INBREEDING AND OTHER BREEDING PRACTICES USED IN THE DEVELOPMENT OF THE S. C. FULLERTON HERD OF ABERDEEN-ANGUS CATTLE

INBREEDING AND OTHER BREEDING PRACTICES USED IN THE DEVELOPMENT OF THE S. C. FULLERTON HERD OF ABERDEEN-ANGUS CATTLE

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TABLE OF CONTENTS

I. Introduction. 1

II. Review of Literature. 2

A. The Breeds That Have Been Analyzed. 2

B. The Herds That Have Been Anlyzed. 6

1. The Duchess Shorthorns As Bred by Thomas Bates. 6

2. The Herd of Hereford Cattle As Bred by Hazlett 6

3. The Herd of Hereford Cattle As Bred by Gudgell and Simpson. 7

4. The Herd of Aberdeen-Angus Cattle As Bred by Congdon and Battles 8

5. Summary and Comparison. 9

C. A Brief History of the Aberdeen-Angus Breed 11

D. A Brief History of the Herd of Aberdeen-Angus Cattle As Bred by S. C. Fullerton 14

III. The Investigation 16

A. Method of Procedure 16

1. Coefficient of Inbreeding 16

2. Coefficient of Relationship 18

3. Approximate Method of Calculating Coefficients of Inbreeding and Relationship from Livestock Pedigrees 19

4. Analysis of the Herd of Aberdeen-Angus Cattle As Bred by S. C. Fullerton 22

B. Results. 23

1. Inbreeding and Inter Se Relationship 23

2. Prominent Animals of the Herd. 25

IV. Discussion 27

V. Summary and Conclusions. 35

VI. Literature Cited 36

I. INTRODUCTION

The objectives of this study are as follows: first, to find out what part inbreeding has played in the development of the Aberdeen-Angus herd bred by S. C. Fullerton of Sunbeam Farm, Miami, Oklahoma; second, to see whether the herd has been developed as a homogeneous group of closely related individuals or whether it has been broken up into definite families and improved in that manner; third, to determine how much influence certain individual animals have had on the herd and, in addition, to determine if there has been a linebreeding or inbreeding program carried on to any particular animal or animals; fourth, to determine how much influence individual animals of early breed history have had on this herd; fifth, to find out how the inbreeding and inter se relationship of this herd compare with those of the Aberdeen-Angus breed and other herds studied; and sixth, to determine if a breeding program of any kind has been used in developing this herd and, if so, to determine the kind of program used.

II. REVIEW OF LITERATURE

A. Breeds That Have Been Analyzed.

The methods used in this study were developed by Wright, 1923, (20) and Wright and McPhee, 1925, (21). Table I gives a summary of the several breeds that have been analyzed by similar methods.

The Shorthorn breed, 1925, (11) was found to have the highest inbreeding coefficient of any breed studied to date. Perhaps the reason for this is the very early base date that was used. Records have been kept on Shorthorns longer than on any other breed; thus it was possible to trace the ancestry much farther back into its formation period and measure the inbreeding that was done very early in the breed's history as well as the inbreeding that has been done in later years. Two-thirds of the inbreeding found in the Shorthorn breed occurred in the first 30 years of the breed's history. A similiar situation was found in the Aberdeen-Angus breed, 1939, (16). Although the inbreeding was much less, over half of the total inbreeding occurred in the first 15 years of the study. In the analysis of the Hereford breed, 1937, (17) something different was revealed as to the time most of the inbreeding occurred. Nearly one-half of the inbreeding found in this breed occurred in the last 10 years of the study or from 1920 to 1930. In nearly all of the other breeds studied the inbreeding coefficient was small in the first few years of the study and gradually increased during the later years of the period observed.

TABLE I

Inbreeding and Inter Se Relationship Found in the Various Breeds Studied (3,4,6,7,9,10,11,12,14,16,17,24)

Breed	Interval Studied	Inbreeding Coefficient %	Inter se Relationship %	Generation Interval Years	Decrease in Heterozygosis per Generation %
Shorthorn	1780 to 1920	26.0	40.0	--	.86
Aberdeen-Angus	1850 to 1939	11.3	13.5	5.65	.66
Poland China	1855 to 1929	9.8	14.2	--	.61
Hereford	1860 to 1930	8.1	8.8	5.40	.68
Clydesdale	Found to 1925	6.2	--	--	.90
Rambouillet	Found to 1926	5.5	2.6	4.70	.70
Holstien-Friesian	Found to 1928	4.7	3.4	4.70	.47
Ayrshire	1877 to 1927	4.3	--	--	.39
Jersey	1876 to 1916	3.9	--	--	.44
Brown Swiss	1884 to 1929	3.8	4.3	5.50	.47
Hampshire	Found to 1935	2.9	0.5	3.50	.90
British Dairy Shorthorn	Samples taken form Vol. 6 of Register of British Short-horn Assn.	27.5	39.7	--	--

In the Hereford breed, inbreeding among show winning animals and Register of Merit animals was much higher than for the breed as a whole. It was found that inbreeding among show winners was not significantly different from random individuals of the Shorthorn breed, 1931, (2). In the studies made of other breeds where the inbreeding of show winners was observed it was found that the inbreeding was almost identical with the breed average.

In most of the breeds the observed inbreeding coefficient was larger than the expected inbreeding coefficient, which indicates that there has been a tendency towards family formations. When the inter se relationship of a group of animals is high and the inbreeding coefficient is low, it indicates a homogeneous group with little separation into separate inbred families or lines; however, if the inbreeding coefficient is high and the inter se relationship is low, this is an indication that the group has been broken up into highly inbred families with little relationship between families and little homogenity in the group as a whole.

