculios.
1	"	"	=	7 potato beetles.
1	"	"	=	1,000 young potato beetles.

"By a system of gauging bulk for bulk it is evident from the table that one coral-winged grasshopper eaten by a bird would give it a credit which would offset completely the destruction of 12,000 military microgasters, a proposition sufficiently absurd."

We may remark that Wilcox's own system of estimating the proportions of animal food according to the number of individuals, violates every intent of this precept, as it also gives all individuals equal weight.

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[1] Wilcox, E. V. Bul. 43, Ohio Agric. Exp. Sta., Sept., 1892, pp. 118–119.

F. H. King, who is thus quoted by Wilcox, further asks:[1]

"*How shall a bird's food account be expressed numerically in terms of debit and credit?* This is at once the most difficult and the most important of all the questions requiring solution in order to express the *specific* economic relations of any bird.

"Nothing can be more certain than that, after the food of a bird has been classified under the heads "Elements Beneficial" and "Elements Detrimental" to man, neither the relative volumes nor the relative weights of these two classes of material can express the true economical relations of the bird. (p. 398.)

"A peck of plums and a peck of curculios, a peck of wheat and a peck of chinch-bugs, or a peck of corn and a peck of cutworms, are manifestly not to be considered as equivalent values on opposite sides of any account." (p. 399.)

And Mason says as above noted "Comparative bulks of food, if expressed merely as percentages, are of absolutely no value whatever, and cannot give any idea as to the true economic ratio of the food of the bird in question."

First it should be stated that these gentlemen have no occasion to be so emphatic; their criticisms are wide of the mark for no one claims that percentages do express economic values. They are simply convenient handles to facts and they must be interpreted.

This point is well brought out by the arguments Wilcox advanced in proposing his hybrid system. He says:

"Having seen from the start that the ratios of the different food materials could not justly be estimated according to bulk, and having seen also that a system based upon the number of insects, plant fruits, etc., found in the stomachs examined would be almost equally likely to introduce error, and that it would be a system particularly difficult to carry out in consequence of the fragmentary condition of the food, I decided to combine these two systems of computing the proportions in a way which seemed to me to represent justly all the elements of food. It would be approximately true to say that I have estimated the proportion of animal food according to the number of the individuals, and vegetable food according to bulk. But all fruits which have a definite number of

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[1] Trans. Wis. State Agricultural Society, Vol. XXIV, 1886.

seeds have been estimated upon a numerical basis. It is evident that this would have been very difficult or even impossible in the case of blackberries or raspberries in which the number of seeds is so variable.

"It may be objected that the computation of the vegetable food on one basis and of the animal food upon another basis is a fruitful source of error. But I have exercised all care and diligence to avoid every possibility of error, and, in fact, an estimation of the relative proportions of the several kinds of food would not make the vegetal part appear larger than it really is, since a raspberry or blackberry is no greater in bulk than an earthworm or May beetle. It may as well be admitted that, in the present state of knowledge, only an approximation to the truth can be attained in a statement of the relative proportion of the various food materials in a bird diet.

"But even after we have tabulated the numerous articles of food in their differing proportions in a more or less satisfactory manner, the task is by no means completed. In order that we may decide whether the robin is on the whole a benefit or an injury to farmers and gardeners, we must first determine the economic relations of the various species of plants and animals upon which the robin feeds."

It is very evident that interpretation of economic values is the most important point in presenting the results of stomach examination. Whether such results are expressed by the numerical or by the percentage system, the figures in themselves are powerless to convey an impression of economic values. Hence the assertions of Mason, King and others are no more a criticism of the percentage-by-bulk system than they are of the numerical system. For instance King's dictum that "a peck of corn and a peck of cutworms are manifestly not to be considered as equivalent values on opposite sides of any account," applies just as well to his own numerical accounts. Does it mean anything definite to say that 10 individuals of a certain species of bird have consumed 20 beneficial insects and 35 injurious ones? Do these figures tell us whether the insects in question are large or small? Whether they are

[1] Bull. 43, Ohio Agric. Exp. Sta., Sept., 1892, pp. 119–120.

greatly or only moderately beneficial or injurious? do the figures give us any idea as to whether this account about balances? or whether one side greatly overbalances the other?

