COEFFICIENTS OF INBREEDING AND RELATIONSHIP AMONG PEDIGREE JERSEY BULLS USED IN ARTIFICIAL BREEDING OR IN NATURAL MATING IN NEW ZEALAND

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CHAPTER I

INTRODUCTION

Since 1950, when the New Zealand Dairy Board assumed responsibility for the commercial development of Artificial Breeding, there has been a tremendous increase in Artificial Breeding usage. Whereas in 1950, 0.2% of the total cow population was artificially inseminated, the corresponding figure for 1960 was 26%.

In any Artificial Breeding scheme there are dangers of inbreeding through the use of a limited number of sires, and if the young sires selected for the scheme are largely the sons of the best sires already in the scheme, then the dangers of inbreeding are increased.

Inbreeding to high levels is undesirable because it generally reduces the mean level of all characters closely connected with fitness in animals and leads in consequence to loss of general vigour and fertility. Since most characters of economic value in domestic animals are aspects of vigour or fertility, inbreeding is generally deleterious. The genetic basis of this inbreeding degeneration is not completely clear. Another harmful effect of inbreeding is the possibility that it may fix undesirable genes in the homozygous state.

In view of the known facts, it seemed of interest to investigate the effects of this wide expansion of Artificial Breeding on the structural changes within the industry, especially with regard to its effect on inbreeding levels resulting from the bull selection policy of the New Zealand Dairy Board Artificial Breeding scheme.

To the animal geneticist this is extremely important as it can supply answers to the following types of question.

1. With the expansion of Artificial Breeding on the lines at present being followed, how rapidly may we expect inbreeding coefficients to reach levels generally thought to be dangerous?

2. Is Artificial Breeding tending to segregate the breed into particular strains or groups within the breed?

3. Are we utilizing the most efficient system in procuring and proving young bulls?

4. Does inbreeding have any significant effects on production?

OPERATION OF ARTIFICIAL BREEDING SCHEME IN RELATION TO PROBLEM & SCOPE OF STUDY

Until 1951, practically all the bulls purchased for use at the Artificial Breeding centre (Newstead) were already proven. They were selected on their sire survey results under natural mating conditions. At this stage, however, it was considered desirable to purchase each year a team of yearling bulls in addition to the proven bulls. These bulls were to be proven under Artificial Breeding with the object of increasing the supply of proven bulls in future years. This type of proof, based on a minimum of 40-50 daughters in different herds, was considered to be a more reliable one than can be obtained when the bulls' daughters have been tested in one herd only. This is because, although the environments of the daughters of any one bull may vary widely, the average environment for each of the daughter groups is about the same. Thus it was hoped that any environmental effects which might bias the progeny test would be best eliminated.

The semen from each of the young bulls, during his first season at the centre, was used to inseminate approximately 500 cows, thus ensuring a sufficiently large first crop of artificially bred daughters.

The great majority of the unproven bulls were all sons of proven bulls similar in standard to those selected for the proven bull team out of cows which had either qualified as "Elite Merit" by producing 4000 lb. butterfat in not more than 10 years, or, in the case of younger cows, by producing at a comparable level.

The standard for selection of the unproven bulls was such that in 1955 (N.Z.D.B.R.) less than 15% of the surveyed bulls reached the required standard.

One of the results of the growth of Artificial Breeding is a decline in the number of naturally proven bulls available both to meet the expansion and to make good losses due to infertility, disease and accident.

The use of yearling bulls to the extent necessary to obtain reliable Artificial Breeding proofs from their daughters and in sufficient numbers to enable adequate selection when proven has been the main method of overcoming the shortage of naturally proven bulls. The most important aspect of the problem of maintaining the high standard of the proven bull team was to obtain sufficient matings to each yearling bull to ensure a sufficient number of identified and tested daughters.

To obtain increased usage from young bulls, the Herd Improvement Council of the New Zealand Dairy Board decided that farmers using the normal commercial Artificial Breeding service on grade cows must accept one insemination in four from young unproven bulls. Further, to encourage the rearing, identification and testing of daughters of these bulls, the New Zealand Dairy Board paid a bonus of £5 for all identified tested two year old daughters from such bulls.

Since the beginning of the 1961-62 season, there has come into being the "Sire Proving Scheme". Under this scheme certain herd owners have agreed to use nothing but unproven bull semen which is supplied free.

Under the scheme, herds using this service were obliged to test all the daughters of these bulls. Thus, fewer inseminations per unproven bull, or fewer daughters are now necessary to get a reliable survey. Only 25 daughters are now considered a reliable survey for a bull.

Thus, in an effort to increase the proven bull team, a large number of unproven bulls, sons of a small nucleus of proven bulls, has been used. It is interesting to compute the inbreeding coefficients and relationship of these young bulls used in Artificial Breeding and to compare these with those for bulls about their own ages not used in Artificial Breeding which could be regarded as alternatives.

These young unproven bulls will, in the future, have an increasing amount of influence on the breed and, if they are closely related, the greater will be inbreeding of their progeny.

CHAPTER II

REVIEW OF LITERATURE

A. Measurement of Inbreeding and Relationship

Inbreeding is essentially the mating together of individuals that are related to each other by ancestry. Its major consequences are a loss of heterozygosis and an increase in homozygosis (Lush 1948). Inbreeding splits the population into a number of inbred lines with decreasing genetic variance within the lines and increasing genetic variance between the lines (see e.g. Lerner 1950 and Robertson 1952).

Various workers have attacked the problem of measuring the Mendelian consequences of inbreeding. The rate of decrease of heterozygosis in systems of mating, which were more complicated than self fertilization, was first worked out from the recurrence relation between successive generations independently by Jennings (1914) and Fish (1914) for brother/sister mating, and by Jennings (1916) for some others. However, the method used by Jennings and Fish becomes too cumbersome to be practicable in systems much more complicated than mating of brother and sister, and practically impossible to follow in the irregular inbreeding which occurs with farm livestock.

Wright, in 1921, published a generalized explanation of the consequences of milder forms of regular and irregular inbreds. In 1931, this author generalized his results still further to establish the identity of the inbreeding effect, and the generalized consequences of finite population size.

Wright's method was essentially based on Path coefficients (standardized Partial Regression coefficients).

The object was to assess the correlation between the genetic values of the uniting gametes. This correlation Wright called the Inbreeding Coefficient "F". It was proposed originally as giving the departure from the amount of homozygosis under random mating towards complete homozygosis (Wright 1922a). Using the method of Path coefficients, Wright deduced the general expression for the inbreeding coefficient of an individual as:

$$Fx = \sum \left[\left(\tfrac{1}{2}\right)^{n_s + N_d + 1} (1 + fa) \right]$$

where n_s and n_d are the number of generations between sire and dam to ancestor a ; fa is the inbreeding coefficient of the common ancestor (if inbred). If an individual is inbred, his sire and dam are connected in the pedigree by lines of descent from a common ancestor or ancestors. The coefficient of inbreeding is obtained by a summation of coefficients for every line by which the parents are connected, each line tracing back from the sire to a common ancestor and thence forward to the dam and not passing through any individual more than once.

When inbreeding coefficients are computed in this way, it is necessary to define the base population to which the present inbreeding is referred. The base population might be the individuals from which an experiment was started or a herd founded, or it might be those born before a certain date. The designation of an individual as belonging to the base population means that it will have zero Inbreeding coefficient.