The rate of decrease in heterozygosis is very similar for the breeds of each type of livestock. In the beef breeds the rate of decrease for the Shorthorn breed is a little higher than it is for the other two breeds of beef cattle. The rates for the Aberdeen-Angus and Hereford breeds are nearly identical. They are .66 per cent and .68 per cent per generation, respectively. The rates of decrease are very nearly the same for all four dairy breeds studied. They vary less than one-tenth of one per cent with a rate of .39 per cent in the Aryshire

breed, 1932, (7) and .47 per cent in the Brown Swiss, 1937, (22) and Holstein-Friesian, 1936, (10) breeds, while the Jersey breed, 1928, (14) strikes and intermediate figure of .44 per cent. For the two breeds of sheep studied the rate of decrease in heterozygosis is somewhat similar. For the Hampshire breed, 1940, (4) it is .90 per cent and for the Rambouillet breed, 1933, (6) it is .70 per cent. Only one breed of horses and one breed of hogs have been analyzed, so the only comparison that can be made with them is to compare them with these other breeds of livestock. The Clydesdale breed, 1927, (3) of horses ties with the Hampshire sheep for the highest rate of decrease, while the rate of decrease for the Poland China breed, 1939, (9) of hogs is about the same as it is for the beef breeds of cattle.

B. The Herds That Have Been Analyzed.

1. The Duchess Shorthorns As Bred by Thomas Bates.

Wright, 1923, (19) made an analysis of Thomas Bates' herd of Duchess Shorthorns. Bates purchased a cow from Collings and renamed her Duchess I. She was a descendant of a cow named Duchess purchased by Collings in 1784. Duchess I was closely related to Favourite. Bates bred the Duchess family for a period of about 40 years of seven generations after Duchess I. He bred 63 Duchess cows and 45 bulls. This family became very popular and caused prbably the greatest pedigree craze that has ever occurred in purebred livestock history. This craze culminated in the New York Mills sale in 1873.

Duchess I was about 40 per cent inbred and Bates maintained an average of that percentage of inbreeding in his entire herd over the 40 year period that his herd was in existence. He was able to keep the inbreeding coefficient generally within a range of from 36 per cent to 47 per cent. The last generation averaged 43 per cent. The relationship between animals within his herd was kept at about 60 per cent. Bates introduced only enough outside blood to keep the inbreeding and relationship from rising above these amounts. In the beginning the relationship of his herd to Favourite was 76 per cent, and this gradually dropped to 57 per cent in the end.

2. The Herd of Hereford Cattle As Bred by Robert H. Hazlett.

Winchester, 1938, (18) in his study of the herd of Hereford cattle bred by Robert H. Hazlett found the coefficient

of inbreeding to be 7.7 per cent in 1900 when the first sample was taken and 15 per cent in 1936, the date the study was concluded. This was an increase of 7.3 per cent in the homozygosis for the period or an increase in homozygosis of about 1.15 per cent per generation. The rate of increase for the Hereford breed as a whole for the period 1900 to 1930 was about 1.0 per cent, so the rate of gene fixation which took place in the Hazlett herd was about the same or slightly above that of the entire breed during this period.

The coefficient of inbreeding observed was well below that expected from the coefficient of inter se relationship which was maintained rather constantly at 29 per cent. This indicates that the herd was a somewhat homogeneous unit of related animals rather than being divided into families between which there was little relationship. The difference between the observed inbreeding and that expected indicated that inbreeding in general was avoided.

Mr. Hazlett demonstrated in his herd that the concentration of the characters of outstanding sires by means of selection and linebreeding is an excellent way to produce superior beef cattle.

3. The herd of Hereford Cattle As Bred by Gudgell and Simpson

Click, 1938, (5) in his analysis of the breeding methods used by Gudgell and Simpson in developing their herd of Hereford cattle found that the rate of gene fixation which took place in the herd was about two and one-half times as fast as that of the entire breed during this period.

The coefficient of inbreeding observed was 14.57 per cent,

which was well below that expected from the coefficient of inter se relationship, which was 32.57 per cent at the conclusion of the study. This indicates that the herd was a somewhat homogeneous unit of related animals rather than one divided into families or groups between which there was little relationship.

Gudgell and Simpson demonstrated in their herd that the concentration of the characters of outstanding sires by selection and linebreeding is an excellent way to produce superior beef cattle.

4. The Herd of Aberdeen-Angus Cattle As Bred by Congdon and Battles

Stephens, 1942, (15) in his analysis of the Aberdeen-Angus herd of Congdon and Battles found that inbreeding was not used to any appreciable extent. The inbreeding coefficient of the herd was 4.6 per cent.

A very definite linebreeding program was followed to Oakville Quiet Lad 109220 and Prizemere 9th 292566.

The herd as it existed in 1938 was a homogeneous unit of related animals with no tendency to separate into family lines. The inter se relationship was 12.25 per cent.

In the early years of the Congdon and Battles herd one complete outcross sire was introduced. In the later years the method used to introduce new blood was to purchase a few outstanding females.

The coefficient of inbreeding observed was slightly below what was expected from the inter se relationship. This indicates that inbreeding was not used to any great extent to maintain the standard of the herd.

The success of this herd was the result of concentrating the superior characteristics of outstanding animals by selection and linebreeding.

5. Summary and Comparison

The four herds briefly reviewed above and summarized in Table II make an interesting comparison study. Each of these herds was among the very best herds in the history of the respective breeds.

