REVIEW

Sewall Wright (1889–1988)

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ABSTRACT

The genetic contributions of Sewall Wright is briefly reviewed with special reference to J.B.S. Haldane's work. These include his work in population genetics, statistics, and animal breeding.

Sewall Wright was the son of Philip Green Wright, who was a member of the faculty of Lombard College, a small Universalist College in Galesburg, Illinois. Most of Sewall's childhood was spent in Galesburg. (He was actually born in Massachusetts.) His father was a man of many talents—an economist by training, he taught astronomy, surveying, mathematics, and English composition, and directed the gymnasium. In addition, he operated a printing press and, in his later years, wrote several books. Sewall Wright (the product of a first-cousin marriage) was a precocious child, who displayed his talent for reading, writing, and arithmetic from an early age. Except for calculus, which Sewall learned from his father at Lombard, much of his mathematical work was self-taught, often employing only a simple desk-top or hand-held calculator. Quite early in his life, his interest in genetics was kindled by Wilhelmina Key, another teacher at Lombard. His assignments included R. C. Punnett's essay on Mendelism in the eleventh edition of the *Encyclopedia Britannica*. After graduating from Lombard in 1911, Wright spent a year at the University of Illinois, where he came into contact with William Castle, who was visiting the campus. Castle hired Wright as his assistant at Harvard, and Wright graduated with the Ph.D. in 1915. For the next ten years, Wright was employed at the U.S. Department of Agriculture in Beltsville, Maryland. He then joined the University of Chicago faculty and continued his research (and teaching) in genetics for another 30 years, retiring at the age of 65. After his retirement from Chicago, Wright accepted a faculty position in genetics at the University of Wisconsin in Madison, where he continued his research for more than 30 years until his death in 1988 at the age of 99.

Wright's contributions to genetics

Wright's early interest in genetics was concerned with coat color inheritance in

mammals. He published a series of papers on comparative coat color inheritance in guinea pigs, mice, rats and several other mammalian species. His studies of guinea pig pigments eventually led to his views on evolution. By devising a number of combinations of crosses involving various color genes, Wright was able to study and analyse the complex interactions. Wright's contribution to the theory of evolution by natural selection, shifting balance theory, was a direct outgrowth of his experience of breeding domestic livestock as well as his experiments with coat color in guinea pigs. He viewed evolution as a process of moving from one harmonious combination of gene frequencies to another that is better adapted to the environment. However, Wright emphasized that the transition from one favorable combination to a better adapted one involves passage through a number of inferior combinations. In order to explain this passage through a valley between two peaks, Wright hypothesised (at least, in some cases) the role of random factors. Wright (1931) wrote: "Finally in a large population, divided and subdivided into partially isolated local races of small size, there is a continually shifting differentiation among the latter (intensified by local differences in selection but occurring under uniform and static conditions) which inevitably brings about an indefinitely continuing, irreversible, adaptive, and much more rapid evolution of the species." Wright stated that complete isolation in this case originates new species. Wright's model was not unlike that suggested by Haldane (1931), who anticipated Wright in his remarkable paper dealing with the evolution of genes in "metastable populations."

Wright (1931) discussed his model in three phases. The first phase is stochastic variability of all gene frequencies in each local population about its set of equilibrium frequencies. The underlying assumption for Wright's model is as follows. The sort of selection involved in influencing their equilibrium values is assumed to result in the same intermediate grade for quantitative characters under multifactorial heredity. Consequently, the result may lead one to believe (with Wright, 1968) that "selection toward such a grade implies the existence of many selective peaks in the "surface" of selective values, separated by saddles, and at various heights because of secondary effects on other characters (pleiotropy)". The occasional crossing of a saddle between a lower and a higher peak as a result of extreme stochastic variation leads to the second phase in which selection favors the set of equilibrium frequencies of the higher peak. The third (and final) phase is concerned with the successful establishment of this "superior" system by means of excess population growth and emigration to neighboring populations, "and ultimately, perhaps, throughout the species as a whole". It was recognized further that local selection in a different direction may also lead to superior general adaptation and replace the first two phases. Wright emphasized that such "random" drift towards favorable combinations of gene frequencies is likely to occur more frequently in small, partially isolated populations.