On the contrary it is evident that they stand just as much in need of interpretation, as do percentages. Hence the question between the two systems is not purely one of expression of economic values, as some supporters of the numerical system would have us believe, but one of the means best adapted to expressing the relations between the various food elements. To the writer's mind the percentage-by-bulk system has all the better of the argument, but let us not so decide without giving the various numerical systems a hearing.

Mason says, "What we want to know is the exact number of grains of corn, the number of insects, etc." To illustrate we may cite one of Mason's summaries: "Of 142 insects taken by 12 birds, 7 are beneficial, 50 injurious and 85 neutral." (p. 118.) Are we to understand that this bird does good and harm in the proportions of 50 to 7? Not unless the insects mentioned are of equal size or at least of equal capacity for good or harm.[1] Suppose the useful species are large forms which do a great deal of good, and the injurious ones small ones of no consequence. Or if you please, make just the reverse supposition. In neither case do the figures above supply the information necessary to reach a final conclusion. The objection that these authors make to our percentages, apply equally well to their figures — they do not give any idea as to the true economic ratios. Like the percentages they must be interpreted.

The principal variation of the numerical system aside from that of Wilcox, which has previously been discussed, is that used by John Gilmour in his paper [2] on the Wood Pigeon, Rook and Starling. In a review of this paper Professor Beal states: [3] "Mr. Gilmour reckons his percentages from the number of times that the bird has taken the food, and from this concludes that grain and husks constitute 58 per cent of the Rook's food. Insects and grubs

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[1] Insects whose economic status depends upon their food habits, and this includes the majority, are very properly reckoned by bulk, for as a rule the larger will do more harm or good than the smaller ones.

[2] Trans. Highland and Agr. Soc. Scotland, 1896, 1–93.

[3] Auk XIV, No. 1, Jan., 1897, p. 10.

reckoned in the same way, amount to 23 per cent. It can hardly be claimed that this is the most accurate method of calculating the relative amounts of food found in a bird's stomach. Birds are fond of eating a great many different things, the aggregate quantity of which may be small, just as human beings eat a little butter and sugar at nearly every meal, but never make a whole dinner of either. To illustrate, in an examination of 2258 stomachs of the Crow Blackbird, corn amounted to 35 per cent of the food by bulk, but when reckoned by the number of times taken it aggregated 52 per cent."

Other illustrations from Professor Beal's work show still greater diversity between percentages obtained by these two methods. For instance spiders were found in 26 per cent of 389 stomachs of *Hylocichla ustulata,* but composed only 1.82 per cent of the stomach contents by bulk. The same data for *Hylocichla guttata* is: spiders were found in 49 per cent of 514 stomachs, but made up only 7.35 per cent of the total contents. Ants, much smaller creatures on the average than spiders, while found in fewer stomachs (249 as contrasted with 254) of the Hermit Thrush, compose a considerably larger volume of the food, namely 12.54 per cent. This fact is just contrary to the normal expectation, and would never be guessed from figures showing merely the frequency of occurrence. The misleading nature of such figures is further shown by the fact that wild fruits found in 243 stomachs somewhat fewer than held ants, compose 26.86 per cent or more than twice as large a proportion of the total bulk of the food. Furthermore caterpillars, occurring in 268 or 52 per cent of the stomachs, and hymenoptera (other than ants), found in 136 or 26 per cent, form nearly equal percentages (within a fraction of one per cent) of the total subsistence.

Beyond showing the futility of Gilmour's particular variety of the numerical system, these instances prove, that frequency notations, no matter whether they refer to systematic or to economic groups, do not indicate the importance of these groups in the diet of the species concerned. Hence they do not suffice for the needs of economic investigations.