Wright looked on the correlation between the genetic value of two individuals as measuring the coefficient of Relationship (i.e. r_{xy}). Looked on in another way it is essentially the probability that the two related individuals will have duplicate genes because they are related by descent. Wright's formula is:

$$r_{X_Y} = \frac{(\frac{1}{2})^n \ (1 + Fa)}{\sqrt{(1 + Fx)\ (1 + Fy)}}$$

where R_{xy} = Relationship between animals X and Y.

Barlett & Haldane (1934) considerably extended Jennings and Fish's original method (1914) by using matrix algebra. The rates of decrease of heterozygosis indicated by this method have agreed in all comparable cases with those obtained by means of Path Coefficients (c.f. Haldane 1930, 1936, 1937, 1949; Wright 1938). More recently, Kempthorne (1954) has extended Haldane's matrix method which gives a rather complete account of the listing of the population in all respects. However, for the irregular systems involved in farm livestock this would require matrices with enormous numbers of elements. Malecot (1948) has also shown how the general formula for "F", given by the method of Path Coefficients, can also be demonstrated directly from the Theory of Probability (c.f. also Haldane 1949). However, this coefficient has the defect, as Pearl himself pointed out that it may have the same value for systems of mating that give the most diverse results experimentally.

Other useful measures of inbreeding that have been proposed, are either identical with "F" (Bernstem's 1930 α) or are related to in a fairly simple way (e.g. Fischers 1950 λ).

The methods mentioned so far for the computation of "F", particularly Wright's Path Coefficient Method or Wright's Long Method, as it is sometimes called, is of extreme importance in analysing the genetic consequences within breeds. However, when pedigrees are long and complicated, the amount of work entailed becomes prohibitive.

A sufficiently accurate estimate can be got by sampling a limited number of lines of descent (Wright and McPhee 1925). The method usually called Wright's Short or Approximate Method consists of tracing back one line of a pedigree from both the sire and the dam of every animal in the sample. The choice of whether in any particular case to draw a line through a male or female is decided by tossing a coin or consulting a table of random numbers. It is necessary that the sample lines be chosen at random, for common ancestors are more likely to be males than females in livestock breeding. Thus, direct male or female lines are unsatisfactory, as also is a system of alternating male and female ancestors in any one line. If the same animal appears in both the sire's line and the dam's line (commonly called a Tie), then the animal is inbred.

Of course, in a second sample, the ancestry of the same animal would probably not show the same sequencies of sires and dams. Thus a single sample of this sort is of practically no value as an indication of the inbreeding of an individual. But the average obtained from a large number of such samples should not differ appreciably from the true value.

The inbreeding, due to a common ancestor A and removed n_s generations from the sire and n_d generations from the dam is $(\frac{1}{2})^{n_s + n_d + 1} (1 + F_A)$, where F_A is the inbreeding coefficient of the common ancestor (Wright 1922).

The sire has 2^{n_s} ancestors in the n^{th} generation and the dam 2^{n_d} ancestors in the n_d^{th} generation. The sample pair of lines is thus only one among $2^{n_s + n_d}$ possible pairs going back as far as the common ancestor. If the single pair of lines is a fair sample of the total, its contribution must be multiplied by $2^{n_s + n_d}$ to obtain an estimate of the inbreeding of the whole pedigree. On carrying out this multiplication, n_s and n_d disappear, and the coefficient takes the simple form $\frac{1}{2}$ ($1 + F_A$). It is thus unnecessary to count the number of generations to the closest common ancestor, but merely to note whether there is a tie and which animal is responsible for it.

By determining the proportion of all such ties in a sufficiently large random sample of a family or a breed, a measure of the average degree of inbreeding for that family or breed, can be obtained to as high a degree of accuracy as desired. If, for example, 60 pedigrees show a tie and 40 do not, then the average inbreeding is 30% (60 x 0.5), i.e. neglecting the term ($1 + F_A$).

Wright and McPhee (1925) recommended that where ancestors are responsible for a large number of ties their inbreeding coefficients should be calculated accurately so that all of the expression $\frac{1}{2}$ ($1 + F_A$) is used. For those which occur infrequently it is usually sufficient to assume an average degree of inbreeding equal to that of the breed as a whole at that time.

Coefficients of Relationship may also be calculated from these random samples of pedigrees so that estimates may be made of direct relationship between a large group of animals and a particular animal (A).

In this case the general formula for the coefficient of relationship

$$R_{XY} = \frac{\frac{1}{2}^{\,n + n^{1}} (1 + F_A)}{\sqrt{(1 + F_X)(1 + F_Y)}}$$

(Where F_X and F_Y are the coefficients of inbreeding of two individuals X and Y; F_A is that of the common ancestor and n and n^1 are the number of generations from X and Y to this common ancestor along the lines in the question)

becomes $$R_{AY} = \frac{\frac{1}{2}^{\,n} (1 + F_A)}{\sqrt{(1 + F_A)(1 + F_Y)}}$$

Since Y could have 2^n ancestors in the generation in which A appears, if the single random line is a fair sample, its contribution must be multiplied by 2^n to obtain an estimate of relationship between A and Y.

Thus R_{AY} is estimated by $\dfrac{(1 + F_A)}{\sqrt{(1 + F_A)(1 + F_Y)}}$ if a single random line is drawn.

If two random pedigree lines are drawn from the descendent and Y appears in one of them, then R is estimated by

$$\frac{\frac{1}{2}(1 + F_A)}{\sqrt{(1 + F_A)(1 + F_Y)}}$$

in the case of four line pedigrees by

$$\frac{\frac{1}{4}(1 + F_A)}{\sqrt{(1 + F_A)(1 + F_Y)}}$$

and so on.

In so far as Y is a sample of the population an estimate of the relationship between A and the population is provided by the above coefficient. By taking a large sample of Y's the sampling errors are reduced and a reliable estimate of the relationship between a particular individual and the population (R_{APop}) is obtained.

When assessing the relationship of a large group to a particular animal the inbreeding coefficient (F_A) of that animal should be calculated accurately. Unless these inbreeding coefficients are of reasonable dimensions, however, little error is introduced if they are neglected. For example if $F_A = 10\%$ and $F_{Pop} = 5\%$ then the expression

$$\frac{1 + F_A}{\sqrt{(1 + F_A)(1 + F_Y)}}$$ would reduce to $$\frac{1 + .10}{\sqrt{(1 + .10)(1 + .05)}} = \frac{1.10}{1.15} = 1.02.$$

Clearly the error introduced by neglecting $\frac{1 + F_A}{\sqrt{(1 + F_A)(1 + F_{Pop})}}$ will be small if inbreeding coefficients are low. As Wright and McPhee (1925) pointed out the method can be extended to determine the relationship between random individuals of a population or between two sections of a breed and so on.

Lush (1932) applied the above method of McPhee and Wright to a study of the Rambouillet breed of sheep. He found the method about as accurate as its theoretical probable errors indicate, if all sources of systematic error which might prevent the lines from truly random are carefully avoided. Lush, thus, warns workers using the method to be continually on guard against such systematic errors.

Robertson and Asker, 1951 state that since the accuracy of the various estimates (using McPhee and Wright's (1925) method) depends on the total number of ties observed, any method of increasing the possible number of ties with the same amount of labour is advantageous.

This can be done by drawing out more than two lines for each animal. If the pedigree is drawn out completely to 8 grandparents and a line is drawn at random from each of them, then there are 4 x 4 = 16 possible inbreeding ties (the same ancestor on both sire and the dam's side) so that there are two possible ties per line drawn compared with ½ a tie per line drawn in the 2 line method. The percentage inbreeding in both cases is ½ the actual ties divided by the possible ties.