Haldane and Wright's Third Phase

We must also consider what Haldane (1959) had called “the weakest point in Wright’s argument”. Haldane wrote: “Wright considered a species divided up into a number of small endogamous tribes. Such a tribe might easily, by chance, become homozygous for several slightly unfavorable genes. If it happened to hit upon a favorable combination, its numbers would increase. To my mind the weakest point in Wright’s argument is that he has not adequately considered what happens when this tribe starts hybridizing with others.” In a recent paper, Crow et al. (1989) examined this aspect of Wright’s work. In particular, they considered the following questions: (a) Does recombination break up favorable combinations before they can spread through the population?, and (b) How much migration is required to prevent this and carry out the third phase? Crow et al. (1989) concluded that remarkably little migration proves to be sufficient to bring about the final phase of Wright’s shifting balance process. They wrote further that the general importance of Wright’s shifting balance theory of evolution remains uncertain. Perhaps, new data on physiological aspects as well as population structure could throw light on this problem. If there are widespread circumstances which can hinder major evolutionary advances by means of small selectively advantageous steps, then Wright’s theory or something similar is required. If the situation were different, however, Fisher’s approach would be adequate to explain the general process of evolution.

Wright’s last paper

In a defense of his “shifting-balance” theory, Wright (1988) wrote a paper—his last paper, written shortly before his death—entitled “Surfaces of selective value revisited”. With reference to Provine’s (1986) criticism of the concept of “surfaces of selective value”, Wright (1988) commented that Provine was “looking for something more mathematical than was intended.” It is of great interest that Wright’s (1931) essential concept was largely based on the multifactorial viewpoint of genetics. As he put it: “The early viewpoint changed with the demonstration by Nilsson-Ehle (1909) and East (1910) that quantitative variation usually depends on the total effect of multiple minor factors.” He emphasized once again that this implied the occurrence of “multiple selective peaks”, because numerous superior combinations could exert more or less similar effects and that the selective value of any particular gene depends on the rest of the genome. Wright’s 1931 paper dealt with a mathematical analysis of the allelic frequencies for pairs of alleles at a single locus under various conditions. The evolutionary implications of multiple loci, each with multiple alleles, were first discussed verbally (in terms of what Wright later called his “shifting-balance” theory), and were first published in an abstract in 1929. The pictorial representation of the basic evolutionary process consisted of six diagrams, each under a different set of conditions: (a) increased

mutation or reduced selection, (b) increased selection or reduced mutation, (c) qualitative change of environment, (d) close inbreeding, (e) slight inbreeding, and (f) division into local races. Wright (1988) stated that the most favorable circumstance for the operation of the shifting balance process would be a sparse population of individuals that are neither excessively mobile nor immobile over a widely extended range.

In Wright's model, random gene fluctuations are regarded not as impediments to the process of natural selection but as the raw material on which evolutionary progress is based. On the other hand, Fisher believed that random gene frequency fluctuations were relatively unimportant to the main process of evolution by natural selection. Wright's views have been held consistently throughout his life's work, during 1920–88. Contrary to Provine's (1986) evaluation of Wright's work, Wright (1980, 1988) had stated that his views on the evolutionary process had not become more selectionist after 1932. With respect to Kimura's (1968) neutral theory, Wright (1988) wrote that his own chief interest had not been evolution in general, but *adaptive* evolution. Kimura, on the other hand, developed his neutral theory on the basis of slowly accumulating biochemical changes in the genome along long successions of species.