Let us see what other objections can rightfully be lodged against the numerical system. In the first place the adherent to this system deprives himself of the possibility of referring accurately to the contents of a very considerable proportion of the stomachs of birds in general, and probably of a majority of those containing vegetable food. In most cases it is impossible to accurately count the number of individuals of much comminuted animal matter, and practically every stomach containing animal food has a portion of it in this condition. Who can reckon the number of earthworms when only the spicules are left, or caterpillars by the spines, or fishes or moths by their scales? Evidently figures cannot be applied to ground up oats, wheat, corn, and their young shoots, nor to fruit pulp, nor to berries containing an indefinite number of seeds. Who can tell from an inspection of the contents of the stomach how many apples, peaches, or grapes a bird has bitten into, or how many strawberries, blackberries or figs it has sampled? Hence a very important feature of economic work, in fact the most important from the standpoint of the farmer, cannot be expressed by the numerical system. This fact alone proves the inadequacy of the method. It is noticeable that Mason was unable to carry out his intention as to counting all items, particularly in the case of *Ficus* fruits, and of various buds and shoots. Neither can he refrain from using expressions denoting bulk proportions of food.[1]

King for the best of reasons takes no cognizance of vegetable food in his tables, but has the audacity to condemn the percentage system almost in the same breath. As an example of the way King's methods work out, we may quote his account of the food of the Blue Jay (*l. c.* p. 540). "Of 31 specimens examined, 19 had eaten acorns; 15, 30 beetles, among them several species of *Harpalidæ* and a *Cetonia;* 2, 2 caterpillars; 2, 2 grubs; one, some other larvæ; 2, grasshoppers; 5, corn; one, wheat; and one berries. No stomach was found to contain only insects; and of those which contained beetles, their remains never composed more than one-fifth of the entire contents, and usually less than one-tenth." Thus King could not count the individuals of 6 out of 9 items of food in stomachs of Blue Jays, and must express himself in percentages, in order to explain that the item — beetles — apparently

[1] See particularly the accounts of *Molpastes bengalensis, Oriolus kundoo, Acridotheres tristis, Sturnopastor contra, Turtur suratensis T. risorius,* and *Francolinus vulgaris.*

second in importance, "never composed more than one-fifth of the entire contents [of stomachs], and usually less than one-tenth."

It should be pointed out also that the numerical system would be of no use at all in the case of a majority of mammal stomachs as the food is so finely ground. Comminuted food presents no great obstacles to percentage estimation, however, as nearly all of its can be reckoned in the account by this system. Lord Kelvin has said "When you can measure what you are speaking about, and express it in numbers, you know something about it; but when you cannot measure it, when you cannot express it in numbers, your knowledge is of a meager and unsatisfactory kind; it may be the beginning of knowledge, but you have scarcely in your thoughts advanced to the stage of science." It follows therefore that a method of estimating bird food which is powerless to express anything about a considerable portion of the food, has "scarcely advanced to the stage of science."

Under the numerical system, the tendency is for insects or other food elements with very resistant parts to get an undue representation among the items contained in the stomachs. For instance the mandibles of grasshoppers or of beetles or certain stony seeds may persist in the stomach while one or more meals following that from which they are derived, have been eaten and digested. When numbers only are used we must count one insect for each pair of mandibles, and it often happens that the numerical majority of the insects in a stomach, form but a small proportion of the food. Under the percentage-by-bulk system the error due to the presence of relics of past meals, is reduced to the minimum.[1]

The reason is that in examining large series of stomachs inequalities of size tend to balance each other. The insects being entire, a grasshopper will equal in bulk say 10 of a certain species of carabid beetle, but another stomach may contain the jaws of 20 or more grasshoppers and only one of the carabids, which, however,

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[1] It should not be understood from this and following remarks, that the writer believes in the long persistence of food particles in birds' stomachs, for his position is just the reverse. What is meant is that in the great majority of birds, digestion is a continuous process, and what may be termed a meal, *i. e.* a stomach full of freshly taken food, is generally accompanied by the harder portions of one, or perhaps more than one previous "meal." It is probable that only in rare cases is any particle of food retained in a stomach more than a few hours.

will exceed the former in bulk. If only the tibial plate of a grasshopper is present, a mosquito will far exceed it in size, and will get a correspondingly greater percentage. Under the numerical system we would write down one grasshopper and one mosquito, and none could guess that the mosquito was a real component of the present meal, and the grasshopper a mere trace of a meal gone by. A small ant may thus surpass in bulk the remains (accessory genital glands) of several much larger moths, and so on. Long series of stomachs, taken in many localities at all seasons, tend to smooth over the irregularities due to differences in size. This happens because the present meal being greatest in bulk always gets chief recognition, and past meals represented by mere traces, receive little or no percentage valuation. A large series of stomachs yields many present meals of all the important food elements. Each of these elements therefore is represented in the stomachs by numerous freshly taken specimens which receive full percentage allowance, as well as by residual traces which add little to the total proportion. Approximate proportionate representation is thus assured.