Fowler (1933) in comparing the Wright's Long Method versus his Short Method, concluded that in breeds of relatively recent origin the former is more reliable.

S U M M A R Y:

The choice of a suitable method seems to be dependent on the inbreeding system. For the irregular inbreeding system encountered with in livestock breeding, Wright's Long Method which involves the tabulation of complete pedigrees is most desirable. However, when pedigrees are long and complicated, his Short or Approximate Method can give a sufficiently accurate coefficient.

B. Effects of Inbreeding on Productive Performance

There have been numerous observations on the effects of inbreeding in many species. This has been especially true of Poultry Populations were it is quite easy to run up fairly high inbreeding coefficients. The picture that has emerged from these observations has been one of great complexity.

As far as dairy cattle go this subject has been extensively reviewed by Robertson 1949. In general, one may say that the type of experiments and the results they have yielded in an attempt to solve the problem have not been at all impressive. Experiments have been of two types:

(a) those specially designed to get information on this, and other aspects of inbreeding.

(b) analysis of records from closed herds.

Most of the programmes of deliberate inbreeding were not started simply to investigate the effects of the breeding system, but rather to try and produce superior inbred stock. The degree of inbreeding obtained from the analysis of records of closed herds has not been high in most cases.

Size, Vigour and Mortality

There was a significant decrease in birth weight among Friesians which were inbred (F = 0.50) as against outbreds. (Woodward and Graves 1933). This decline was from an average of 80 - 85 lbs. for outbred animals to 65-70 lbs. for inbreds.

Mortality was higher (15% for all inbreds versus 8% for all outbreds).

Little effect of inbreeding on birth weight was found for Jerseys, but rather more for Friesians (84 lbs. versus 70 lbs. for F more than 0.375). In this same experiment also, a decrease in size at all degrees of inbreeding was found. There was no significant difference between outbred and inbred animals, provided that the coefficient of inbreeding did not exceed 20% (Bartlett et al 1939). In his analysis of several Friesian herds, Dickerson (1940) states that calves averaging F = 0.16 were 10% less in birth weight than outbred calves by the same sires.

Milk and Fat Production

The greatest inbreeding effect on productivity is the depression in total milk yield (Laben et al, 1955). These workers also came to the general conclusion that, although production declines with inbreeding, the shape of the lactation curve was not greatly influenced by inbreeding. The time interval from the start of milking their Holstein - Friesian herd, to the maximum production, did not change significantly with inbreeding. There was a decline of 0.32 per cent of milk yield for each percent increase in the inbreeding coefficient for British Friesians (Robertson 1954).

For comparison, some of the results obtained by various studies are expressed as a percentage change in yield for each percent increase in F in Table I.

TABLE 1:

Author	Effect of Inbreeding	No.of Animals above F = 0.20
Davis and Plum (1952)	- 0.25	29
Laben and Herman (1950)	- 0.60	20
Nelson and Lush (1950)	- 1.00	?
Tyler,Chapman,Dickerson (1949)	- 0.59	14
Robertson (1954)	- 0.32	82

The effect of inbreeding on fat percentage is not clear. Some experiments show slight increases with increases in F, others slight decreases, others no effect. There was a significant increase in butterfat test of + 0.008 per cent per degree increase in inbreeding. (Tyler, Dickerson et al 1955). Whether this rise in test is due to the true negative relationships between milk production and test or a concentration of genes for higher test is not known.

As far as other species go, the same general depression is found and has been studied in sheep (Doney 1958); pigs (McPhee et al 1931); and quite extensively in poultry (Schoffner 1948; Schoffner and Sloan, 1948; Stephenson 1953).

In general, as far as cattle go, the following points are relevant.

(1) There is not much good data and the work that has been done leaves much to be desired.

(2) In most studies done there has been great variability between and within breeds as to the true nature of the effect. It should be carefully noted here, however, that there is no reason why inbreeding should have the same effect in different situations, especially between breeds, since they may be genetically distinct entities. Genetic separation with allied migration of new genes and also the differing aims of various breeders can make the genetic situation different under differing conditions.

(3) Most investigators agree in finding a reduction in the phenotypic mean of a character especially with those closely connected with fitness, but the linearity of the depression, the inbreeding level at which the depression starts, and the magnitude of the depression in absolute terms is still clouded in doubt.

Some investigators are of the opinion that dairy cattle may be successfully inbred up to an inbreeding coefficient of about 20% (Robertson 1949), as animals up to this intensity of inbreeding were generally equal in size and productive capacity to outbreds. There is also evidence that inbreeding may have a somewhat lesser effect on production in ranges up to F = 0.20 than in ranges above F = 0.25 (Laben, Cupps, Mead and Regan 1955).

As regards linearity, the effect of inbreeding on production has been shown in one experiment with poultry to be non-linear for inbreeding coefficients under 25%, but was essentially linear over 25% (Stephenson et al 1953). Whether this same picture of linearity holds for cattle populations is not known.

With the progeny testing scheme in practice now in the United

Kingdom there would be a decline in yield of about 1/10th of the expected gains per year if the lowest estimates of inbreeding's effect of production are assumed and about $\frac{1}{3}$rd of the expected gains if the highest estimates of F on production are accepted (Robertson 1954).

Robertson is, however, assuming complete linearity of effect over the whole of F's range here, which may not be necessarily so.

<u>Inbreeding and Deleterious Recessive Genes</u>

Many recessive genes become fixed in the homozygous state during the inbreeding process. Known genes with undesirable effects are more common in the recessive state, so it is not alarming then to find many undesirable recessives (both lethals and non-lethals) cropping up in most cases of known inbreeding. There has been extensive documentation of these undesirable recessives (Lerner 1944, Donald, Deas & Wilson 1952, Meads et al 1946).

Twenty six lethals have been reported, and the undesirable non-lethals reported are probably more numerous, although there has been no compilation of them (Lerner 1944).

<u>S U M M A R Y</u>:

There is complete agreement by most workers that inbreeding adversely affects production. The magnitude and other structural aspects of these effects are, however, in doubt. In addition, there has been reported various recessive genes with undesirable effects cropping up in inbreeding experiments.

C. Studies of Genetic Changes in Livestock Populations

Studies concerned with changes in genetic makeup of particular breeds with time have been numerous. One must, however, be careful in comparing results of various studies, as the genetic situation in one particular situation may be quite different from another. This is true between and within breeds, at different times, and at different places. Genetic analyses of various breeds and studies aimed at elucidating the breed structure are most common (Wright 1925; Robertson and Asker 1951; Fowler 1933; Brocklebanck and Winters 1951; Stonaker 1943; Willham 1937; Yoder and Lush 1937; Donald 1945; Robertson 1954; Wiener 1953; Wiener and Yao 1952; Barker 1957, 1960). The nearest approach to this present study has been a comparison between the inbreeding and relationship coefficients for bulls of artificial insemination and natural mating for German Friesian Cattle (Langlet and Gravert 1961).

A summary of some of these studies are shown in Table 2.