Statistics

In addition to his genetical papers dealing with the selection theory, Wright contributed several papers on statistics. In 1917, he used methods of analysis of guinea pig weights that were later called analysis of variance and covariance, long before such techniques were developed by Fisher for general statistical use. His most famous contribution, the path diagram, was developed in 1920 to delineate the variance of coat color into genetic and environmental components. His extensive paper, "Correlation and Causation", was published in 1921 and contained the first complete treatment of the method of path analysis. The diagram gives a clear, graphic picture of the underlying causal connections, each step associated with a "path coefficient" which is a partial regression coefficient standardized by being measured in units of the standard deviation. The method was applied especially to livestock breeding with reference to inbreeding, selection, assortative mating, and other aspects. Later, it was applied to a great range of problems in biology, sociology, econometrics and numerous other social sciences. Among other topics, Wright (1930) contributed to the study of genetic and environmental components in IQ determination, concluding that heredity plays a large role but also emphasizing that there were too many uncertainties concerning the method of data collection and the underlying assumptions.

Wright's influence

Wright's move from Chicago to Madison brought him into daily contact with James F. Crow, well-known population geneticist and a distinguished member of

the University of Wisconsin's Genetics Department in Madison. Dr. Crow had a number of highly gifted students, among them were Motoo Kimura and Newton E. Morton. Kimura's Ph.D. work under Crow began only a few months before Wright's arrival. This chain of events had a very significant impact on the development of population genetics. Kimura's work was deeply influenced by Sewall Wright. Kimura (1985) wrote: "Through reading Wright's papers, I became more and more absorbed in problems of random genetic drift in finite populations... I was also attracted by Wright's idea that individually deleterious but jointly advantageous mutants can be utilized in evolution when the population is subdivided; the advantageous gene combination will become fixed in some of the local populations due to sampling drift."

During his Chicago period, Wright had a number of graduate students, who later became well-known geneticists in their own right. These include W. L. Russell, E. S. Russell, L. B. Russell, J. P. Scott, Herman Slatis, and Janice Spofford. Indirectly, he influenced the work of many geneticists world-wide.

Animal breeding

When Wright took up his position at the U. S. Dept. of Agriculture, he inherited several inbred lines of a guinea pig colony. He wrote several papers analysing the effects of inbreeding and cross-breeding, and suggesting combinations of inbred lines to produce vigorous hybrids while maintaining genetic control over weakly heritable traits (Wright, 1920). These and other results of his guinea pig work were of great relevance to the actual problems encountered in livestock breeding as well as plant breeding. Other Wright's classics include his paper, "Systems of Matings" (1921), and his attempt to measure the degree of inbreeding in terms of the correlation between the genetic values of alleles in uniting gametes (Wright, 1922). Later, Wright expanded this approach to measure various components of population structure.

Wright was a Visiting Professor at Edinburgh University's Institute of Animal Genetics in Scotland in 1949, and wrote a detailed account of population structure, which was later applied to both livestock breeding as well as to analyze the evolution of natural populations (Wright, 1951). His contributions in this field had a very significant impact on animal breeding, mostly indirectly through the work of such individuals as J. L. Lush and A. B. Chapman. During the same visit to Edinburgh, he wrote a monograph on quantitative genetics as well (see Wright, 1952).

Wright made important contributions to physiological and developmental genetics much of which was based on his work on pigment genetics of guinea pigs. Crow (1987) has recently evaluated Wright's contributions in these fields.

Wright and Haldane

Sewall Wright was a mild mannered and quiet gentleman. He was known to

Fig. 1. Dr. Sewall Wright with the author at the Haldane Memorial Session, XII International Congress of Genetics, Tokyo, 1968.

give his time freely to anyone who sought his help in genetic research. Like his contemporary, J. B. S. Haldane, Wright was totally dedicated to his work in genetics. Neither had any other distractions. I was fortunate to have had opportunities to enjoy his friendship. He participated in the XII International congress of Genetics in Tokyo in 1968, lecturing on Haldane's contributions to genetics (Wright, 1969). During an informal luncheon in Madison shortly before his death, in 1988, Wright stated that he first met Haldane during the International Congress of Genetics in Ithaca, New York, in 1932. There were some important differences between Haldane and Wright. Haldane was a highly skilled and prolific popularizer of science whereas Wright's writings were almost entirely of a technical nature. Wright's scientific work was entirely in genetics, whereas Haldane showed great versatility, contributing to physiology, biochemistry, biometry, astronomy, and several other branches of science including genetics.

