

# PopReport

## A Pedigree Analysis Report

**Population:** 51  
**Inputfile:** POPREP.TXT  
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## Some Notes About Your PopReport Job:

- INFO: This job ran on machine rie-ex-web160 with 12 CPUs and MemTotal: 32950668 kB
- INFO: Your entered dateformat was 'YYYYMMDD', your dateseparator 'undef'.  
144245 input lines processed.  
144245 animals accepted.
- INFO: (concerning Inbreeding Report)  
This table shows the shortening of the number of male and female animals per year for the AGR computations. The original (orig) number of records is shortened (cut) to keep the product of *male \* female* within acceptable limits. See details later in the Inbreeding Report.

Year	No. of Male		No. of Female	
	orig.	cut	orig.	cut
1974	743	743	6102	5384
1975	808	808	7398	4950
1976	882	882	9320	4535
1977	946	946	10781	4228
1978	893	893	11243	4479
1979	883	883	12116	4530
1980	840	840	13368	4762
1981	797	797	14331	5019
1982	809	809	15711	4944
1983	790	790	16306	5063
1984	801	801	17739	4994
1985	794	794	18863	5038
1986	802	802	20536	4988
1987	827	827	21889	4837
1988	840	840	23656	4762
1989	855	855	24741	4678
1990	876	876	25384	4566
1991	849	849	25285	4711
1992	831	831	25309	4813
1993	825	825	25205	4848
1994	809	809	24892	4944
1995	805	805	23886	4969
1996	767	767	22836	5215
1997	737	737	22223	5427
1998	746	746	22050	5362
1999	764	764	21641	5236
2000	771	771	21118	5188
2001	781	781	20792	5122
2002	798	798	21041	5013

Year	No. of Male		No. of Female	
	orig.	cut	orig.	cut
2003	868	868	21743	4608
2004	935	935	22641	4278
2005	1012	1012	23699	3953
2006	1090	1090	24980	3670
2007	1150	1150	25737	3478
2008	1216	1216	26042	3289
2009	1261	1261	25821	3172
2010	1308	1308	25672	3058
2011	1323	1323	25377	3023
2012	1338	1338	24503	2990
2013	1338	1338	23704	2990
2014	1344	1344	22977	2976
2015	1323	1323	22281	3023
2016	1299	1299	21219	3079
2017	1208	1208	19000	3311
2018	1060	1060	15808	3774
2019	864	864	12790	4630

# Pedigree Analysis Report for Population: 51

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## Contents

<b>1 Pedigree completeness per year</b>	<b>1</b>
<b>2 Inbreeding</b>	<b>4</b>
2.1 Distribution of animals by year and inbreeding level . . . . .	4
2.2 Number of <i>all</i> and <i>inbred</i> animals, sires and dams by year . . . . .	6
2.3 Descriptive statistics of inbreeding coefficients of <i>all</i> animals by year . . . . .	8
2.4 Descriptive statistics of inbreeding coefficient of <i>inbred</i> animals by year . . . . .	10
<b>3 Effective Population Size</b>	<b>12</b>
3.1 Effective Population Size based on the rate of inbreeding . . . . .	12
3.2 Effective population size based on the number of parents . . . . .	14
<b>4 The Average and Rate of Additive Genetic Relationships by year</b>	<b>16</b>

## List of Tables

1 The average pedigree completeness (%) for 1 to 6 generations deep by year . . . . .	1
2 Distribution of animals by year and inbreeding levels . . . . .	4
3 Numbers and average inbreeding of animals and parents by year . . . . .	6
4 Inbreeding coefficients ( $F$ ) of ALL animals by year . . . . .	8
5 Inbreeding coefficients ( $F$ ) of INBRED animals by year . . . . .	10
6 Effective population size by year via rate of inbreeding . . . . .	12
7 Effective population size by year via number of parents . . . . .	14
8 Average Additive Genetic Relationships (AGR) . . . . .	16

## List of Figures

1 Average pedigree completeness for 1 to 6 generations . . . . .	3
2 Comparison between the average inbreeding coefficients ( $F$ ) and the number of inbred animals by year . . . . .	11
3 Average Additive Genetic Relationships and Inbreeding Coefficients by year of birth . . . . .	19
4 Average $\text{Log}(1-F)$ by year of birth for animals born between 1927 and 2019. . . . .	20
5 The Rate of Inbreeding and Increase in the Additive Genetic Relationships by year of birth . . . . .	21

## 1 Pedigree completeness per year

An estimate of an individual's inbreeding coefficient depends on the extent to which its ancestry is known to some defined generation in the past. The more complete the knowledge of an individual's ancestry, the more reliable is its estimate of inbreeding coefficient relative to some defined base population. MacCluer *et al.* (1983) proposed an index to measure pedigree completeness. This index summarizes the proportion of known ancestors in each ascending generation. It quantifies the chance of detecting inbreeding in the pedigree (Sørensen *et al.*, 2005). The following formula was used to compute pedigree completeness (MacCluer *et al.*, 1983):

$$I_d = \frac{4I_{d_{pat}}I_{d_{mat}}}{I_{d_{pat}} + I_{d_{mat}}}$$

and

$$I_{d_k} = \frac{1}{d} \sum_{i=1}^d a_i \quad k = pat, mat$$

where  $k$  represents the paternal (*pat*) or maternal line (*mat*) of an individual,  $a_i$  is the proportion of known ancestors in generation  $i$ . The  $d$  is the number of generations considered in the calculation of the pedigree completeness. For example, if  $d = 5$  then five ancestral generations will be taken into account in the computations. The values for pedigree completeness range from 0 to 1. If all ancestors of an individual to some specified generation ( $d$ ) are known, then  $I_d = 1$  or if one of the parent (*i.e.* sire or dam) is unknown,  $I_d = 0$ . The pedigree completeness values averaged per year are presented on the Table.