TABLE 2:

Inbreeding within various Livestock Breeds

Breed studied	Year to which F computed	Inbreeding %		Author
		Total	Rise per generation	
British Shorthorns	1920	26.0	0.6	McPhee & Wright 1925
Ayrshires (Gt.Britain)	1927	5.3	0.5	Fowlee 1933
Holstein Friesian (U.S.A.)	1931	4.0	0.4	Lush et al 1936
Brown Swiss (U.S.A.)	1929	3.8	0.5	Yoder et al 1937
Herefords (U.S.A.)	1930	8.1	0.6	Willham et al 1937
Aberdeen Angus (U.S.A.)	1939	11.3	0.3	Stonaker 1943
Jerseys (Gt.Britain)	1925	3.9	0.2	Smith 1926
Telemark (Norway)		7.0	0.5	Berge 1930
Brown Swiss (Switzerland)	1927	1.0	0.2	Scinchetti 1935
Friesian (Gt.Britain)	1945	1.21	0.2	Robertson et al 1951
Red Danish (Denmark)	1951	11.2	1.6	Robertson & Mason 1954
Polled Hereford (Australia)	1950	1.8	0.3	Barker & Davy 1960

From this table it can be seen that the increase per generation with one exception is remarkably uniform in view of the diversity of species and regions represented. Great variability exists between studies for total inbreeding, although this is partly due to pedigrees being traceable to more remote dates in some breeds than in others. Most of the studies agree with Lush (1946) that pure breeds of livestock lose, on the average, about 0.5%

of their heterozygosis per generation from inbreeding alone.

The term $\frac{r}{2-r}$ (where r is the average relationship between random members of the breed), is a sufficiently accurate estimate of the Inbreeding expected under conditions of random mating, and finite population size (Lush 1946).

The ratio $\frac{\text{Inbreeding Found}}{\text{Inbreeding Expected}}$ sometimes called the "Index of Subdivision" (Lush 1946) gives an estimate of the tendency of a breed to subdivide into partially isolated groups or families. From the above studies, only a moderate tendency is shown for breeds to isolate in this manner.

Langlet and Gravert (1961) calculated inbreeding and relationship coefficients for 356 bulls of Artificial Insemination and for 159 bulls of natural mating for German Friesian cattle. They were desiring to see whether with the great increase in Artificial Breeding which occurred between 1943 to 1960 (1% - 66% of all cows inseminated), whether the breed was being split into particular lines. Their results are shown in Table 3.

TABLE 3:

Inbreeding and Relationship for bulls of Artificial Insemination and Natural Mating in German Friesian Cattle

	Inbreeding	Relationship
Bulls of Artificial Insemination	2.46%	3.39%
Bulls of Natural Service	0.78%	3.35%

The above authors concluded from these results that "inbreeding and relationship can be regarded as unimportant in all cases and do not show an undesirable narrowing of the blood lines".

As far as New Zealand is concerned various workers have investigated structural and genetic changes of the Jersey Breed with time. (Jhala 1952; Fahimuddin 1952; Stewart 1952, 1954, 1951).

Jhala (1952) and Stewart (1954) analysed the breed at 5 yearly intervals from 1905-1950. Total inbreeding relative to 1895 as zero was divided into three parts:

(1) Current Inbreeding:- due to relationship in the Parental and Grandparental generations. (Sib or Parent offspring Mating).

(2) Long term inbreeding:- due to relationship of important animals to the whole breed which are likely to appear beyond the grand parental generation in both the top and bottom halves of the pedigrees.

(3) The inbreeding due to the separation of the breed into strains - Strain Inbreeding.

Estimates of Current Inbreeding were calculated from eight line pedigrees of animals drawn at random from the herd book. Non-Current Inbreeding (comprising Long Term Inbreeding and Strain Inbreeding) was made from the eight line pedigrees after omission of the Current Inbreeding in them. This was estimated by the modification of Wright's Short Method as explained by Robertson and Asker (1951). Long Term Inbreeding was estimated by the use of the formula $\frac{r}{2 - r}$ (Lush 1946) where r is the average relationship between animals drawn at random from the breed. Subtraction of Long Term Inbreeding from Non-Current Inbreeding gives an estimate of Strain Inbreeding.

These authors showed where Total Inbreeding referred to 1895 as zero has remained uniform at about 2½%. If one takes the generation interval for New Zealand cows as about 5 years (Fahimuddin 1952), then this is equivalent to an increase per generation of about 0.2 - 0.5% in the Inbreeding Coefficient. Prior to 1920, Long Term Inbreeding, due to the relationship of individual animals to the breed was the most important component of Total Inbreeding. Between 1920 and 1930, Current Inbreeding, due to relationship in the parental and grandparental generations, has been the most important.

The Jersey Breed in New Zealand is divided into several strata (Fahimuddin 1952; Stewart 1952). The top stratum consists of a small self contained group of herds supplying sires to each other and to herds in any stratum below it. The second stratum obtains sires from the top stratum only, but supplies sires to herds in any stratum below it. The third stratum obtains sires from either of the top two strata and supplies sires to herds in any stratum below it. These authors thus picture the whole Jersey Breed being graded up to the top stratum, and differences between herds in the top and lower strata are largely determined by the number of strata through which genes have passed.

This functional stratification is not peculiar to the New Zealand Jersey Breed and is reported elsewhere in the literature (Lush 1946; Wiener 1953) for other breeds.

<u>S U M M A R Y</u>:

Inbreeding and Relationship coefficients reported in most studies have been generally small. The increase in inbreeding coefficients per generation has also been relatively uniform and small in most studies. The New Zealand Jersey Breed does not appear to be peculiar in these respects.

CHAPTER III

MATERIALS AND METHODS

Source of Data

The data used in this study have been collected from two sources.

(a) Unproven Bulls used in Artificial Breeding

The New Zealand Dairy Board's Artificial Breeding Catalogue (1960), and its supplement have a complete list of Pedigrees of the Unproven Jersey Bulls present at Newstead Artificial Breeding centre in 1960. This formed the source of data as far as the compilation of pedigrees were concerned. Such pedigrees were traced to the great grandparental generations.

There were 254 unproven bulls at the centre in 1960, of which 131 were in use that year - the remainder awaiting proofs. Their age distribution is shown in Table 4.

TABLE 4:

Age Distribution of Unproven Jersey Bulls at Newstead (1960).

Age of Bull	Number present
1	8
2	19
3	22
4	44
5	85
6	76
Total:	254

(b) Young Bulls not used in Artificial Breeding

The sample of young bulls not used in Artificial Breeding, but about the same age distribution as the Artificial Breeding ones, was procured by Herd Book sampling. To obtain a satisfactory random sample of bulls which would serve as a sound basis for comparison with the 254 bulls used at the centre, it seemed the following facts should be kept in mind.

(1) The sample should be at least equivalent in numbers.

(2) The age distribution should be approximately the same.

Bearing these prerogatives in mind, a total of 250 bulls were sampled from the herd books concerned and their pedigrees traced to the great grandparental generations. Fischer and Yates' (1953) Random Number tables were used in the sampling.

The age distribution of the 250 bulls sampled are shown in Table 5.

TABLE 5:

Age Distribution of the Non-Artificial Breeding Bulls

Age of Bull	Number Present
1	15
2	15
3	18
4	45
5	80
6	77
	Total: 250

These two samples of bulls were tested for Homogeneity by the use of a Contingency Table and Chi-Square distribution by the method of Snedecor (1948). (See Appendix I for working)

The χ^2 for 5 d.f. = 1.6990, which was Non-significant (the χ^2 for significance at the 5% level being 11.07).

This sample, although a reasonably sound one in the light of the above requirements, suffers from the disadvantage that it is certainly not a random sample of non- Artificial Breeding bulls being used in the industry.

Certain herds have a greater impact on the industry than others, as their sires are used more extensively (Fahimuddin 1952). Hence, for a sample to be indicative of the bulls being used in the industry, some weight should be attached to

(a) The size of the various studs, and

(b) some quantitative measure of the relative importance of the various studs in spreading genes throughout the industry.