Wright was working and writing papers in genetics almost until his death in his 99th year, when he slipped on a patch of ice during one of his frequent walks in Madison. His last years were spent in close friendship with his friends, Dr. and Mrs. James F. Crow.

Sewall Wright received many honors in recognition of his contributions to genetics. He was a member of the U. S. National Academy of Sciences and President of the Genetics Society of America. He was a foreign member of the Royal Society of London and an honorary member of the Genetical Society of Great Britain. He was also an honorary member of the Genetics Society of Japan.

Personal meetings with Sewall Wright and James F. Crow were beneficial in writing this paper. Dr. Crow, in particular, has been most helpful in providing much information about Sewall Wright and his work. I am grateful to him further for suggesting improvements in this manuscript.

REFERENCES

- CROW, J. F. (1982) Sewall Wright, The scientist and the man. *Persp. Biol. and Med.* **25**, 279–294.
- CROW, J. F. (1987) Sewall Wright and physiological genetics. *Genetics* **115**, 1–2.
- CROW, J. F., ENGELS, W. R. and DENNISTON, C. (1989) Phase Three of Wright's shifting balance theory. *Evolution* (in press).
- DRONAMRAJU, K. R. (ed.) (1968) *Haldane and Modern Biology*, Johns Hopkins University Press, Baltimore.
- DRONAMRAJU, K. R. *Haldane: The Life and Work of J. B. S. Haldane with special reference to India*. Aberdeen University Press-Pergamon Press.
- FISHER, R. A. (1930) *The Genetical Theory of Natural Selection*. Clarendon Press.
- HALDANE, J. B. S. (1932) *The Causes of Evolution*. Logmans, Green.
- HALDANE, J. B. S. (1959) Natural selection. In: *Darwin's Biological Work, Some Aspects Reconsidered* (ed.: P. R. Bell), pp. 101–149. Wiley, New York.
- KIMURA, M. (1985) Genes, populations, and molecules: A memoir. In: *Population Genetics and Molecular Evolution* (eds.: T. Ohta and K. Aoki), pp. 459–479. Springer-Verlag, Berlin.
- PROVINE, W. B. (1986) *Sewall Wright and Evolutionary Biology*. University of Chicago Press, Chicago.
- WRIGHT, S. (1917) The average correlation within subgroups of a population. *J. Wash. Acad. Sci.* **7**, 532–535.
- WRIGHT, S. (1920) The relative importance of heredity and environment in determining the piebald pattern of guinea-pigs. *Proc. Natl. Acad. Sci. USA* **6**, 320–332.
- WRIGHT, S. (1921a) Correlation and causation. *J. Agric. Res.* **20**, 557–585.
- WRIGHT, S. (1921b) Systems of mating. *Genetics* **6**, 111–178.
- WRIGHT, S. (1922) Coefficients of inbreeding and relationship. *Amer. Nat.* **56**, 330–338.
- WRIGHT, S. (1930) Statistical methods in biology. *J. Am. Stat. Assoc.* **26** (suppl.), 155–163.
- WRIGHT, S. (1931) Evolution in Mendelian populations. *Genetics* **16**, 97–159.
- WRIGHT, S. (1951) The genetical structure of populations. *Ann. Eugen.* **15**, 323–354.
- WRIGHT, S. (1952) The genetics of quantitative variability. In: *Quantitative Inheritance* (eds.: E. C. R. Reeve and C. H. Waddington), Agric. Res. Council, London.
- WRIGHT, S. (1968–78) *Evolution and the Genetics of Populations* (Vols. 1–4). University of Chicago Press, Chicago.
- WRIGHT, S. (1969) Haldane's contribution to population and evolutionary genetics. *Proc. XII Intern. Cong. Genet.*, **3**, 445–451.
- WRIGHT, S. (1980) Genic and organismic selection. *Evolution* **34**, 825–843.
- WRIGHT, S. (1987) Personal communication to K. R. Dronamraju.
- WRIGHT, S. (1988) Surfaces of selective value revisited. *Amer. Nat.* **131**, 115–123.