Table 1: The average pedigree completeness (%) for 1 to 6 generations deep by year

Year	No of Animals	Compl. gen 1	Compl. gen 2	Compl. gen 3	Compl. gen 4	Compl. gen 5	Compl. (%) gen 6(%)
1927	4	0.0	0.0	0.0	0.0	0.0	0.0
1929	6	33.3	16.7	11.1	8.3	6.7	5.6
1931	6	50.0	33.3	22.2	16.7	13.3	11.1
1933	2	100.0	66.7	47.2	35.4	28.3	23.6
1958	1	0.0	0.0	0.0	0.0	0.0	0.0
1959	2	0.0	0.0	0.0	0.0	0.0	0.0
1960	9	0.0	0.0	0.0	0.0	0.0	0.0
1961	4	25.0	12.5	8.3	6.2	5.0	4.2
1962	13	30.8	16.7	11.1	8.3	6.7	5.6
1963	22	9.1	5.3	3.5	2.6	2.1	1.8
1964	25	24.0	14.7	9.9	7.4	5.9	5.0
1965	34	32.4	17.9	12.0	9.0	7.2	6.0
1966	58	20.7	12.8	9.1	6.8	5.5	4.6
1967	75	24.0	16.8	11.7	8.8	7.0	5.9
1968	124	22.6	12.8	8.6	6.5	5.2	4.3
1969	193	18.6	11.3	8.0	6.1	4.9	4.0
1970	264	23.5	13.7	9.3	7.0	5.6	4.6
1971	1767	6.2	3.6	2.4	1.8	1.5	1.2
1972	1283	12.2	7.0	4.8	3.6	2.9	2.4
1973	1517	54.0	29.4	19.8	14.8	11.9	9.9
1974	1697	61.9	34.7	23.6	17.7	14.2	11.8
1975	1485	71.3	41.5	28.5	21.5	17.2	14.3
1976	2189	45.2	29.8	21.0	15.8	12.7	10.6
1977	1789	43.1	32.1	23.4	17.8	14.3	11.9
1978	2176	56.8	41.1	29.9	22.9	18.4	15.3
1979	2146	50.6	38.0	28.5	22.1	17.8	14.8
1980	2726	46.7	36.7	28.7	22.7	18.2	15.2

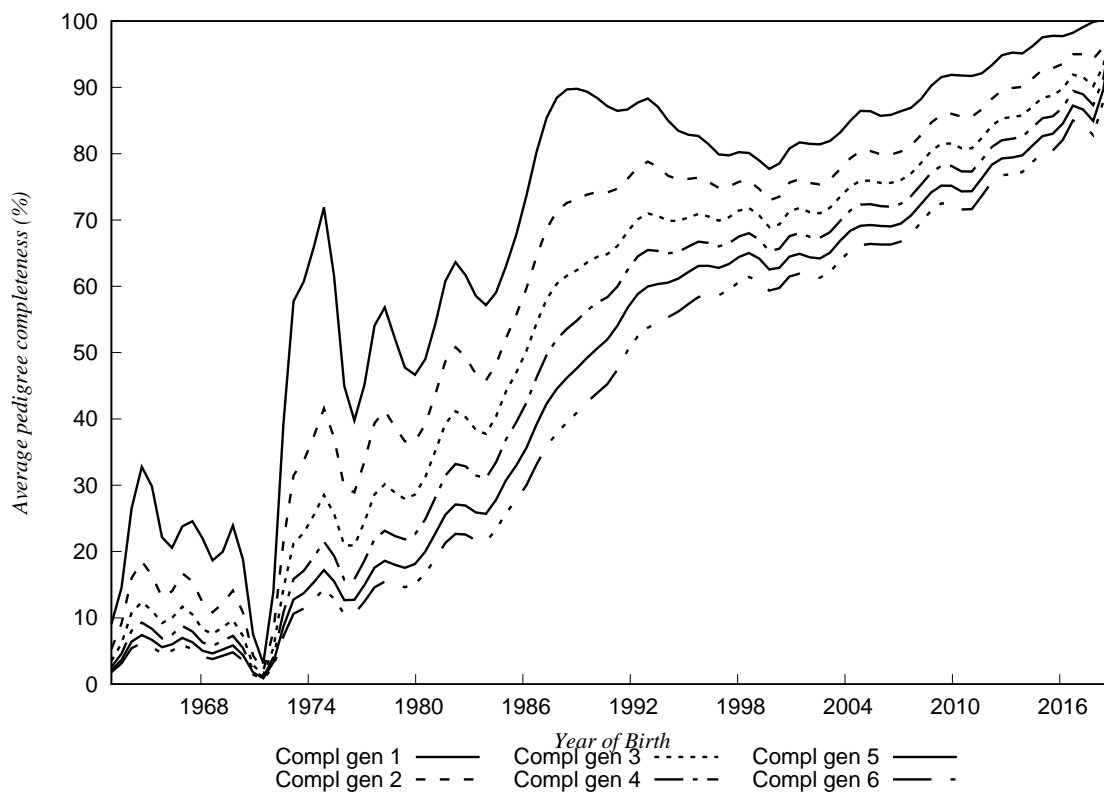
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Year	No of Animals	Compl. 1 gen	Compl. 2 gen	Compl. 3 gen	Compl. 4 gen	Compl. 5 gen	Compl. (%) 6 gen (%)
1981	2617	53.2	42.8	34.4	27.5	22.2	18.5
1982	2877	63.2	50.5	40.8	32.8	26.7	22.3
1983	2765	60.5	48.4	39.6	32.4	26.6	22.3
1984	3233	57.2	45.9	37.9	31.2	25.8	21.6
1985	3293	62.6	51.8	43.8	36.6	30.5	25.6
1986	3827	71.5	58.2	49.0	41.3	34.6	29.1
1987	4104	82.7	66.4	56.1	47.8	40.6	34.4
1988	4397	88.8	71.7	60.7	52.4	44.9	38.2
1989	3977	89.8	73.1	62.4	54.8	47.6	40.9
1990	3429	88.7	74.2	64.3	57.3	50.3	43.6
1991	3107	86.7	74.3	65.3	59.0	52.9	46.2
1992	3299	86.9	76.7	68.8	63.1	57.4	51.0
1993	3717	88.3	78.8	71.0	65.5	60.0	53.8
1994	3775	85.4	76.9	70.0	65.0	60.5	55.2
1995	3387	83.0	76.1	70.1	65.6	61.7	56.8
1996	2889	82.4	76.3	70.9	66.8	63.2	58.6
1997	2786	79.8	74.8	69.9	66.0	62.8	58.7
1998	2943	80.2	75.7	71.3	67.4	64.3	60.5
1999	2908	79.5	75.3	71.3	67.6	64.7	61.2
2000	3201	77.7	72.8	68.7	65.1	62.3	59.2
2001	3459	81.1	75.9	71.6	67.8	64.7	61.7
2002	3653	81.5	75.6	71.2	67.5	64.4	61.4
2003	3661	81.7	75.8	71.5	67.8	64.7	61.8
2004	3751	84.0	78.5	74.3	70.7	67.7	64.7
2005	4078	86.6	80.5	76.0	72.4	69.2	66.3
2006	4267	85.7	79.9	75.6	72.1	69.1	66.3
2007	4018	86.3	80.2	75.9	72.3	69.3	66.6
2008	3830	87.5	82.0	77.8	74.5	71.6	68.8
2009	3477	90.8	85.2	80.9	77.6	74.6	71.9
2010	3559	91.9	86.0	81.5	78.1	75.1	72.4
2011	3471	91.7	85.5	80.7	77.2	74.2	71.5
2012	3219	92.8	87.7	83.6	80.4	77.7	75.1
2013	3468	95.2	89.8	85.5	82.2	79.4	76.9
2014	3297	95.2	90.2	85.9	82.7	79.9	77.4
2015	3113	97.5	92.6	88.4	85.3	82.6	80.1
2016	2391	97.7	93.2	89.3	86.3	83.8	81.3
2017	1249	98.6	95.3	92.2	89.8	87.6	85.4
2018	131	100.0	94.4	90.4	87.6	85.3	83.2
2019	5	100.0	100.0	100.0	100.0	99.8	98.7