It was found most difficult to include these prerogatives in sampling. The use of bull sale catalogues to assess (b) was attempted, but it was soon realized that probably as many or even more bull sales are private as are public. The bias introduced, however, should not be a large one since most of the genes within the industry are coming from a fairly small nucleus (Stewart 1952). As he states: "There is a top stratum of pedigree breeders which consists of a small self contained group of herds supplying sires to each other and to herds in any stratum below".

The sample of non-Artificial Breeding bulls is, therefore, sufficient for comparison with the Artificial Breeding ones, although it may not entirely reflect the exact structural pattern of the non-Artificial Breeding bulls in the industry.

Methods of Analysis

Coefficients of Inbreeding and Relationship have been calculated back to the great-grandparental generation by use of Wright's Long Method as explained earlier. The Inbreeding Coefficient of a common ancestor (F_A) has been allocated 0.025. This figure seems reasonable in lieu of Stewart's 1954; Jhala's 1952 figures. These workers show where the Inbreeding in the New Zealand Pedigree Jersey Breed relative to 1895 as zero has remained fairly constant at 2½%. In case an animal has no common ancestor in his sires and dams pedigree up to the great-grandparental generation, the inbreeding coefficient is allocated as zero. The average relationship coefficients for the sample are calculated. The first animal on the list is checked with, say, 253 others for the 254 animal sample, the second with 252, and the third with 251, etc. The relationship coefficient for each of the combinations is added and the result is divided by the total possible amount of combinations to give the average relationship of all bulls amongst the group. For example, 254 bulls would have 32,385 possible combinations, and 250 bulls would have 31,375 possible combinations (excluding that of the bull with itself). The two groups are tested for differences in the distribution of F by the use of Chi-square. (Snedecor 1948).

CHAPTER IV

RESULTS AND DISCUSSION

Inbreeding amongst Unproven Artificial Breeding Bulls

Of the 254 bulls present, only 23 were inbred with Inbreeding Coefficients ranging from 0.03203 - 0.19218.

Average Inbreeding for 23 = 0.0724

" " " whole sample = 0.00656.

The number of bulls in the various ranges of F are shown in Table 6.

TABLE 6:

Number of Bulls in various ranges of F

No. of Bulls	F's Range
8	0.01 - 0.05
10	0.06 - 0.10
3	0.11 - 0.15
2	0.16 - 0.20

Thus approximately 80% of bulls actually inbred are below F levels of 10%. Only 2 bulls exceeded 15% F level, the highest being Pampas Opals' Prestige (Herd Book 249505) with an Inbreeding Coefficient of 19%. Inbreeding coefficients of bulls "per se" is of little significance since Inbreeding is not a hereditary trait, but careful examination of how such coefficients arose can give a rough yardstick of general breeding practices and will certainly give some indication of how inbreeding trends could go in the long run if present breeding practices are maintained.

A highly inbred group of bulls in an isolated set-up will lead to greater inbreeding of progeny than otherwise.

The eight bulls in Column 1 above, arose as a result of having the same animal as a grandsire and great-grandsire on the sire and dam's side respectively. The three in Column 1 came about by the mating of Paternal Half Sibs. The last two arose as a result of Paternal Half Sib mating, plus small contributions due to the first two types being included as well. Inbreeding due to animals having common great-grandsires in both lines, is as frequent as that due to animals having the same individual as grandsires, as well as great-grandsires in the two lines. Inbreeding, due to Paternal Half Sib mating, is somewhat smaller.

<u>Inbreeding amongst Non-Artificial Breeding Bulls</u>

Of the 250 randomly chosen bulls, 30 were inbred with F values ranging from 0.03203 - 0.16013.

Average F for the 30 actually Inbred	=	0.07473
" " " " whole sample	=	0.00897

Number of bulls in the various levels of F are shown below in Table 7.

TABLE 7:

Number of Bulls in the various ranges of F.

No. of Bulls	F's Range		
11	0.01	-	0.05
10	0.06	-	0.10
8	0.11	-	0.15
1	0.16	-	0.20

As in the Artificial Breeding sample the largest group has values less than 10% F. The average inbreeding coefficients for the two groups are approximately similar, and the types of matings giving rise to the Inbreeding again show the same trend with the greatest frequency in the first two columns.

S U M M A R Y:

There is no great difference between the two groups as regards inbreeding coefficients and the manner in which each arose. Inbreeding coefficients are, in general, quite low. The tests for differences in the distribution of χ^2 values for these samples is Non-significant. (A χ^2 of 2.439 being obtained and one of 5.99 being required for significance at the 5% level). (See Appendix II). Hence, as far as inbreeding levels go, the two groups are not statistically different.

Relationship amongst Unproven Artificial Breeding Bulls

There were 246 of the 254 bulls or 97% which had relatives within the groups (i.e. only eight were unrelated to any others in the group).

Average Relationship amongst 246 that were Related = 0.007356
" " for whole sample = 0.00694

Table 8 shows the intensity of the Relationship

TABLE 8:

Intensity of Relationship amongst Unproven Artificial Breeding Bulls

No.of Bulls	Related to other Animals in Sample
8	None
79	1 - 10
101	11 - 20
47	21 - 30
16	31 - 40
3	Over 40

Of the 246 related bulls, 167 (i.e. 68%) were related to more than 11 other animals in the group. Only 7% of the 246 related animals were, however, related to more than 30 others in the group.

Relationship amongst Non-Artificial Breeding Bulls

There were 116 of the 250 bulls or 47% which had relatives within the group.

Average Relationship amongst the 116 that were related = 0.00449
" " " whole sample = 0.000963

The intensity of the Relationship is shown in Table 9.

TABLE 9:

Intensity of Relationship amongst Unproven Non-Artificial Breeding Bulls

No. of Bulls	Related to other animals in group
134	0
82	1 - 10
8	11 - 20
6	21 - 30
20	31 - 41

Of the 116 animals, only 34 animals (i.e. 29%) here, as compared to 68% in the previous sample, were related to more than 11 other animals in the group. 22% of animals were related to over 20 others as compared with 27% in previous sample. A greater percentage of the animals related to more than 30 others, however, exists in the non-Artificial Breeding sample (17% v. 8%).

S U M M A R Y:

There are vast differences in average relationships amongst both samples. The structural makeup of such relationships also differ to a great extent. These differences are highly statistically significant (1% level of significance). (See Appendix III)

Numbers and Sizes of Paternal Half Sib Groups

(a) Artificial Breeding Bulls

One hundred and ninety-one of the 246 animals that were related in the Artificial Breeding Sample were members of the Half Sib groups. The numbers and sizes of such are seen in Table 10.

TABLE 10:

Numbers and Sizes of Paternal Half Sib Groups amongst Artificial Breeding Bulls

Size of Paternal Half Sib Groups	No. of such groups
* 2	30
3	10
4	5
5	4
6	1
7	1
8	1
9	-
10	-
11	1
12	-
13	1
14	-
15	-
16	1
Total:	191 animals

About 30% of the unproven Artificial Breeding bulls were members of Paternal Half Sib groups - size 5 or more. The groups in preponderance was that of size 2. In addition, 2 animals were full sibs.

* Means that 2 animals have a common sire.

(b) **Non-Artificial Breeding Bulls**

There were three groups of two Paternal Half Sibs in the non-Artificial Breeding group.

The bulls having the greatest number of sons in the Artificial Breeding scheme are shown in Table 11.