TABLE II

Inbreeding and Inter se Relationships of Herds Studied (5, 15, 18, 19)

Herd	Observed Inbreeding Coefficient %	Expected Inbreeding Coefficient %	Inter se Relationship %	Decrease in Heterozygosis Per Generation %
Bates Duchess Shorthorns	43.0	42.8	60.0	--
Hazletts Herefords	15.0	17.2	29.1	1.15
Gudgell & Simpson Hereford	14.59	19.45	32.57	2.44
Congdon & Battles Aberdeen-Angus	4.6	6.53	12.25	--

The one tool used perhaps to the same extent in the development of each of the herds was rigid selection. Another tool used in all four of the herds but to a varied degree was linebreeding. Bates used the most intensive linebreeding and inbreeding

program of all. He linebred to Favourite and purposely kept the inbreeding of his herd at the high mark of about 40 per cent throughout the 40 years his herd was in existence. No breeder of recent years has been able to maintain a herd so highly inbred. Hazlett and Gudgell and Simpson developed excellent herds with less than half as much inbreeding as Bates used. Congdon and Battles purposely avoided any inbreeding in developing their excellent herd of Aberdeen-Angus cattle. They established a linebreeding program to Oakville Quiet Lad 109220 and Prizemere 9th 292566, but the herd was kept as a homogeneous unit with no tendency to separate into family lines. The inter se relationship was kept high and the inbreeding coefficient was kept low.

C. A BRIEF HISTORY OF THE ABERDEEN-ANGUS BREED

The Aberdeen-Angus breed, 1928, (13) originated as a cross between two somewhat similar strains of cattle native to the Scottish counties of Aberdeenshire and Forfarshire. Forfarshire was formerly called Angus-shire. The breed got its name from these two counties. Polledness and black color were found often in these native stocks. The principal value of these cattle lay in their use for work stock and the production of feeders to be sold for fattening in the southern counties. Later, with the development of turnip raising, the cattle were fattened in the northern counties and sold on the English market. This practice resulted in an increased interest in improving the cattle so they would be more profitable under these conditions. The practice of crossing Shorthorn bulls on the native stock became very popular and threatened extinction of this stock. A few breeders, however, gathered together herds of the native strains and maintained their purity.

The first Aberdeen-Angus cattle were imported into the United States in 1872 by George Grant of Victoria, Kansas. Credit for establishing the first purebred herd in America goes to James Anderson and George Findlay of Lake Forest, Illinois. These men, natives of Aberdeenshire, Scotland, imported to this country a bull and five females in 1878. They were exhibited at the Chicago Fat Stock Show in 1879 and proved to be a good advertisement for the breed. Encouraged by the interest aroused, Anderson and Findlay made further

importations in 1881 and 1882.

In 1881 approximately 80 head of Aberdeen-Angus cattle were imported and divided among Anderson and Findlay, T. W. Harvey and J. V. Farwell. Mr. Farwell was one of the first men to become interested in the breed following their introduction into this country. Later he was identified with the famous XIT ranch in Texas where Aberdeen-Angus bulls were used.

Mr. Harvey established the Turlington herd at Turlington, Nebraska, with the cattle he received from the 1881 importation mentioned above.

The firm of Gudgell and Simpson of Independence, Missouri, developed one of the early Aberdeen-Angus herds. This herd was later dispersed and the firm bred only Herefords. Mr. Gudgell, however, helped to organize the American Aberdeen-Angus Breeders' Association and was its first secretary.

The herd of B. R. Pierce and Son of Creston, Illinois was founded in 1883 and is still in existence under the name of Stanley R. Pierce and Sons. The herd has produced many noted animals, chief of which was the bull, Black Woodlawn.

The herd of W. A. McHenry of Denison, Iowa was established in 1889 and is of particular interest in this study because most of the foundation animals of the Fullerton herd are descendants of it. This herd produced Earl Marshall, which was one of the greatest sires in the history of the breed and the sire with the greatest influence on the Fullerton herd. Earl Marshall sired five bulls and one cow that were made Grand Champions at the International Livestock Exposition at

Chicago, Illinois. The McHenry herd of 205 animals was sold to Charles Escher, Jr. in 1916 for $80,000.

The herd of Congdon and Battles, which was established in 1905 by Otto Battles, is of interest in this study because many animals of the S. C. Fullerton herd either came directly or were descended from it. The foundation animals of the Congdon and Battles herd were purchased from such breeders as W. A. McHenry, E. T. Davis and P. J. Donohoe, who were considered to have among the best herds of that time.

The bull, Black Woodlawn 42088, was gaining in prominence at this time and Mr. Battles decided to found his herd on Black Woodlawn breeding. He used a prominent son and grandson of this bull. They were Oakville Quiet Lad 109220 and Glenfoil Thickset 2d 88142, respectively.

D. A BRIEF HISTORY OF S. C. FULLERTON'S ABERDEEN-ANGUS HERD

In the spring of 1918 Judge Sam C. Fullerton and son, Sam, Jr., 1946, (1) started their herd of Aberdeen-Angus cattle at Sunbeam Farms, Miami, Oklahoma, with the purchase of three heifers at the sale held at the Oklahoma City Fat Stock Show. Then in 1920 they bought eleven cows at a sale held by Mr. L. R. Kershaw near Muskogee, Oklahoma. In this group was the great cow, Elmland Jessie 2d 194074. In the fall of 1920 she dropped a bull calf sired by Plowman. This calf was Playman of Sunbeam, the International Grand Champion at Chicago in 1925. He was the first bull to interrupt the championships being won by sons of the great Earl Marshall. "Playman" was a good breeding bull as well as a good show bull. He was an especially great sire of females.

In the early twenties Judge Fullerton purchased the entire herd of Berry and Redfield of Hurley, South Dakota. There were about 100 head of cattle in this transaction, most of which came originally from Charles Escher, Jr. of Iowa. Mr. Escher had bought the entire herd of W. A. McHenry in 1916.