The average pedigree completeness for animals born within the last 10 years: 1 generations deep = 94.6%. 2 generations deep = 89.4%. 3 generations deep = 85.1%. 4 generations deep = 81.9%. 5 generations deep = 79.2%. 6 generations deep = 76.6%.

Figure 1: Average pedigree completeness for 1 to 6 generations



The figure above presents the average percentage of pedigree completeness for a pedigree depth of 1 to 6 generations by year of birth, between 1963 and 2019 for the 51 breed.

## 2 Inbreeding

### 2.1 Distribution of animals by year and inbreeding level

This section presents a distribution of animals by inbreeding levels and year of birth. Eleven inbreeding classes of size 5% were defined. The last inbreeding class included all animals with inbreeding coefficient  $>50\%$ . The number of animals by inbreeding class and year are given in the table.

Table 2: Distribution of animals by year and inbreeding levels

(Classes 1=0-5%, 2=6-10%, 3=11-15%, 4=16-20%, 5=21-25%, 6=26-30%, 7=31-35%, 8=36-40%, 9=41-45%, 10=46-50% and 11= $>50\%$ )

Year	Classes										
	1	2	3	4	5	6	7	8	9	10	11
1927	4	-	-	-	-	-	-	-	-	-	-
1929	6	-	-	-	-	-	-	-	-	-	-
1931	6	-	-	-	-	-	-	-	-	-	-
1933	2	-	-	-	-	-	-	-	-	-	-
1958	1	-	-	-	-	-	-	-	-	-	-
1959	2	-	-	-	-	-	-	-	-	-	-
1960	9	-	-	-	-	-	-	-	-	-	-
1961	4	-	-	-	-	-	-	-	-	-	-
1962	13	-	-	-	-	-	-	-	-	-	-
1963	22	-	-	-	-	-	-	-	-	-	-
1964	25	-	-	-	-	-	-	-	-	-	-
1965	34	-	-	-	-	-	-	-	-	-	-
1966	58	-	-	-	-	-	-	-	-	-	-
1967	74	-	1	-	-	-	-	-	-	-	-
1968	124	-	-	-	-	-	-	-	-	-	-
1969	190	1	1	-	1	-	-	-	-	-	-
1970	264	-	-	-	-	-	-	-	-	-	-
1971	1767	-	-	-	-	-	-	-	-	-	-
1972	1280	1	-	-	2	-	-	-	-	-	-
1973	1512	2	3	-	-	-	-	-	-	-	-
1974	1684	2	6	-	3	2	-	-	-	-	-
1975	1457	3	12	-	13	-	-	-	-	-	-
1976	2152	4	21	-	12	-	-	-	-	-	-
1977	1751	11	21	-	6	-	-	-	-	-	-
1978	2120	21	24	4	5	2	-	-	-	-	-
1979	2080	17	14	12	20	1	2	-	-	-	-
1980	2632	30	28	20	14	-	1	-	1	-	-
1981	2506	40	35	9	20	3	1	-	2	1	-
1982	2773	37	29	10	19	6	2	1	-	-	-
1983	2656	34	31	11	22	9	2	-	-	-	-
1984	3138	29	31	3	24	7	1	-	-	-	-
1985	3139	58	36	13	41	4	2	-	-	-	-
1986	3615	84	46	20	52	5	4	1	-	-	-
1987	3847	100	47	13	71	12	13	-	1	-	-
1988	4147	99	40	13	60	25	9	3	1	-	-
1989	3777	85	30	18	47	19	1	-	-	-	-
1990	3218	89	34	20	42	22	-	4	-	-	-

*Continue...*

Year	Classes										
	1	2	3	4	5	6	7	8	9	10	11
1991	2930	78	27	11	24	32	3	2	-	-	-
1992	3050	113	56	17	24	31	7	1	-	-	-
1993	3407	169	48	29	30	30	4	-	-	-	-
1994	3505	142	48	17	29	31	2	1	-	-	-
1995	3110	126	67	17	18	43	3	2	1	-	-
1996	2649	145	34	8	14	34	5	-	-	-	-
1997	2507	170	42	14	7	43	3	-	-	-	-
1998	2656	161	71	16	3	35	1	-	-	-	-
1999	2588	211	50	17	2	36	-	2	2	-	-
2000	2949	148	34	18	4	45	1	1	1	-	-
2001	3165	175	43	9	1	61	1	2	2	-	-
2002	3350	179	42	12	3	59	5	3	-	-	-
2003	3367	189	44	19	4	37	1	-	-	-	-
2004	3405	205	41	18	14	65	2	1	-	-	-
2005	3658	250	67	17	13	68	3	2	-	-	-
2006	3806	267	77	28	8	78	2	1	-	-	-
2007	3562	262	88	26	11	64	3	2	-	-	-
2008	3367	283	72	24	14	69	1	-	-	-	-
2009	2969	318	74	20	9	85	-	2	-	-	-
2010	3147	281	51	16	2	59	2	1	-	-	-
2011	3016	290	65	23	5	69	1	2	-	-	-
2012	2769	311	59	19	3	56	2	-	-	-	-
2013	3002	330	55	17	1	59	2	-	1	1	-
2014	2854	316	43	24	2	57	1	-	-	-	-
2015	2655	296	49	27	2	80	-	4	-	-	-
2016	1990	264	41	26	3	63	3	1	-	-	-
2017	1040	157	14	13	1	24	-	-	-	-	-
2018	106	20	3	1	1	-	-	-	-	-	-
2019	5	-	-	-	-	-	-	-	-	-	-

## 2.2 Number of *all* and *inbred* animals, sires and dams by year

This section presents the number of *all* and *inbred* animals, sires and dams by year. The following information is given in the table for all animals, sires and dams:

a given year.