TABLE 11:

Bulls with greatest numbers of sons in the Artificial Breeding Scheme

Bull	Herd Book Number	No. of sons
Pampas Mogul	192828	16
Jersey Glen Storm	184103	13
Lamorna Minor	179685	11
Glenmore Royal Guide	202348	8
Sproston Pal's Ensign	176291	7

The relationships of these young bulls (i.e. sons of bulls in Table 11) to the rest of the group are important since, if this relationship is high, the greater is the probability of an Artificial Breeding bull being mated to the daughter of a fairly close relative giving rise to inbreeding. The average relationship coefficient of a son of the above different bulls to the whole Artificial Breeding sample is computed, using only that part of the relationships caused by the young bulls' sires (Table 12). One is thus able to see the importance of any one line amongst young Artificial Breeding Bulls.

TABLE 12:

Artificial Breeding Bull	Sire	Av.Relationship to other A.B. Bulls in sample	Total No. of Animals Related to in group	Size of Paternal ½ Sib group
1. Auchenhove Reward (Herd Book 254502)	Pampas Mogul (Herd Book 210026)	0.02001	28	16
2. Merivale Superior Storm (Herd Book 243460)	Jersey Glen Storm (Herd Book 184103)	0.013103	18	13
3. Massey Minors Larry (Herd Book 235320)	Lamorna Minor (Herd Book 179685)	0.01315	18	11
4. Whaka Hiki Viceroy (Herd Book 235473)	Sproston Pal's Ensign (Herd Book 176291)	0.01041	31	7
5. Coldsprings Emperor (Herd Book 244342)	Glenmore Royal Guide (Herd Book 202348)	0.01525	40	8

Bulls having the greatest number of Paternal Half Sibs in the group are also related to a large number of other animals in the same group. The bull - "Coldsprings Emperor" (Column 5) - for example, has seven Paternal Half Sibs in his group, and is related to 34 other bulls by other relationship routes through Paternal connections.

The great-grandparental and grandparental ancestors on the sire's side of this bull is responsible for nearly all of the twenty bulls which were related to 5- 40 others in the non - Artificial Breeding group (see Appendix for pedigree).

Dunlavin Excellency, his great-grandsire, and Glenmore Royal Vagabond, his grandsire, have been responsible for most relations in the non-Artificial Breeding group of bulls as well.

S U M M A R Y:

Of the young unproven Artificial Breeding bulls, about 75% have one or more Paternal Half Sibs in the group. Only three Paternal Half Sibs were found in the sample of non-Artificial Breeding bulls. Artificial Breeding bulls in the larger Paternal Half Sib groups were also related to many other animals (apart from their Half Sib mates) in the group.

Relationships of the Inbred Bulls

The relationships amongst inbred bulls is important, since if the ancestors of a particular bull is inbred, then the greater will be the inbreeding in the progeny. It was, therefore, deemed necessary to see how highly related one particular inbred bull was to the rest of the group, and also how many other inbreds this bull was related to.

(a) Artificial Breeding Group (23 Inbreds)

Table 13 shows the relationship between each of the 23 inbred bulls and the whole sample of bulls in the Artificial Breeding group.

TABLE 13:

Relationship of Inbred Bulls to Group as a whole (Artificial Breeding)

No. in A.B. Catalogue	Av. Relationship to the whole sample	Inbreeding Coefficient	No. of Animals Related to in Group	No. of other Inbreds Related to in Sample
532	0.00688	0.16015	31	3
558	0.00068	0.03203	2	Nil
563	0.00012	0.06406	1	Nil
572	0.01396	0.12810	30	2
591	0.01420	0.19218	28	2
596	0.00942	0.06406	32	3
606	0.00658	0.06406	17	1
618	0.00158	0.03203	10	0
624	0.00751	0.09609	21	3
655	0.00669	0.06406	17	1
673	0.00325	0.03203	14	5
681	0.00969	0.06406	34	3
682	0.00561	0.03203	30	0
705	Nil	0.012810	Nil	0
720	0.00296	0.06406	10	5
746	0.00229	0.06406	13	5
750	0.00707	0.03203	25	5
751	0.00732	0.03203	27	5
757	Nil	0.06406	Nil	Nil
780	0.00233	0.12810	3	2
781	0.00216	0.03203	3	2
782	0.00277	0.06406	15	2
794	0.00674	0.06406	33	7

In general, from Table 13, most of the inbred bulls have a much lower coefficient of relationship to the other group of bulls than does the average bull in the sample (i.e. where $r = 0.009$). Only two inbred bulls, No. 572 (Pampas Masterful) and No. 591 (Pampas Opals' Prestige) show a much greater relationship to the whole group than the average bull of the sample. The pedigrees of these bulls are shown in the Appendix.

Of the 23 Inbred bulls in the Artificial Breeding group, six were unrelated to none of the other inbreds in the group. Of this 6, two were also unrelated to the other animals, two were related to a very small number of sample animals, and two others to a substantial number of sample animals. All, but two (Nos. 780 and 781), of the remaining 17 inbreds were related to a large number of other animals in the group. Bull No. 794, "Tane Phillipa's Sambo (Herd Book No. 265389) was related to 7 other inbreds and to 33 other animals in the group, but the relationship is not high.

Relationships amongst Inbred Artificial Breeding Bulls

Table 14 shows the relationship amongst the inbred bulls when a relationship does exist.

TABLE 14:

Relationships amongst Inbred Artificial Breeding Bulls

Relationship Between	Relationship Coefficient
532/596	0.28827
624	0.28416
681	0.36038
572/591	0.44142
794	0.18841
591/794	0.22756
596/624	0.37072
681	0.25584
606/655	0.31607
624/681	0.28172
673/720	0.13751
750	0.06207
746	0.03056
751	0.01504
794	0.03056
720/746	0.01504
750	0.03056
751	0.03056
794	0.03056
750/751	0.34139
794	0.03056
751/794	0.03056
780/781	0.31169
782	0.31886
781/782	0.30561

Average Relationship amongst all Artificial Breeding Bulls = 0.01729 (Inbred)

Average Relationship amongst the 17 that were related = 0.03165 (Inbred)

In general, there are two distinct types of relationships amongst the inbred bulls.

(a) Those which are very highly related when a relationship exists (i.e. R > 25%) of which there are eleven.

(b) Those which are very poorly related when they show any relationship (i.e. R = 1.5% - 6%) of which there are nine.

The highest relationship between inbred bulls is that of 44% between Pampas Masterful (Herd Book 242666) and Pampas Opals' Prestige (Herd Book 249503). These are the same inbred bulls having the greatest relationship to all the other bulls (both inbred and outbred) in the sample.

(B) Non-Artificial Breeding Group (30 Inbreds)

Table 15 shows the relationship of inbred bulls to the group as a whole (Non-Artificial Breeding) and Table 16 shows the relationships amongst the inbred bulls themselves.