The Fullerton herd was not represented at any of the livestock shows from 1928 until 1930 due to the lack of a show herdsman. However, in 1930 Sam Fullerton, Jr. returned from school, took charge and began showing Fullerton cattle again.

In 1930 there were about 200 cows in the Fullerton herd.

In 1932 Sam, Jr. was looking for a herd bull and found Black Peer of St. Albans at the St. Albans Farm of Pacific, Missouri. He tried to buy this calf but was unable to do so until in 1934. "Black Peer" was put on the show circuit in the fall of 1934 and was Grand Champion at all major shows including the International at Chicago. He died in 1936 leaving only two crops of calves but he sired one bull that was International Grand Champion at Chicago in 1938 and is making an indelible record on the Aberdeen-Angus breed. This bull was Black Prince of Sunbeam. His progeny are the most popular animals of the breed today. Ten of the herd bulls in service at Sunbeam Farms now are sons of "Black Prince". His two most outstanding sons are Prince Sunbeam 29th 629408 and Prince Sunbeam 100th 677649.

The herd now numbers about 300 head of breeding cows.

III. THE INVESTIGATION

A. Method of Procedure.

1. Coefficient of Inbreeding.

Wright, 1923, (20) worked out the method of calculating the inbreeding coefficient used in this study. In 1925 Wright and McPhee worked out a short method for calculating the coefficients for large groups of animals with long pedigrees.

The coefficient of inbreeding measures the percent of heterozygosis lost from a population since its foundation as a result of inbreeding or, to state it another way, it measures the percentage of increase in homozygosis of a population since the foundation animals as a result of inbreeding. It is also the correlation between the egg and sperm that unite to form the individual. The two general classes of effects of inbreeding are: (1) a decline in vigor and (2) greater likeness between inbred animals and increased prepotency when the inbred individuals are used in outcrosses.

For an animal to be inbred it must have the same animal or animals appearing in both the sire's side and the dam's side of the pedigree. The closer inbred an animal is to the ancestor or ancestors causing the inbreeding, the higher the coefficient of inbreeding. It varies from 0 up to 1 as the homozygosis increases toward 100%. Wright, 1923, (20) uses the following formula for figuring the inbreeding coefficient:

$Fx = \Sigma\left[\left(\frac{1}{2}\right)^{n+n'+1}(1+F_A)\right]$. Fx equals the inbreeding coefficient of the animal X. The Greek letter sigma, Σ, means "the sum of", N is the number of generations back to the common ancestor from the sire and N' is the number of generations from the dam back to the common ancestor. The $\frac{1}{2}$ represents the chance at each Mendelian segregation or, in other words, at each Mendelian segregation or generation away from the common ancestor, the chances are halved of that animal receiving the same genes as the common ancestor had. The 1 is added to allow for the animal being one-half of a generation away from the sire and one-half of a generation away from the dam. Fa is the inbreeding coefficient of the common ancestor. If the common ancestor is inbred, the chances of an increase in homozygosity of the animal X are increased. This is taken care of by the (1+Fa) factor. The inbreeding coefficient of an animal is the sum of all the $\Sigma\left[\left(\frac{1}{2}\right)^{n+n'+1}(1+F_A)\right]$ in the pedigree of the animal. One animal may cause many ties in a pedigree but it can appear only once in any one path. This coefficient of inbreeding will not be accurate for a single animal or for a small group of animals but for a large group it is very accurate.

This measure of inbreeding is dependent upon two things: first, that inheritance is Mendelian and, second, that inheritance from sire and dam is equal.

2. Coefficient of Relationship.

The coefficient of relationship measures the correlation that may be expected between two animals with respect to highly hereditary characters and with no dominance. It is closely related to the coefficient of inbreeding. The formula used in figuring the relationship coefficient is as follows:

$$Rxy = \frac{\leq (\frac{1}{2})^{n} (1 + F_A)}{\sqrt{1+Fx}\ \sqrt{1+Fy}}$$

The Rxy is the coefficient of relationship between animal x and animal y and may vary from 0 to 1. The Greek letter $\leq$ means "the sum of". N is the total number of generations or Mendelian segregations from the two animals x and y to the common ancestor. The (1+Fa) factor is 1 plus the inbreeding coefficient of the common ancestor and is used to weight the numerator and allow for the tendency toward a higher correlation between two animals whose common ancestor is highly inbred. The factors (1+Fx) and (1+Fy) are 1 plus the inbreeding coefficients of the two animals x and y. These factors are used to correct for increased variability caused by inbreeding. Inbred lines tend to drift apart.

3. An Approximate Method of Calculating Coefficients of Inbreeding and Relationship from Livestock Pedigrees.

Wright and McPhee, 1925, (21) worked out a short method of calculating inbreeding and relationship coefficients from livestock pedigrees. They used the same principles given in the above formulae but used random sample lines in the pedigrees instead of using the complete pedigree. It is first necessary to get a fair sample of animals of the breed or herd studied and then it is necessary to decide upon a base date. After the sample is taken, the sire and dam of each animal are tabulated and then a random line is traced from the sire and a random line is traced from the dam back to the base date. The two random lines are then checked closely to determine if the same animal appears in both lines of the pedigree. There can be only one tie in the two line pedigree and the tie appearing highest up in the pedigree is the one used. Each animal whose pedigree contains a tie is given a value of $\frac{1}{2}$. The farther back of the sire and dam the random line goes the greater is the chance of missing a tie. In the Nth generation back of either the sire or dam there are 2 n ancestors. The random pair of lines is only one pair of lines out of 2 n + n' pairs of possible lines which might go back to the common ancestor. So if the random pair of lines is a fair sample of the pedigree the value of the tie must be multiplied by 2 n + n' to allow for the possible ties missed by the random method. Upon carrying this out it is found that the n and n' disappear and all that is left is merely $\frac{1}{2}$ (1 + Fa) so this makes it

unnecessary to count the generations back to the common ancestor. After evaluating each pedigree of the sample either at 0 or $\frac{1}{2}$ (1 + Fa), the total contributions of all pedigrees in the sample are added together and the sum is divided by the number of animals in the sample. This gives the average inbreeding for the herd or breed being studied.