**Inbred No.** : the number of inbred animals / sires / dams in a given year.

**Tot No.** : the number of animals / sires / dams in a given year. **Avg  $F$**  : the average inbreeding coefficient.

Table 3: Numbers and average inbreeding of animals and parents by year

Year	Animals			Sires			Dams		
	Tot No	Inbred No	Avg $F$	Tot No	Inbred No	Avg $F$	Tot No	Inbred No	Avg $F$
1927	4	-	-	-	-	-	-	-	-
1929	6	-	-	2	-	-	2	-	-
1931	6	-	-	3	-	-	3	-	-
1933	2	-	-	2	-	-	2	-	-
1958	1	-	-	-	-	-	-	-	-
1959	2	-	-	-	-	-	-	-	-
1960	9	-	-	1	-	-	-	-	-
1961	4	-	-	1	-	-	1	-	-
1962	13	-	-	5	-	-	4	-	-
1963	22	-	-	2	-	-	2	-	-
1964	25	-	-	7	-	-	6	-	-
1965	34	-	-	10	-	-	12	-	-
1966	58	-	-	12	-	-	12	-	-
1967	75	1	0.0017	16	-	-	18	-	-
1968	124	-	-	28	-	-	32	-	-
1969	193	4	0.0024	31	-	-	38	1	0.0033
1970	264	-	-	52	-	-	64	-	-
1971	1767	-	-	73	2	0.0021	110	1	0.0023
1972	1283	3	0.0004	91	1	0.0014	159	-	-
1973	1517	5	0.0003	212	1	0.0006	816	-	-
1974	1697	14	0.0013	265	2	0.0014	1046	3	0.0004
1975	1485	29	0.0034	262	2	0.0010	1041	2	0.0002
1976	2189	39	0.0027	216	3	0.0023	974	5	0.0007
1977	1789	47	0.0029	207	5	0.0042	762	5	0.0008
1978	2176	66	0.0033	268	11	0.0073	1219	13	0.0013
1979	2146	78	0.0052	237	15	0.0088	1079	21	0.0029
1980	2726	137	0.0052	235	19	0.0095	1268	29	0.0028
1981	2617	184	0.0068	232	21	0.0101	1375	41	0.0032
1982	2877	195	0.0059	253	38	0.0164	1792	58	0.0038
1983	2765	209	0.0068	247	45	0.0181	1659	70	0.0044
1984	3233	244	0.0054	253	55	0.0217	1831	61	0.0035
1985	3293	339	0.0080	230	58	0.0242	2083	98	0.0044
1986	3827	435	0.0093	246	70	0.0256	2739	128	0.0044
1987	4104	659	0.0115	303	92	0.0235	3388	186	0.0040
1988	4397	878	0.0112	317	107	0.0252	3891	228	0.0047
1989	3977	850	0.0099	319	123	0.0294	3577	265	0.0057
1990	3429	874	0.0123	276	125	0.0326	3056	301	0.0077
1991	3107	971	0.0128	261	135	0.0377	2740	343	0.0077
1992	3299	1371	0.0157	293	171	0.0388	2915	470	0.0105

*Continue...*

Year	Animal			Sires			Dams		
	Tot No	Inbred No	Avg <i>F</i>	Tot No	Inbred No	Avg <i>F</i>	Tot No	Inbred No	Avg <i>F</i>
1993	3717	1730	0.0164	287	170	0.0356	3312	540	0.0087
1994	3775	1943	0.0164	285	189	0.0331	3317	661	0.0101
1995	3387	1864	0.0186	266	197	0.0342	2916	729	0.0117
1996	2889	1701	0.0186	288	223	0.0324	2481	738	0.0130
1997	2786	1698	0.0210	281	235	0.0344	2279	797	0.0135
1998	2943	1875	0.0206	300	260	0.0317	2421	959	0.0144
1999	2908	1897	0.0216	294	269	0.0314	2488	1103	0.0156
2000	3201	1978	0.0195	306	282	0.0287	2670	1220	0.0149
2001	3459	2238	0.0212	343	323	0.0294	3029	1474	0.0159
2002	3653	2321	0.0206	356	341	0.0298	3240	1573	0.0163
2003	3661	2348	0.0195	379	364	0.0284	3274	1654	0.0172
2004	3751	2546	0.0232	399	389	0.0290	3423	1867	0.0177
2005	4078	2790	0.0244	446	435	0.0280	3773	2065	0.0177
2006	4267	2935	0.0252	480	472	0.0291	3977	2214	0.0171
2007	4018	2750	0.0257	518	513	0.0288	3753	2124	0.0190
2008	3830	2722	0.0265	528	520	0.0273	3622	2149	0.0202
2009	3477	2578	0.0300	554	547	0.0311	3302	2001	0.0217
2010	3559	2624	0.0266	592	587	0.0314	3411	2022	0.0210
2011	3471	2527	0.0284	610	607	0.0312	3355	1897	0.0196
2012	3219	2479	0.0297	598	595	0.0324	3108	1948	0.0219
2013	3468	2726	0.0297	634	632	0.0326	3380	2100	0.0225
2014	3297	2626	0.0300	634	632	0.0338	3234	2014	0.0222
2015	3113	2561	0.0344	629	627	0.0333	3072	1986	0.0241
2016	2391	2005	0.0363	568	565	0.0329	2365	1599	0.0245
2017	1249	1105	0.0366	399	397	0.0351	1235	917	0.0274
2018	131	108	0.0344	65	65	0.0353	131	94	0.0257
2019	5	5	0.0376	5	5	0.0357	5	5	0.0394

### 2.3 Descriptive statistics of inbreeding coefficients of *all* animals by year

This section presents the summary statistics of inbreeding coefficients of *all* animals born in a given year. The columns in the table are:

**No. of animals** : all animals born in a given year.

**Min** : the lowest inbreeding coefficient.

**Max** : the highest inbreeding coefficient.

**Avg  $F$**  : the mean inbreeding coefficient.

**Std** : the standard deviation of inbreeding coefficients.

Table 4: Inbreeding coefficients ( $F$ ) of ALL animals by year

Year	No of Animals	$F$			
		Min	Max	Avg	Std
1927	4	0.0000	0.0000	0.0000	0.0000
1929	6	0.0000	0.0000	0.0000	0.0000
1931	6	0.0000	0.0000	0.0000	0.0000
1933	2	0.0000	0.0000	0.0000	0.0000
1958	1	0.0000	0.0000	0.0000	-
1959	2	0.0000	0.0000	0.0000	0.0000
1960	9	0.0000	0.0000	0.0000	0.0000
1961	4	0.0000	0.0000	0.0000	0.0000
1962	13	0.0000	0.0000	0.0000	0.0000
1963	22	0.0000	0.0000	0.0000	0.0000
1964	25	0.0000	0.0000	0.0000	0.0000
1965	34	0.0000	0.0000	0.0000	0.0000
1966	58	0.0000	0.0000	0.0000	0.0000
1967	75	0.0000	0.1250	0.0017	0.0144
1968	124	0.0000	0.0000	0.0000	0.0000
1969	193	0.0000	0.2500	0.0024	0.0206
1970	264	0.0000	0.0000	0.0000	0.0000
1971	1767	0.0000	0.0000	0.0000	0.0000
1972	1283	0.0000	0.2500	0.0004	0.0100
1973	1517	0.0000	0.1250	0.0003	0.0060
1974	1697	0.0000	0.2813	0.0013	0.0162
1975	1485	0.0000	0.2500	0.0034	0.0260
1976	2189	0.0000	0.2500	0.0027	0.0221
1977	1789	0.0000	0.2500	0.0029	0.0204
1978	2176	0.0000	0.2813	0.0033	0.0219
1979	2146	0.0000	0.3125	0.0052	0.0314
1980	2726	0.0000	0.4063	0.0052	0.0288
1981	2617	0.0000	0.4531	0.0068	0.0340
1982	2877	0.0000	0.3750	0.0059	0.0310
1983	2765	0.0000	0.3125	0.0068	0.0335
1984	3233	0.0000	0.3125	0.0054	0.0292
1985	3293	0.0000	0.3125	0.0080	0.0356
1986	3827	0.0000	0.3750	0.0093	0.0386
1987	4104	0.0000	0.4063	0.0115	0.0440
1988	4397	0.0000	0.4063	0.0112	0.0430
1989	3977	0.0000	0.3394	0.0099	0.0376
1990	3429	0.0000	0.3948	0.0123	0.0422
1991	3107	0.0000	0.3750	0.0128	0.0413
1992	3299	0.0000	0.3750	0.0157	0.0430

*Continue...*

Year	No of Animals	<i>F</i>			
		Min	Max	Avg	Std
1993	3717	0.0000	0.3145	0.0164	0.0416
1994	3775	0.0000	0.3679	0.0164	0.0394
1995	3387	0.0000	0.4102	0.0186	0.0439
1996	2889	0.0000	0.3203	0.0186	0.0407
1997	2786	0.0000	0.3203	0.0210	0.0429
1998	2943	0.0000	0.3213	0.0206	0.0391
1999	2908	0.0000	0.4402	0.0216	0.0412
2000	3201	0.0000	0.4023	0.0195	0.0398
2001	3459	0.0000	0.4023	0.0212	0.0426
2002	3653	0.0000	0.3857	0.0206	0.0421
2003	3661	0.0000	0.3140	0.0195	0.0358
2004	3751	0.0000	0.3746	0.0232	0.0431
2005	4078	0.0000	0.3927	0.0244	0.0435
2006	4267	0.0000	0.3844	0.0252	0.0439
2007	4018	0.0000	0.3806	0.0257	0.0440
2008	3830	0.0000	0.3109	0.0265	0.0438
2009	3477	0.0000	0.3818	0.0300	0.0480
2010	3559	0.0000	0.3817	0.0266	0.0412
2011	3471	0.0000	0.3822	0.0284	0.0446
2012	3219	0.0000	0.3131	0.0297	0.0423
2013	3468	0.0000	0.4724	0.0297	0.0419
2014	3297	0.0000	0.3148	0.0300	0.0411
2015	3113	0.0000	0.3906	0.0344	0.0479
2016	2391	0.0000	0.3860	0.0363	0.0490
2017	1249	0.0000	0.2916	0.0366	0.0421
2018	131	0.0000	0.2120	0.0344	0.0327
2019	5	0.0297	0.0467	0.0376	0.0065

## 2.4 Descriptive statistics of inbreeding coefficient of *inbred* animals by year

This section presents the summary statistics of inbreeding coefficients of *inbred* animals by year of birth. The columns in the table are:

**No. of animals** : all *inbred* animals born in a given year.

**Min** : the lowest inbreeding coefficient among in-

bred animals.