On the other hand if we use the numerical system, an insect or other food item receives the same recognition if represented by a mere trace as it would if entire. In summing up the food of a number of individuals therefore, instead of getting a cross-section as it were of the various typical meals, we get records of the more durable elements of meals piled on each other, until an entirely false idea of the food is obtained.

Dr. Fisher justly observes that this is not the case with the majority of the birds of prey, which disgorge the less digestible remains of each meal, leaving the stomach entirely empty. It is probable that a numerical system is better adapted to stating the food of these birds than of any other group.

In the writer's opinion the estimation of the percentage of food items by bulk, logically rests on the firm foundation of a bird's natural requirement of a certain average quantity of food per day. A bird, just as a man, needs a certain food value, or number of calories per day,[1] and in the long run, this is obtained from a

[1] Dieticians make their computations on the basis of weight, and one economic ornithologist — Rörig of Germany — has used dry weights in part of his work. But these methods consume much time and are probably unnecessary for the degree of accuracy now required in economic work. Estimation of bulk percentages comes nearest in scientific accuracy to weighing.

certain average bulk of food. We thus have for each species a standard of food consumption, by which we can computate its demands for any multiple or fraction of the standard period. The number of insects, seeds, etc., consumed cannot be so standardized. This is true partly because, many of the items cannot be counted (as explained above), and partly because the elements of food vary so much in size. Thus a bird may take as a certain proportion of its subsistence, 10 grasshoppers, or it may take instead 50 beetles, or 1000 ants. In view of this fact what does it mean to say so many birds took a certain number of beneficial and a certain number of injurious insects. Can we possibly learn by numbers their relation to the whole food? It is perfectly evident that a bird requires, not a certain number of insects and seeds per day, but a certain average bulk of food, which may be made up of an exceedingly wide variety of items of very diverse sizes. It follows therefore that we can estimate the importance of any element of the diet, only when we know its proportion to the standard requirement.

We must express ourselves in terms of bulk also when we desire to state the amount of damage done to crops. The cultivator wishes to know how many quarts of cherries or pecks of grain the birds are apt to destroy in a year. We can make these estimates with greatest accuracy when we know the proportion of the annual food of birds, composed of these items.

Suppose, using the numerical system, we say we have examined 100 Crow stomachs and found in them 675 kernels of corn. What does this mean? Can we learn by a numerical comparison with the grasshoppers, or acorns eaten, what proportion of the yearly food consists of corn? The case is different if we can say that corn constituted 15 per cent of the food of these 100 Crows. We then know something about the Crows' relative taste for corn, know that they could have taken much more, but chose to eat other things. The farmer in the locality in which they were collected knows from such a statement about what damage he may expect from Crows.

Without the percentage-by-bulk system the writer would have been unable to make the following statements [1] regarding the food of the Black-headed Grosbeak, namely: "that the animal food of

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[1] Bull. 32, Biol. Survey, 1908, p. 76.

the Black-head, consisting almost wholly of injurious insects, is practically twice the bulk of the vegetable food, or more than four times that portion which is pilfered from man"; and that "for every quart of fruit eaten, more than 3 pints of black olive scales and more than a quart of flower-beetles, besides a generous sprinkling of codling moth pupæ and cankerworms fall prey to this grosbeak."