The following formula is used in figuring the standard error for the inbreeding coefficient obtained by the approximate method $\sqrt{\frac{pq}{N}} \times \frac{Fx}{p}$. In this formula p equals the proportion of ties observed, q is the proportion of lines in which ties do not occur, n is the number of animals in the sample and Fx is the inbreeding of the group. The part of the formula $\sqrt{\frac{pq}{N}}$ gives the standard error for the percentage of ties and the factor $\frac{Fx}{p}$ rates down the standard error for the percentage of ties so that it will apply to the inbreeding coefficient.

By using the number of ties as p, the number of pedigrees without ties as q and the total number of pedigrees as n, some work involved in the calculation of the standard error may be saved. This gives the same results and p and q do not have to be put on a proportion basis. This standard error measures the sampling error which results from the use of incomplete pedigrees. This does not consider the sampling error of Mendelian inheritance which cannot be measured. This latter sampling error is that due to the sampling which takes place between gene pairs during Mendelian segregation.

The coefficient of relationship is determined in a similar manner. By some purely random method, pair up all lines

or sides of the pedigrees of the sample and compare them. Never use the same line twice nor compare the two lines of the same pedigree with one another. Whenever the same animal appears in both lines compared, the two individuals are related through this common ancestor. The common ancestor appearing highest up the line is the one used. Each such tie is given a value of .50 and multiplied by (1 + Fa) or 1 plus the inbreeding of the common ancestor. All of these products are then added together and the sum is divided by the total number of possible ties. This gives the average inter se relationship for the herd or breed being studied.

4. Analysis of Sunbeam Farms' Aberdeen-Angus Herd

In the analysis of S. C. Fullerton's Aberdeen-Angus herd the sample of animals used was the entire sale offerings of the annual sales of 1939, 1940, 1941, and 1942. There was a total of 290 animals in the sample. The base date used was 1880 because that is about the date the breed was brought into the United States.

Each pedigree was traced back to the base date by using the random method described above. The sequence of sires and dams which was used in the random lines was determined by the tossing of a coin. "Heads" represented a sire and "Tails" represented a dam.

The same samples were used in determining the inter se relationship. The lines of the pedigrees were paired up at random, compared and the ties marked. Each pair of lines compared was given a number so that no line would be used twice. All ties were tabulated according to the common ancestor.

In computing the relationship coefficient between important individuals and the sample, only direct relationship was considered. This was determined by tabulating the number of times each animal appeared in the random lines. The direct relationship = $\frac{\text{Total number of appearances}}{\text{Maximum possible appearances}}$.

No particular study was made of the foundation animals in the herd of Mr. Fullerton's. The original source of these animals was merely noted.

B. Results.

1. Inbreeding and Inter se Relationship.

The average coefficients of inbreeding and inter se relationship for the Fullerton herd is represented in Table III. The coefficient of inbreeding measures the percentage of genes fixed which were fixable but not yet fixed in the foundation animals of the herd.

Table III

Inbreeding and Inter se Relationship

Pedigrees Sampled	Inbreeding Coefficients			Inter se Relationship
	Actually Found	Expected from inter se relationship	Less than Expected	
	%	%	%	%
290	6.68±1.03	7.57	.89	14.08±1.47

For example, the coefficient of inbreeding for the herd was found to be 6.68 percent which means that the average animal included in this sample was 6.68 percent less heterozygous than the average animal in the foundation stock of 1880.

The base date to which the pedigrees were traced was 1880. It is obvious, however, that all of the lines would not end with an animal born exactly on that date. In this study, no animal which was dropped after 1880 was used, and many of the lines ended with animals born shortly before 1880. The

average length of generation was not considered in this study. However, if the average generation interval found by Stonaker, 1939, (17) to be 5.6 years for the breed as a whole can be applied to the Sunbeam Farms herd, and increase of .67 per cent in gene homozygosity of the herd would be indicated per generation.

The coefficient of relationship, also shown in Table III is a measure of the approximate relationship existing between animals in the herd selected at random. The significance of these figures is dependent upon the coefficient of inbreeding. McPhee and Wright, 1925, (11) have shown that the percentage of inbreeding expected from the purely random mating of sires and dams of a group of any size may be calculated by the formula $Fx = \frac{R}{2-R}$ where Fx is the expected coefficient of inbreeding and R is the coefficient of inter se relationship.

In column three of Table III is presented the inbreeding coefficient of the sample which would be expected from purely random mating in the herd. This figure, when compared with the coefficient of inbreeding observed, reveals at once whether the herd has tended to be divided into rather distinct groups or families or whether the members of the herd were rather highly inter-related. The expected inbreeding was higher than the observed inbreeding which indicates no appreciable segregration or grouping and it also shows that there was a closer relationship between parents matched at random than between the sires and dams.

2. Individuals Contributing Most to the Herd.

Table IV shows the coefficients of inbreeding and relationship of important individuals.

The percentage of inbreeding shown in column six of the table is important in that it is a measure of the prepotency of this group of the most influential animals. Column five in the table shows the percentage of direct relationship existing between these individuals and the sample. This indicates the concentration of the blood of these animals within the herd at that time. The date each animal was calved is shown in column three.