**Max** : the highest inbreeding coefficient.

**Avg  $F$**  : the mean inbreeding coefficient.

**Std** : the standard deviation of inbreeding coefficients.

Table 5: Inbreeding coefficients ( $F$ ) of INBRED animals by year

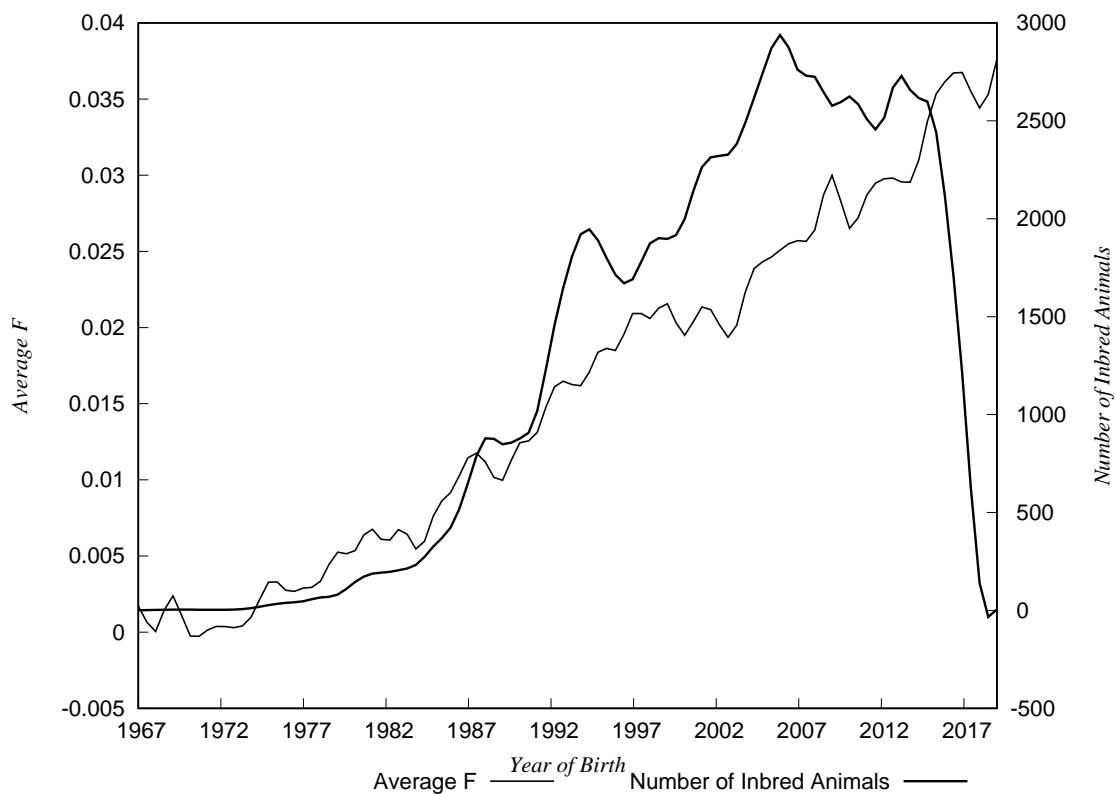
Year	No of Animals	$F$			
		Min	Max	Avg	Std
1967	1	0.1250	0.1250	0.1250	-
1969	4	0.0313	0.2500	0.1172	0.0967
1972	3	0.0625	0.2500	0.1875	0.1083
1973	5	0.0625	0.1250	0.1000	0.0342
1974	14	0.0313	0.2813	0.1585	0.0862
1975	29	0.0313	0.2500	0.1721	0.0748
1976	39	0.0078	0.2500	0.1508	0.0712
1977	47	0.0313	0.2500	0.1090	0.0660
1978	66	0.0039	0.2813	0.1083	0.0672
1979	78	0.0078	0.3125	0.1425	0.0874
1980	137	0.0039	0.4063	0.1041	0.0793
1981	184	0.0039	0.4531	0.0963	0.0888
1982	195	0.0020	0.3750	0.0871	0.0844
1983	209	0.0010	0.3125	0.0898	0.0863
1984	244	0.0001	0.3125	0.0719	0.0807
1985	339	0.0015	0.3125	0.0778	0.0833
1986	435	0.0010	0.3750	0.0815	0.0852
1987	659	0.0005	0.4063	0.0715	0.0881
1988	878	0.0001	0.4063	0.0559	0.0822
1989	850	0.0001	0.3394	0.0463	0.0701
1990	874	0.0001	0.3948	0.0481	0.0726
1991	971	0.0002	0.3750	0.0409	0.0657
1992	1371	0.0001	0.3750	0.0378	0.0602
1993	1730	0.0001	0.3145	0.0352	0.0553
1994	1943	0.0001	0.3679	0.0319	0.0503
1995	1864	0.0001	0.4102	0.0338	0.0546
1996	1701	0.0001	0.3203	0.0315	0.0491
1997	1698	0.0001	0.3203	0.0344	0.0506
1998	1875	0.0000	0.3213	0.0323	0.0450
1999	1897	0.0001	0.4402	0.0331	0.0472
2000	1978	0.0001	0.4023	0.0315	0.0468
2001	2238	0.0001	0.4023	0.0328	0.0493
2002	2321	0.0001	0.3857	0.0324	0.0490
2003	2348	0.0001	0.3140	0.0304	0.0408
2004	2546	0.0003	0.3746	0.0342	0.0485
2005	2790	0.0000	0.3927	0.0357	0.0487
2006	2935	0.0000	0.3844	0.0367	0.0488
2007	2750	0.0001	0.3806	0.0376	0.0488



Continue...

Year	No of Animals	<i>F</i>			
		Min	Max	Avg	Std
2008	2722	0.0008	0.3109	0.0373	0.0479
2009	2578	0.0002	0.3818	0.0404	0.0518
2010	2624	0.0002	0.3817	0.0361	0.0442
2011	2527	0.0001	0.3822	0.0390	0.0481
2012	2479	0.0010	0.3131	0.0385	0.0445
2013	2726	0.0008	0.4724	0.0378	0.0439
2014	2626	0.0005	0.3148	0.0377	0.0428
2015	2561	0.0006	0.3906	0.0418	0.0498
2016	2005	0.0011	0.3860	0.0433	0.0506
2017	1105	0.0018	0.2916	0.0414	0.0424
2018	108	0.0052	0.2120	0.0417	0.0315
2019	5	0.0297	0.0467	0.0376	0.0065

Figure 2: Comparison between the average inbreeding coefficients (*F*) and the number of inbred animals by year



### 3 Effective Population Size

#### 3.1 Effective Population Size based on the rate of inbreeding

Effective population size ( $N_e$ ) is the number of individuals that would give rise to the observed or calculated rate of inbreeding ( $\Delta F$ ), if they bred in the manner of the idealized population (Falconer & Mackay, 1996). The  $N_e$  is a a measure of genetic diversity within a population. It is therefore an important parameter in breeding of domestic animals and planning strategies for conservation of endangered animal and plant species (Nomura, 2002). This section presents effective population size calculated using  $N_e = 1/2\Delta F$ . The rate of inbreeding per generation ( $\Delta F$ ) was calculated using

$$\Delta F = \frac{F_t - F_{t-1}}{1 - F_{t-1}}$$

where  $F_t$  and  $F_{t-1}$  are the average inbreeding of offspring and their parents, respectively (Falconer & Mackay, 1996). The columns in the table are:

**Avg  $F$  Animals** : average inbreeding coefficient for animals born in a given year.

**Avg  $F$  Sires** : average inbreeding coefficient for sires of animals born in a given year.

**Avg  $F$  Dams** : average inbreeding coefficient for dams of animals born in a given year.

**Avg  $F$  Parents** : average inbreeding coefficient for sires and dams of animals born in a given year.

$\Delta F$  : the rate of inbreeding per generation.

$N_e$  : the effective population size.

*Note:* The effective population size was not computed for  $\Delta F = 0$  since it is undefined.

Table 6: Effective population size by year via rate of inbreeding

Year	Avg $F$				$\Delta F$	$N_e$
	Animals	Sires	Dams	Parents		
1927	-	-	-	-	-	-
1929	0.0000	0.0000	0.0000	0.0000	0.0000	-
1931	0.0000	0.0000	0.0000	0.0000	0.0000	-
1933	0.0000	0.0000	0.0000	0.0000	0.0000	-
1958	-	-	-	-	-	-
1959	-	-	-	-	-	-
1960	0.0000	0.0000	0.0000	0.0000	-	-
1961	0.0000	0.0000	0.0000	0.0000	0.0000	-
1962	0.0000	0.0000	0.0000	0.0000	0.0000	-
1963	0.0000	0.0000	0.0000	0.0000	0.0000	-
1964	0.0000	0.0000	0.0000	0.0000	0.0000	-
1965	0.0000	0.0000	0.0000	0.0000	0.0000	-
1966	0.0000	0.0000	0.0000	0.0000	0.0000	-
1967	0.0005	0.0000	0.0000	0.0000	0.0005	924
1968	0.0004	0.0000	0.0000	0.0000	0.0004	1404
1969	0.0011	0.0000	0.0010	0.0005	0.0006	852
1970	0.0008	0.0000	0.0007	0.0003	0.0004	1188
1971	0.0002	0.0019	0.0013	0.0016	-0.0014	-367
1972	0.0003	0.0027	0.0009	0.0018	-0.0015	-341
1973	0.0003	0.0014	0.0003	0.0009	-0.0006	-906
1974	0.0005	0.0009	0.0003	0.0006	-0.0001	-5498
1975	0.0011	0.0007	0.0003	0.0005	0.0006	893
1976	0.0014	0.0009	0.0004	0.0006	0.0008	654
1977	0.0016	0.0016	0.0004	0.0010	0.0006	790
1978	0.0022	0.0030	0.0006	0.0018	0.0004	1236