TABLE 15:

Average Relationships of Inbred Non-Artificial Breeding Bulls to the Group as a Whole

Herd Book No.	Av.Relationship to Group as a Whole	Inbreeding Coefficient	No.of Animals Related to in Group	No.of other Inbreds Related to in Sample
224967	0.000063	0.12810	1	-
225606	0.00218	0.06406	9	2
226614	-	0.012810	-	-
226856	0.001104	0.03203	4	2
227708	0.00176	0.012810	8	-
230616	0.000753	0.06406	8	-
231588	-	0.06406	-	-
231696	0.00038	0.03203	2	-
232188	-	0.06406	-	-
235964	0.00618	0.06406	32	4
236178	-	0.03203	-	-
236561	0.00044	0.03203	5	2
236786	0.00469	0.03203	8	1
237042	0.00104	0.16013	5	2
237521	-	0.03203	-	-
240099	-	0.06406	-	-
241632	0.00092	0.06406	8	3
242667	0.00057	0.06406	7	1
242943	0.00075	0.03203	4	2
244633	-	0.06406	-	-
245211	0.00096	0.12810	9	2
239124	-	0.12810	-	-
253972	-	0.06406	-	-
254514	0.00088	0.06406	12	1
255237	0.00600	0.06406	33	4
255373	0.00604	0.03203	33	4
247152	-	0.12810	-	-
247744	-	0.12810	-	-
248524	-	0.12810	-	-
251221	0.00600	0.03203	33	4

TABLE 16:

Relationship amongst Non-Artificial Breeding Inbred Bulls themselves

Relationship Between	Relationship
Herd Book No. 225606/236561	0.09167
" " " 225606/245211	0.17392
" " " 226856/237042	0.14636
" " " 226856/247843	0.05937
" " " 235964/254514	0.01504
" " " 235964/255237	0.04515
" " " 235964/255373	0.04583
" " " 235964/251221	0.09167
" " " 236561/245211	0.11874
" " " 236786/242667	0.06112
" " " 237042/242943	0.20591
" " " 241632/255237	0.06019
" " " 241632/255373	0.03056
" " " 241632/251221	0.03056
" " " 241632/251221	0.18606
" " " 255237/255373	0.15279
" " " 255237/251221	0.06207

Av.Relationship amongst 30 Non-Artificial Breeding Bulls = 0.003353

Av.Relationship amongst the 14 that are Related = 0.014847

Table 15 and 16 shows that a large amount of inbred bulls show a much greater relation to the other bulls in the sample than the relationship shown by the average bull (where r = 0.0009). In some cases, the relationship of some of these inbred bulls to the whole sample is as much as seven times as great as the average bull. Of the 30 inbred bulls -

12 were totally inherited .

4 were Related to other bulls, but not Inbreds.

14 were Related to other bulls, including Inbreds.

Thus, the inbred non-Artificial Breeding bulls seem to be in two distinct lines - one line with little or no interrelationship to the group as a whole, and another closely interrelated line. The relationship amongst the inbred bulls themselves are all fairly small from Table 16.

S U M M A R Y:

Both samples of inbreds are not closely interrelated. The Artificial Breeding inbred bulls consist of a subgroup within which relationships are extremely high, and another in which relationships are very low.

DISCUSSION OF RESULTS

The most important point about the inbreeding and relationship coefficients for both samples is that they are extremely small.

Stewart (1954) gives a figure of 0.62% for Current Inbreeding in the New Zealand Pedigree Jersey Breed as at 1950. The figures obtained here suggest that the rise of inbreeding in this particular breed has been extremely small in the past two generations that have elapsed since that date.

Artificial Breeding, as such, does not appear to be causing great increases in the inbreeding levels.

The patterns of mating giving rise to these inbreeding coefficients are approximately similar in both cases. Inbreeding due to animals having common great-grandsires in both lines is as frequent as that due to animals having the same individual as grandsires, as well as great-grandsires in the two lines. Inbreeding due to Paternal Half Sib Matings (i.e. common grandsires in both lines) is somewhat smaller. There is, however, more of this particular type of inbreeding in the non-Artificial Breeding group of bulls. This may indicate that some Pedigree breeders are still following a slight line breeding policy. This fact should not be given too much credence, however, in view of the small size of the samples involved, and also due to the fact that there are more inbreds in the non-Artificial Breeding group (30 versus 23).

Although both samples have small average coefficients of relationship, the Artificial Breeding Sample shows a much greater coefficient than the non-Artificial Breeding Sample.

The fact that the inbreeding coefficients for both samples show closer agreement immediately signifies two possibilities:-

(a) Non-Artificial Breeding bulls have within them a group which is much more closely related than the Artificial Breeding bulls.

(b) There are within the non-Artificial Breeding group certain well defined lines which, although highly inbred in themselves, show little or no relationship to the rest of the group as a whole.

Both these possibilities seem to exist. By closer examination of the intensity of relationships (Tables 8 and 9), it is seen that the percentage of Artificial Breeding bulls related to more than 30 others in the group is less than half of the corresponding figure for non-Artificial Breeding bulls. Of the thirty inbred bulls within the non-Artificial Breeding sample, twelve were totally unrelated to other animals in the sample. This shows the existence of separate lines within the group and points out again to the possibility of line breeding.

The two samples of bulls seem to exhibit a definite structural pattern. In the non-Artificial Breeding bulls there is:

(a) A completely unrelated subgroup.

(b) A subgroup in which intermediate interrelationships exist.

(c) A top group in which interrelationships are higher than the corresponding group for Artificial Breeding bulls.

Group (a) seems to be the largest, and within this group are found many inbreds which again points to the fact that some form of line breeding is taking place amongst the Pedigree breeders.

Artificial Breeding seems to be drawing its bulls mainly from categories (b) and (c).

This structural pattern resembles closely that of Stewart's (1952). This author subdivided the breed into various strata.

(1) A top stratum, consisting of a small self contained group of herds, supplying sires to each other, and to herds in any stratum below it.

(2) A second stratum, which obtains sires from the top stratum only, but supplies sires to herds in any stratum below it.

(3) A third stratum, which obtains sires from either of the top two strata, and supplies to any below it and so on.

In this way, Stewart envisages the breed as being graded up to the top stratum.

This pattern can be looked upon as a triangle in which the genes going in the industry have to pass through a fairly small bottleneck, in which relationships are fairly high. At the base, relationships get very small. The non-Artificial Breeding bulls presumably are mainly to be found at the base where interrelationships are small. There is, however, some of them which are drawing their bulls mainly from the upper reaches of the triangle where interrelationships are higher.

Artificially Bred bulls, on the other hand, are being drawn in the main from the top reaches of the triangle where interrelationships are highest. Thus by the use of Artificial Bred bulls on herds in the lower strata, the grading up process is hastened.

The fact that these bulls are being drawn mainly from a comparatively narrow top stratum with little genetic diversity may cause inbreeding problems in the long run, but so far such has been negligible. The problem will, however, be intensified when the stage is reached in the Artificial Breeding set-up when all young bulls are proven within the Artificial Breeding scheme (i.e. no Naturally Proven bulls available). Since there are now two Artificial Breeding centres in New Zealand (Newstead and Awahuri), such a problem could be solved by switching bulls from one centre to another.

Approximately 5% of all matings resulting in the birth of registered offspring in the New Zealand Pedigree Jersey Breed (1903-1958) have been between animals with a common sire (Stewart 1954). For this reason, it was deemed of great importance to enquire into the exact makeup of the relationships amongst the Artificial Breeding bulls as regards Paternal Half Sib groups. The larger the size of the Half Sib groups, the greater is the possibility for a bull to be mated to either his half sister or his half brothers' daughter. Table 10 shows that approximately 75% of all the bulls in the Artificial Breeding sample had at least one half brother in the sample as well. Those bulls having the greatest number of sons within the Artificial Breeding group are also related to a large number of other animals in the group as well (Table 12).

This is most important, as these young sons can subscribe to inbreeding, both from the fact that they are members of a large Half Sib group, but also they are well related to other animals, apart from their Half Sib mates as well. The probability of a bull being mated to his Half Sib mates' daughter or other close relative is thus increased.

At the present time, the chances of this happening are quite small indeed, due to the system of proving Young bulls, and the fact that not all Proven bulls are proven in the Artificial Breeding scheme.

Each young bull is brought into the Artificial Breeding scheme, used lightly for the first year, and then rested until the Artificial Breeding proofs of his daughters are available (usually 4 years later).