TABLE IV

Coefficients of Inbreeding and Relationship of Important Animals

Name	Registry Number	Date Calved	Number of Appearances	% Related to Sample	% Inbreeding
Earl Marshall	183780	9-14-13	137	24.65	4.35
Erica McHenry 12th	104123	10-5-06	83	14.61	2.10
Black Peer of St. Albans	456385	10-17-31	66	11.37	0.02
Blackcap Revolution	287269	1-12-19	59	10.33	1.56
Protine	138372	9-26-09	55	9.69	2.15
Revolution of Sunbeam	468380	9- 2-33	54	9.51	18.85
Playman of Sunbeam	338509	11-30-20	48	8.53	3.14
Elga Elliott 29th	274052	9- 5-18	46	7.44	0.18
Black Woodlawn	42088	3-27-00	41	7.06	none
Erie Revolution	404801	10-10-26	40	6.89	none
Black Prince of Sunbeam	504521	10-16-35	37	6.38	0.20
Iliad	14937	3-11-82	33	5.75	0.13
Barbarian of Rosemere 103d	495064	9- 2-36	32	5.60	1.56
Total Possible Appearances			580		

IV. DISCUSSION

The fact shown in Table III that the expected inbreeding was above the observed inbreeding tells something of the system of mating used in the Fullerton herd. There seemed to be no attempt to breed separate families within the herd. The difference in the expected inbreeding of 7.57 per cent and the observed inbreeding of 6.68 per cent is evidence of the extent to which close matings were avoided. Further evidence of this is the small amount of inbreeding found in the herd. Mr. Fullerton concentrated the blood of the noted sire, Earl Marshall 183780, to such a great extent that, intentionally or untentionally, a line breeding program toward this bull has been established. Earl Marshall was about 25 per cent directly related to the herd or he was a grand sire of the herd. Earl Marshall was the common ancestor in about one-half of the ties found in the inbreeding study. He appeared 137 times out of a possible 580 times in the sample. It is remarkable that such a high percentage of relationship exists between Mr. Fullerton's herd and Earl Marshall since he was never used in the herd and the nearest relatives used, to any great extent, were grandsons and great grandson. Some of the sons, grandsons, great grandsons and one great great grandson of Earl Marshall having the greatest influence on the Fullerton herd are shown on page 28.

next page

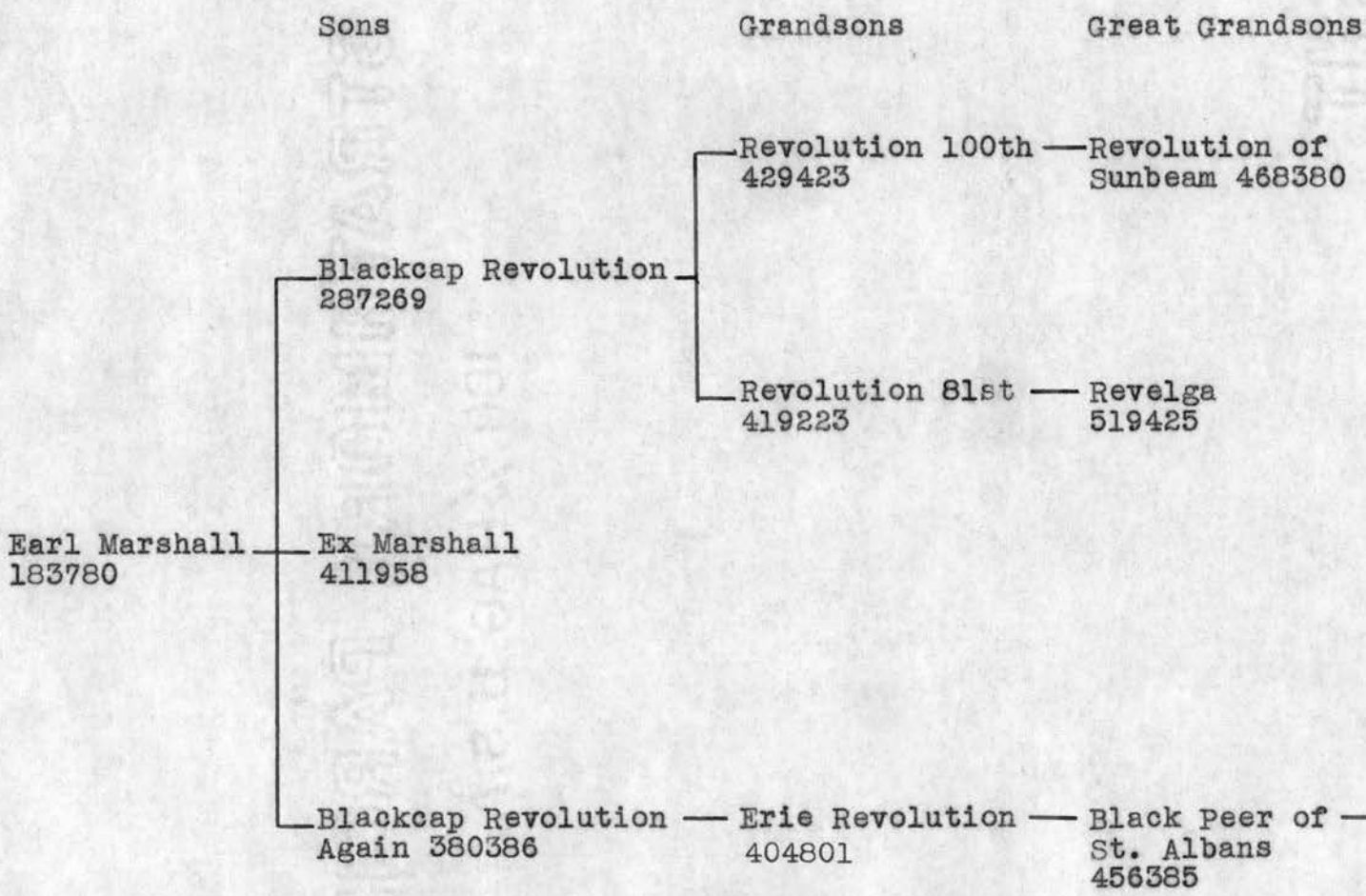

Sons
Grandsons
Great Grandsons
Earl Marshall 183780
Blackcap Revolution 287269
Revolution 100th 429423
Revolution of Sunbeam 468380
Revolution 81st 419223
Revelga 519425
Ex Marshall 411958
Blackcap Revolution Again 380386
Erie Revolution 404801
Black Peer of St. Albans 456385
Black Prince of Sunbeam 504521