*Continue...*

Year	Avg $F$		Dams	Parents	$\Delta F$	$N_e$
	Animals	Sires				
1979	0.0028	0.0045	0.0009	0.0027	0.0001	3614
1980	0.0036	0.0076	0.0014	0.0045	-0.0009	-551
1981	0.0044	0.0106	0.0018	0.0062	-0.0018	-272
1982	0.0047	0.0128	0.0024	0.0076	-0.0029	-171
1983	0.0053	0.0143	0.0030	0.0086	-0.0033	-151
1984	0.0056	0.0146	0.0032	0.0089	-0.0034	-149
1985	0.0062	0.0156	0.0036	0.0096	-0.0034	-146
1986	0.0069	0.0160	0.0039	0.0099	-0.0031	-164
1987	0.0079	0.0157	0.0040	0.0098	-0.0019	-258
1988	0.0086	0.0162	0.0042	0.0102	-0.0016	-318
1989	0.0091	0.0191	0.0045	0.0118	-0.0027	-186
1990	0.0098	0.0213	0.0050	0.0131	-0.0034	-149
1991	0.0107	0.0237	0.0055	0.0145	-0.0039	-129
1992	0.0117	0.0256	0.0062	0.0158	-0.0042	-118
1993	0.0127	0.0273	0.0068	0.0170	-0.0044	-115
1994	0.0134	0.0289	0.0077	0.0182	-0.0049	-103
1995	0.0145	0.0304	0.0088	0.0195	-0.0050	-99
1996	0.0158	0.0297	0.0098	0.0196	-0.0039	-128
1997	0.0170	0.0294	0.0106	0.0198	-0.0029	-172
1998	0.0180	0.0283	0.0114	0.0197	-0.0018	-283
1999	0.0188	0.0274	0.0121	0.0196	-0.0008	-598
2000	0.0193	0.0271	0.0131	0.0200	-0.0007	-752
2001	0.0201	0.0269	0.0141	0.0203	-0.0002	-2436
2002	0.0204	0.0266	0.0149	0.0206	-0.0001	-3796
2003	0.0205	0.0261	0.0155	0.0206	-0.0001	-5694
2004	0.0209	0.0250	0.0161	0.0204	0.0005	933
2005	0.0215	0.0248	0.0166	0.0205	0.0011	472
2006	0.0221	0.0242	0.0168	0.0203	0.0018	273
2007	0.0230	0.0239	0.0173	0.0204	0.0026	192
2008	0.0237	0.0237	0.0179	0.0207	0.0031	163
2009	0.0249	0.0240	0.0186	0.0212	0.0038	131
2010	0.0259	0.0248	0.0191	0.0219	0.0041	121
2011	0.0266	0.0259	0.0194	0.0225	0.0042	120
2012	0.0273	0.0267	0.0200	0.0232	0.0042	120
2013	0.0280	0.0279	0.0208	0.0243	0.0038	131
2014	0.0286	0.0292	0.0213	0.0252	0.0036	140
2015	0.0297	0.0304	0.0218	0.0261	0.0038	132
2016	0.0304	0.0312	0.0221	0.0266	0.0039	128
2017	0.0315	0.0318	0.0227	0.0272	0.0044	114
2018	0.0321	0.0323	0.0233	0.0278	0.0045	112
2019	0.0327	0.0328	0.0236	0.0282	0.0046	108

### 3.2 Effective population size based on the number of parents

This section presents the effective population size calculated based on the number of parents. The following formula was used to calculate  $N_e$  (Falconer & Mackay, 1996):

$$N_e = \frac{4N_m N_f}{N_m + N_f} * .7$$

where  $N_m$  and  $N_f$  are the number of male and female parents, respectively.

Accounting for mass selection as proposed by Caballero (1994) yields the added factor of .7 assuming that selection is on a trait with a heritability of .4 .

The above formula refers to the number of breeding males and females in a population with discrete generations. Here, we identify a generation of animals as those animals born in the time span of one generation interval (GI window) which ends in the reporting year. The parents of animals born in this GI window are then entered in the above equation to compute the  $N_e$  for each reporting year as listed in the table.

Thus, a sliding window will run over the years

counting all animals born in that window and their sires and dams. To obtain the number of years involved in that GI window go to the population report and find the total generation interval which is the last figure at the bottom of table 5.

This setup implies that the number of parents in consecutive reporting years will include, in part, to the same animals.

The columns in the table are:

**Number of animals :** born in GI window ending in the reporting year

**Number of sires :** of animals born in the GI window

**Number of dams :** of animals born in the GI window

**Number of parents :** number of sires plus dams of animals born in the GI window

**Ne :** effective population size in the reporting year

Table 7: Effective population size by year via number of parents

Year	Number of				$N_e$
	Animals	Sires	Dams	Parents	
1927	4	1	1	2	1
1929	10	3	3	6	4
1931	16	6	6	12	8
1933	18	8	8	16	11
1958	1	1	1	2	1
1959	3	1	1	2	1
1960	12	2	1	3	2
1961	16	3	2	5	3
1962	29	8	6	14	10
1963	51	10	8	18	12
1964	76	15	14	29	20
1965	109	23	26	49	34
1966	165	35	38	73	51
1967	231	48	56	104	72
1968	351	68	86	154	106
1969	531	89	118	207	142
1970	773	125	177	302	205
1971	2515	173	278	451	299
1972	3764	222	422	644	407
1973	5223	366	1196	1562	785
1974	6845	482	2080	2562	1096
1975	8206	577	2896	3473	1347