At the present time, usually about 25% (N.Z.D.B.R. 1960) of the Unproven Bulls are taken into the Proven Bull team for extensive service. Thus, if 16 Paternal half sibs were taken in the first year, only 4 will be used extensively (when proven). The chances of these being mated to his daughter or his mates' daughter out of an inseminated cow population of 500,000 (N.Z.D.B.R.) is thus extremely small. However, the greater the initial amount of Paternal Half Sibs, and the greater the amount of Unproven Bulls are proven within the scheme, the greater the probability.

The extremely small number of Paternal Half Sibs in the group of non-Artificial Breeding bulls was surprising, in view of the great interrelationship between members of a subgroup in this sample. However, on closer examination of this subgroup, it was seen that although there are many relatives in this group, the relationship is mainly a weak one, with great-grandparental common ancestors most common. Thus it seems that, although there is a group within the non-Artificial Breeding group drawing their genes from higher strata, this strata is still below that from which most Artificial Breeding bulls draw theirs.

The Inbred bulls in the non-Artificial Breeding sample showed very low relationships with each other, but within the Artificial Breeding is present a subgroup of inbreds in which relationships with each other are extremely high. This same group of bulls are also related to many others in the sample. It would appear that it is amongst this group of bulls that the greatest potential dangers of inbreeding lie, since there is the possibility of progeny of these bulls having more than one common inbred ancestor. As more proven bulls are procured from the Artificial Breeding scheme this danger will be intensified.

CHAPTER V

SUMMARY AND CONCLUSIONS

Inbreeding and Relationship Coefficients have been computed for two samples of bulls in the New Zealand Pedigree Jersey Breed. One of the samples was the unproven bulls at the Artificial Breeding Centre in 1960, whilst the other was that of bulls of about the same age distribution, but not used in Artificial Breeding.

The Inbreeding Coefficients for both groups of bulls did not differ significantly and were very small (0.65% and 0.89% for Artificial Breeding and non-Artificial Breeding bulls respectively). The manner in which these Inbreeding Coefficients arose did not appear to differ in the two samples. The highest Inbreeding Coefficient found was 19% for an Artificial Breeding bull (Pampas Opals' Prestige, Herd Book No. 249505), but in general most inbred bulls had Inbreeding Coefficients below 10%.

Of the bulls at the Artificial Breeding centre which were sampled, 23 or 9% were Inbred, as compared with 30 or 12% in the other group, but this difference was not significant.

Coefficients of Relationship for both samples are also very low, but there is a highly significant difference between relationships of the two samples. The average coefficient of relationships amongst the Artificial Breeding group of bulls is approximately seven times that of the non-Artificial Breeding bulls in this particular sample. Only eight bulls in the Artificial Breeding sample were totally unrelated (back to the great-grandparental generation) as compared with 116 in this sample of non-Artificial Breeding bulls.

Approximately 75% of the Artificial Breeding bulls have one or more Paternal Half Sibs present in the group with the largest Paternal Half Sib group being 16. Only three groups of two Paternal Half Sibs each were found in the sample of non-Artificial Breeding bulls. The relationship amongst inbred bulls in each of the samples is discussed in the light that such could cast on future inbreeding levels.

There is no evidence that the large increase in the use of Artificial Breeding over the last decade has been adversely affecting inbreeding levels in the New Zealand Pedigree Jersey Breed at the present time.

It does appear, however, that there is enough available potential for this to occur later on. The chances of this happening become progressivly greater, as the proportion of young bulls proven within the scheme is increased.

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APPENDIX I

Tests for differences in the Distribution of χ^2

TABLE 1:

Age distribution of Artificial Breeding and Non-Artificial Breeding Bulls

Age of Bull	Artificial Breeding		Non-Artificial Breeding		Totals
		*			
6	8	(11.6)	15	(11.4)	23
5	19	(17.1)	15	(16.9)	34
4	22	(20.2)	18	(19.8)	40
3	44	(44.8)	45	(44.2)	89
2	85	[illegible]	80	(81.5)	165
1	76	(77.1)	77	(75.9)	153
Totals:	254		250		504

* Bracketed figures give the expected values

$$\chi^2 = \sum \left[\frac{(\text{Observed-Expected})^2}{\text{Expected}}\right] = 1.1 + .21 + .16 + .014 + .039 + .015 + 1.14 + .02 + .001 + .11$$

$$\chi^2 = 1.6990$$

$\chi^2_{5^d f}$ required for significance at 5% level = 11.07. Hence, Non-significant.

APPENDIX II

Tests for differences in the Distribution of χ^2

TABLE 2:

Inbreeding for the two groups of Bulls

	F's Ranges:			Total:
	0.01-0.05	0.06-0.10	0.11-0.20	
Artificial Breeding Bulls	8 (8.2)	10 (8.6)	5 (6.2)	23
Non-Artificial Breeding Bulls	11 (10.8)	10 (11.4)	9 (7.8)	30
Total:	19	20	14	53

$$\chi^2_{2d_f} = .005 + .004 + .78 + 0.2 + .17 + .18$$
$$= 2.439$$

$\chi^2_{2d_f}$ wanted is 5.99. Hence, two groups of $2^{d}f$ bulls are Non-significant as far as Inbreeding trends go.

APPENDIX III

Tests for differences in the Distribution of χ^2

TABLE 3:

Relationship amongst 2 groups of Bulls

	Relationships' Range			
	0.00-0.05	0.06-0.10	0.11-0.512	Total
Artificial Breeding Bulls	31093 (31637)	779 (481)	513 (269)	32385
Non-Artificial Breeding Bulls	31195 (30651)	168 (466)	12 (256)	31375
Totals:	62288	947	523	63760

Numbers bracked to represent Expected Values

$\chi^2_{2^d f} = 9.35 + \ldots\ldots$ etc

The χ^2 necessary for significance at the 1% level for 2 degrees of freedom is 9.21, hence, the differences between the two groups is highly significant.

(a)

Coldspring's Emperor H. B. No. 244342	Glenmore Royal Guide H. B. No. 202348	Glenmore Royal Vagabond H. B. No. 157911	Dunlavin Excellency H. B. No. 139720
			Glenmore Flashlight Bub
		Glenmore Lady Portia H. B. No. 264338	Dunlavin Excellency H. B. No. 39720
			Glenmore Diana
	Sungleam Evelyn H. B. No. 259251	Beaulieu Dominator H. B. No. 138937	Beaulieu Signor
			Beaulieu Lotus
		Sungleam Alma H. B. No. 160353	Tahitarata Lomarch
			Sungleam Magpie

(b)

Pampas Masterful
H.B.No.242666

Pampas Prestige
H.B.192831

Maori Precision
H.B.No.139439

Maori Barber

Maori Dancing Flower

Pampas Flower
H.B.No.133101

Erinview Flight

Red Poppy

Pampas Maureen
Precision
H.B.No.253705

Maori Precision
H.B.No.138439

Maori Barber

Maori Dancing Flower

Pampas Maureen
H.B.No.199410

Erinview Teddy

Pampas Mavis

(c)

Maori Barber
" Dancing Flower

Maori Precision
H. B. No. 139439

Pampas Prestige
H. B. No. 192831

Erinview Flight

Pampas Flower
H. B. No. 133101

Pampas Opal's Prestige
H. B. No. 249505

Red Poppy

Maori Barber
" Dancing Flower

Maori Precision
H. B. No. 139435

Pampas Opal
H. B. No. 326058

Maori Precision

Pampas Queen
Jewell
H. B. No. 244951

Pampas Queen of Hearts