The percentage-by-bulk system has a further advantage in that it indicates approximately the proportion of the total feeding time a bird spends in eating the various elements of its food. For instance, if we state that a certain Blackbird spends about half its time eating grain, as we may with approximate truth if 50 per cent of its food is grain, we present this fact in a much more graphic way, than we would be able to do, were our knowledge confined to the number of kernels contained in a series of stomachs. The writer expressed this idea in a slightly different form when writing about the food of wild ducks. He then said: [1] "Although on first thought a percentage of less than 5 for wild rice may seem small it really means that these 16 species of ducks get a twentieth of their annual subsistence from this grain; in other words, the quantity they eat would support them for two and a half weeks, if wild rice were fed upon exclusively. Similarly, wild celery, which forms 6.65 per cent of their food, would suffice for three and a half weeks; and pondweeds, which form 13.88 per cent, for more than seven weeks."

These illuminating expressions of the importance of various items of bird food are impossible under any numerical system. Neither does a numerical system supply the basis for graphic representation of the proportions of bird food, such as the sectors of circles method devised by Judd,[2] the curve plottings introduced by Professor Beal,[3] or the shaded columns used by the writer.[4]

The chief beauty of the percentage system however is that it permits those comparisons of one part of a bird's diet with another part, or the food of one species or group of species with that of

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[1] Circular 81, Biol. Survey, 1911, p. 2.
[2] See Yearbook U. S. Dep't of Agriculture, 1900.
[3] See Bull. 13, Biol. Survey.
[4] See Bull. 23, Biol. Survey, 1905, p. 29.

another, which are a *sine qua non* in scientific economics. It means so little to say for instance as Mason does: "Of 110 insects taken by 35 birds [Common Mynah], 58 are injurious, 5 beneficial and 47 neutral," (p. 103) and "of 39 insects taken by 14 birds [Pied Mynah], 1 is beneficial, 25 injurious, and 13 neutral." (p. 109). How can the import of these figures be judged unless they are put into proportions? And they cannot be so compared, from the data given, since the insects are of many sizes, and consequently of varying economic importance.

But when we read that weed seeds form 36 per cent of the annual food of the Cardinal and 15 per cent of the diet of the Rose-breasted Grosbeak, we can appreciate at once the comparative value of weed seed as food to these two birds, and the rank of the species as destroyers of weed seeds. Citation of long lists of the numbers of neutral, beneficial and injurious insects which are not susceptible of direct comparison, soon confuses the mind, while the same facts expressed in percentages have directness and clearness obtainable in no other way.

Professor S. A. Forbes, the pioneer economic ornithologist, whose skillful laboratory work and clear thinking, laid so firm a foundation for subsequent workers in this field, adopted the percentage-by-bulk method. He explains [1] that in stomach examination "opportunity is afforded for careful and trustworthy estimates of the ratios each element bears to the other, so that the average significance of the food can be discovered. Practically, this is indispensable. Whatever method fails of this, while its results may be interesting, and may have a certain general value, can never afford a basis for anything better than indefinite opinion. It can never settle the case for or against the birds.

"This method, while by far the best of the three, has its slight disadvantages. Some things eaten by birds leave no appreciable trace in the stomach. For example, it is difficult, by this method, to determine with certainty those birds which greatly injure grapes by breaking the skin of the fruit and sipping the juice. This difficulty applies only to liquid food. Other errors may arise from the shorter or longer periods for which different kinds of food will last in the stomach; but of this we have no proof. I have

[1] Bull. Ill. State Lab. Nat. Hist., Vol. I, No. 3, 1880.

depended almost entirely on this....method of investigation, because it is evidently the most profitable and reliable, and because the method of cursory observation having been resorted to heretofore, most of the recorded facts are due to it. So far as one method could correct the deficiencies of the other, it was desirable that this more tedious and laborious but more fruitful one should be given greater prominence." (pp. 87–88).

The volumetric method of stomach analysis has twice received official sanction by the Biological Survey. In 1895 Professor W. B. Barrows wrote that "In the case of a bird which eats insects only it might be possible to use the numerical method with some accuracy; yet even then much would have to be left to individual judgment in estimating how many small insects were equivalent to one large one, or how many harmful insects would be necessary to offset the consumption of a given number of beneficial insects. Moreover, only under the most favorable circumstances would it be possible to determine just how many individuals of each kind were represented in the stomach contents, for, even if swallowed whole, so soon as digestion begins the individual insects become dismembered, crushed and broken, and within a short time only the hardest parts, such as heads, wing covers, legs, and jaws, remain in recognizable condition.