Table IV shows Erica McHenry 12th and Protine to be quite highly related to Mr. Fullerton's herd. These two individuals are the dam and sire, respectively, of Earl Marshall and all of their relationship to the herd traced through this one son. Every time either of these two animals appeared in a pedigree it was as the parent of Earl Marshall.

Black Peer of St. Ablans 456385 was found to be about 11.5 per cent related to the herd which is the highest relationship of any sire used in the herd. This is quite high when it is taken into consideration that he was used only two years. He was purchased in 1934 and died in 1936. "Black Peer" was International Grand Champion at Chicago in 1934.

Black Prince of Sunbeam, the famous son of Black Peer of St. Albans, was found to be about six and one-half per cent related to the herd which is quite high for a bull used in the herd during just the last three years included in this study. Progeny of "Black Prince" are the most popular animals of the breed at present. 10 sons of this bull are in service in the Fullerton herd now. His two most outstanding sons are Prince Sunbeam 29th 629408 and Prince Sunbeam 100th 677649. "Black Prince" was International Grand Champion at Chicago in 1938.

Blackcap Revolution was found to be over 10 per cent related to the herd. This relationship was built up chiefly

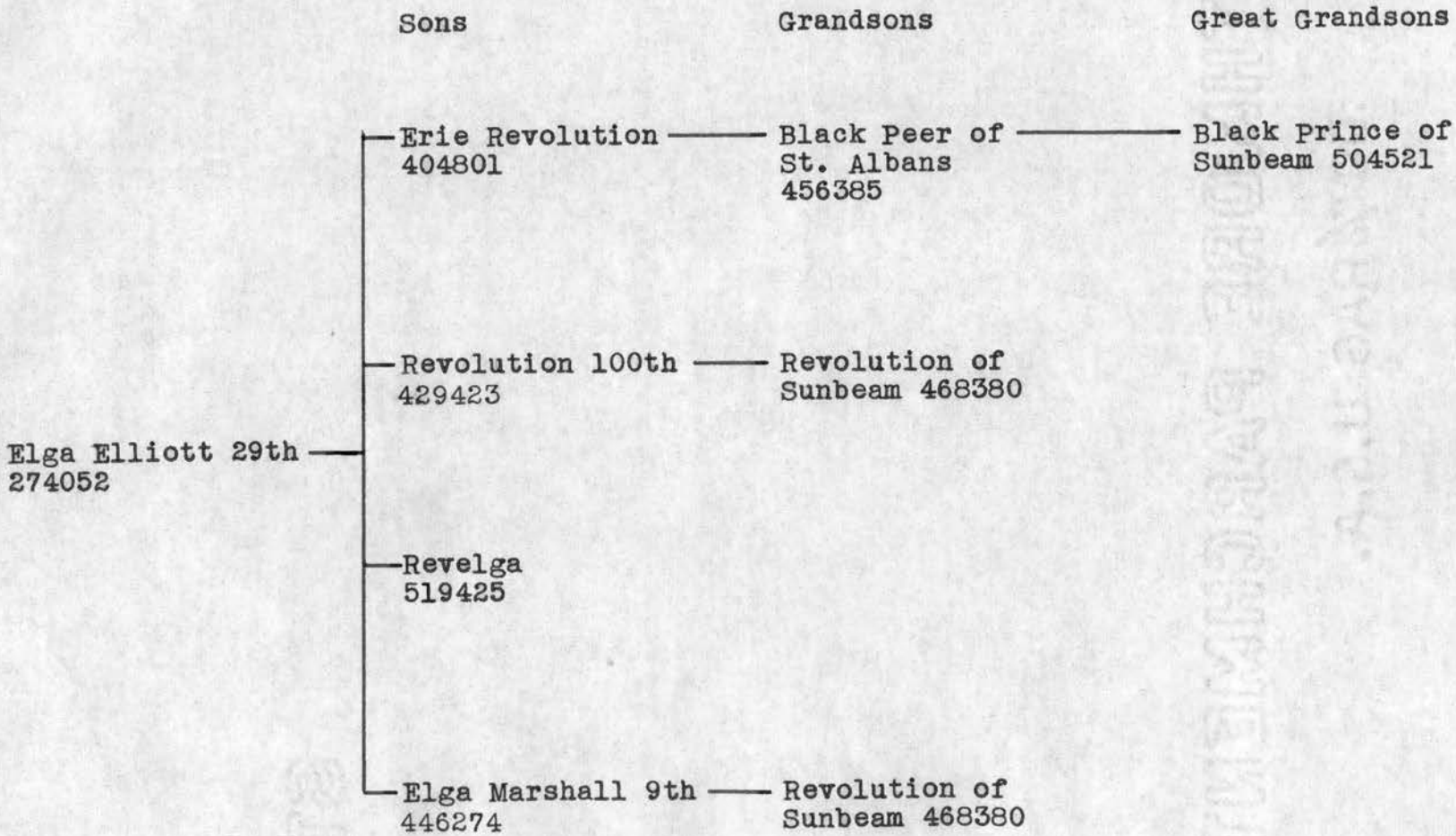
by two of his sons and two of his grandsons.