"It has seemed best, therefore, in attempting to determine the proportions of the various food substances in Crow stomachs, to depend upon the method of equal masses or bulks, which method is adopted in the present bulletin. In most cases the number of individual seeds, insects, or other animals has been recorded also, but these numbers have not been considered in determining percentages." [1]

In 1901 Dr. Sylvester D. Judd in describing the process of stomach examination said: "After each element in a bird's stomach has been identified and placed in a separate pile, the percentages of the different elements are estimated by volume. (Of course it must be understood that mathematical exactness is not attainable in these examinations; but every possible means is taken to reduce the error to a minimum, and with a sufficient number of stomachs a very correct idea may be obtained of the proportions of the

[1] Bull. 6, Biological Survey, 1895, pp. 28–29.

different elements of the food.) [A footnote in original]. In recording the results of examinations a separate record is made for each species and for each month. Monthly averages are based on the number of stomachs collected in the month, but yearly averages are determined from the monthly averages; for unless the collections of stomachs were much more evenly distributed as to months than they are at present, an average based directly on the number of stomachs collected in the year would be misleading."

The results would be just so much more accurate if the abundance and distribution of material warranted reduction of the time-unit to a week, or better a day. The writer has proposed also, as a further step toward accuracy, to reduce the disturbing effect of peculiar local conditions by averaging the contents of stomachs collected in one locality in the same month, and giving such averages (of more than a certain minimum number of stomach contents) equal weights in the monthly tabulation.

Summary.

The principal objection to the method of reckoning the contents of bird stomachs solely by the number of individual insects or seeds, is that the method takes no account of size of the objects, and hence conveys no idea to those unacquainted with the groups concerned of the relative importance of the foot elements.

Size has much to do with economic status — i. e., capacity for good or harm — and it receives proper recognition only under the percentage-by-bulk system.

We have shown furthermore that statements as to the frequency with which certain food items are taken by birds, by no means indicate the importance of these items in the diet of the species. Under the volumetric method however, the proportions the various elements contribute to the animal's subsistence are evident at a glance, and the animal's capacity for good and for harm are clearly shown.

Numerical notations in most cases greatly exaggerate the im-

[1] Bull. 15, Biological Survey, 1901, pp. 14–15.

portance of elements of the food that have parts very resistant to digestion, a difficulty which is reduced to the minimum when proportions are estimated according to the volumes.

Numerical systems are not sufficiently comprehensive. Finely comminuted, fleshy, or pulpy food, or food occurring in indefinite masses cannot be reckoned by numbers. Under the percentage-by-bulk system, all food can be included in the computations. Intelligible comparison of one part of the diet with another or of the food of one species or group of species with that of another, as well as graphic representation of the proportions of the food, are only possible when the volumetric method is used. This system is the better therefore, as the more complete is always superior to the less.

On the other hand statements of the frequency of occurrence of food items in bird stomachs may perhaps be taken as rough indices of availability of the food or of relish for it. And statements of the number of individuals in stomachs have an interest as "records," the interest being in direct proportion to the bigness of the number.

The ideal system from the writer's point of view is one that combines the good points of both the numerical and volumetric methods — a system which, as a matter of record, counts individuals as far as possible, or at least in enough instances to assure the inclusion of typical cases, and which further estimates the proportion of all important items by bulk. Such a system has been approved and used by Forbes, Beal, Barrows, Kalmbach, Judd, Sanderson, Dearborn, Weed and the writer, among American investigators. The consistency with which it has been applied is in striking contrast to the vagaries of numerical systems which have scarcely been used alike by any two writers. We have shown that the chief criticisms that have been aimed against the volumetric system, apply equally well to the numerical methods. The latter have other weak points that do not appear in the percentage-by-bulk system, and the few good points peculiar to the numerical system can profitably be combined with the volumetric method. This gives us a compromise technique that contains all of the good features and a minimum of the weaknesses of its components.