Playman of Sunbeam was one of the first calves born in Mr. Fullerton's herd. He was the International Grand Champion at Chicago in 1925, breaking the winning streak of four years in succession of sons of Earl Marshall. "Playman" was used quite extensively in Mr. Fullerton's herd. He was an outstanding sire of females particularly. His daughters were mated with descendants of Earl Marshall as a part of the program of breeding. Black Price of Sunbeam was produced in this way.

Elga Elliott 29th shows a relationship of seven and one-half per cent to the herd chiefly because she was the grand dam of Black Peer of St. Albans and double grand dam of Revolution of Sunbeam. See the example on page 31.

Only two animals calved in 1900 or before showed any appreciable influence on the herd. They were Black Woodlawn 42088 and Iliad 14937.

Barbarian of Rosemere 103d 495064 was the most widely used individual of Congdon and Battles breeding. Barbara of Rosemere 100th 449669 was the most important female brought into Mr. Fullerton's herd from the Congdon and Battles herd. This cow was Grand Champion at the International at Chicago in 1933 and the dam of several outstanding cows and bulls in the Fullerton herd. Prince Sunbeam 100th, sired by "Black Prince" and out of this cow, is an example. Mr. Fullerton


Sons
Grandsons
Great Grandsons
Erie Revolution 404801
Black Peer of St. Albans 456385
Black Prince of Sunbeam 504521
Revolution 100th 429423
Revolution of Sunbeam 468380
Elga Elliott 29th 274052
Revelga 519425
Elga Marshall 9th 446274
Revolution of Sunbeam 468380

has used bulls of Earl Marshall descent on females of Congdon and Battles breeding.)

From the inter se relationship of 14.08±1.03 per cent it may be concluded that the S. C. Fullerton herd is a quite homogenous group of animals. The relationship has been kept much higher than the inbreeding and there has been no tendency for the herd to break up into inbred families or lines.

The inter se relationship of 14.08 per cent found in Mr. Fullerton's herd is comparable with the 13.3 per cent found in the Aberdeen-Anbus breed by Stonaker, 1939, (16). The observed inbreeding of 11.3 per cent for the breed as a whole was much higher than the observed inbreeding of this herd which was found to be 6.68 per cent; however, much of the inbreeding found in the breed occured prior to 1880 which is the base date used in this study of the Fullerton herd. The rate of increase in inbreeding is almost the same. It was found to be .66 per cent per generation for the breed and .67 per cent per generation for this herd. The observed inbreeding for the breed was higher than the expected inbreeding indicating a definite tendency for it to split up into families or lines while the observed inbreeding for this herd was lower than the expected inbreeding thus showing no tendency to break up into inbred lines.

The results of the analysis of Mr. Fullerton's herd compare very closely with the results of Stephens', 1942, (15) analysis of the herd of Aberdeen-Angus cattle as bred

bred by Congdon and Battles. About the same breeding program was followed in both herds and the inbreeding and inter se relationship were very similar, also. Congdon and Battles avoided close matings as much as possible but line bred to Oakville Quiet Lad 109220 and Prizemere 9th 292566. Mr. Fullerton used the same program by line breeding to Earl Marshall and Black Peer of St. Albans. There was also a definite tendency to line breed to Black Prince of Sunbeam in the last two or three years of the study and from observing some of the breeding done since 1942, the concluding date of this study, it may be said that now there is a definite line breeding program to "Black Prince".

In comparing the observed inbreeding found in Mr. Fullerton's herd with that observed in Bates' Duchess Shorthorns, Hazlett's Herefords and Gudgells and Simpson's Herefords it is noted that the inbreeding in the Fullerton herd is approximately one-sixth as much as was found in the Bates' herd and approximately one-half the amount found in the other two herds. Mr. Fullerton has carried on a line breeding program in his herd the same as these other breeders did in their herds but close matings were more carefully avoided.

The breeding program employed by Mr. Fullerton was the combination of rigid selection and the concentration of the blood of outstanding individuals by line breeding. Mating closely related animals was avoided. After the foundation animals were purchased, new blood was introduced into the herd by bringing in outstanding sires and outstanding dams. Herd

bulls were not bought when better ones could be produced within the herd than could be found outside of the herd.

V. SUMMARY AND CONCLUSIONS

1. The S. C. Fullerton herd of Aberdeen-Angus cattle was found to have an inbreeding coefficient of 6.68±1.03 per cent in about 1940. This coefficient was measured from a base date of about 1880. Random two line pedigrees were used.

2. The inter se relationship in the herd was 14.08±1.47 per cent. The expected inbreeding from an inter se relationship of this magnitude would be 7.57 per cent.

3. Inbreeding was avoided in the S. C. Fullerton herd and it was developed up to 1939-1942 as a homogenous group rather than a group of inbred families within the herd.

4. The herd was about 25 per cent related to Earl Marshall. A definite linebreeding program to him has been practiced in the Fullerton herd.

5. Black Peer of St. Albans was more closely related to the herd than any other bull used in the herd.

6. A line breeding program is being established to Black Price of Sunbeam.

7. Daughters of Playman of Sunbeam have been mated with sires of Earl Marshall descent as a part of the breeding program. Another part of Mr. Fullerton's breeding program was the mating of dams of Congdon and Battles breeding with sires of Earl Marshall descent.

8. Animals of the early part of the period covered in this study had little influence on this herd.

9. The rate of increase in homozygosis was .67 per cent per generation.

10. Mr. Fullerton has demonstrated in his herd that superior beef cattle can be produced by the use of rigid selection and linebreeding to outstanding sires.

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