*Continue...*

Year	Number of				$N_e$
	Animals	Sires	Dams	Parents	
1976	10202	648	3639	4287	1540
1977	11727	702	4099	4801	1678
1978	12136	802	4955	5757	1933
1979	12999	852	5636	6488	2072
1980	14208	862	5960	6822	2109
1981	15128	849	6194	7043	2091
1982	16520	815	6765	7580	2037
1983	17096	811	7264	8075	2043
1984	18540	818	8082	8900	2080
1985	19657	775	8699	9474	1992
1986	21338	770	10004	10774	2002
1987	22716	783	11633	12416	2054
1988	24496	811	13514	14325	2142
1989	25596	833	14754	15587	2208
1990	26260	838	15722	16560	2228
1991	26134	841	16325	17166	2239
1992	26140	897	16958	17855	2385
1993	26030	929	17360	18289	2469
1994	25701	927	17265	18192	2463
1995	24691	899	16543	17442	2387
1996	23603	888	15613	16501	2353
1997	22960	864	14976	15840	2287
1998	22796	870	14749	15619	2300
1999	22405	844	14464	15308	2233
2000	21889	840	14051	14891	2219
2001	21573	851	13808	14659	2244
2002	21839	868	13950	14818	2288
2003	22611	900	14341	15241	2371
2004	23576	946	15055	16001	2492
2005	24711	988	15891	16879	2604
2006	26070	1063	16856	17919	2800
2007	26887	1139	17565	18704	2995
2008	27258	1201	17971	19172	3152
2009	27082	1286	18092	19378	3362
2010	26980	1358	18275	19633	3539
2011	26700	1419	18311	19730	3687
2012	25841	1478	17898	19376	3823
2013	25042	1536	17562	19098	3955
2014	24321	1567	17279	18846	4023
2015	23604	1617	16855	18472	4131
2016	22518	1640	16265	17905	4171
2017	20208	1604	14911	16515	4055
2018	16868	1463	12891	14354	3679
2019	13654	1304	10898	12202	3261

## 4 The Average and Rate of Additive Genetic Relationships by year

The coefficient of inbreeding ( $F$ ) of an individual is equal to the additive genetic relationship (AGR) between its parents or the coefficient of co-ancestry *i.e.*  $F_i = f_{sd}$  where  $i$  is the individual and  $s$  and  $d$  are its sire and dam respectively (Falconer & Mackay, 1996). Under random mating, the rate of inbreeding ( $\Delta F$ ) is equal to the rate of additive genetic relationships ( $\Delta f$ ). Thus, the effective size ( $Ne$ ) can be obtained from either  $\frac{1}{2\Delta F}$  or  $\frac{1}{2\Delta f}$ . Therefore, the discrepancy between the two effective sizes indicates a deviation from a random mating system.

In this report, the additive genetic relationships were computed using the PEDIG Fortran Package of Boichard (2002) and specifically the *par3.f* program (see the PEDIG manual for details). Briefly, the average additive genetic relationship among individuals within a group (*e.g.* animals born in a given year) is computed as the average inbreeding of the progeny of all possible matings among the individuals. Two steps were followed to calculate the rate of AGR ( $\Delta f$ ) per generation or for animals born in a given year and a generation earlier. Firstly, the generation interval for animals born in a given year was calculated as the average age of their parents they were born. Secondly, the generation interval was subtracted from the year of birth of the current cohort to obtain the year of birth of the cohort born a generation earlier. Thus, the rate of additive genetic relationship is:

$$\Delta f = \frac{f_t - f_{t-1}}{1 - f_{t-1}}$$

where  $f_t$  and  $f_{t-1}$  are the average additive genetic relationship of the cohort born in generation  $t$  (or

the current year) and the cohort born a generation earlier.

The number of animals born in the cohort beginning with the reporting year year as well their average AGR and inbreeding and their rate is presented in the Table. Notice that the AGR value reported is the average of all possible matings between males and females in the cohort. Thus, with 1000 males and 2000 females in the cohort this average is based on  $1000 * 2000 = 2000000$  additive genetic relationships. The generation interval between this cohort and their parents is also presented. The average and rate of inbreeding and AGR are also presented in the Figures below. The effective population size based on the rate of AGR (computed as a regression of AGR on year) over the entire period is also presented.

**Note:** Due to computer hardware constraints, datasets with huge numbers of animals will be shortened preventing weeks of computation. The currently implemented algorithm is based on the number of acceptable computations in terms of CPU time:

$$2000male * 2000female = 4000000computations$$

This should give a sufficiently precise estimate of the average AGR.

Operationally, from cohorts larger than 2000 males and 2000 females 2000 males and 2000 females as picked through a random number generator, thereby cutting the files to be processed down to a size which can computationally be handled.

The affected years will be documented in the coverpages of this report. Please refer to this information.

Table 8: Average Additive Genetic Relationships (AGR)

Year	No Animals	AGR		$F$		Generation Interval
		Avg	$\Delta f$	Avg	$\Delta F$	( ) = True GI
1927	4	0.00000	-	0.00000	-	-
1929	10	0.02000	-	0.00000	-	2 (2.0)
1931	16	0.02344	-	0.00000	-	-
1933	18	0.02969	-	0.00000	-	-
1944	-	-	-	-	-	-
1945	-	-	-	-	-	-
1946	-	-	-	-	-	-
1947	-	-	-	-	-	-
1948	-	-	-	-	-	-
1949	-	-	-	-	-	-

*Continue...*

Year	No Animals	AGR		F		Generation Interval
		Avg	$\Delta f$	Avg	$\Delta F$	() = True GI
1950		--	-	-	-	-
1951		--	-	-	-	-
1952		--	-	-	-	-
1953		--	-	-	-	-
1954		--	-	-	-	-
1955		--	-	-	-	-
1956		--	-	-	-	-
1957		--	-	-	-	-
1958	1	0.00000	-	0.00000	-	-
1959	3	0.00000	-	0.00000	-	-
1960	12	0.00694	-	0.00000	-	-
1961	16	0.00781	-	0.00000	-	-
1962	29	0.00721	-	0.00000	-	5 (5.0)
1963	51	0.00343	-	0.00000	-	-
1964	76	0.00320	-	0.00000	-	2 (2.2)
1965	109	0.00270	0.00270	0.00000	0.00000	6 (6.4)
1966	165	0.00172	0.00172	0.00000	0.00000	2 (2.0)
1967	231	0.00135	-0.00563	0.00170	0.00170	2 (2.2)
1968	351	0.00091	-0.00696	0.00000	0.00000	2 (2.1)
1969	531	0.00058	-0.00668	0.00240	0.00240	3 (3.1)
1970	773	0.00042	-0.00302	0.00000	0.00000	4 (4.4)
1971	2515	0.00010	-0.00311	0.00000	0.00000	4 (4.3)
1972	3764	0.00007	-0.00263	0.00040	0.00040	4 (4.3)
1973	5223	0.00017	-0.00155	0.00030	0.00030	4 (4.2)
1974	6127	0.00024	-0.00111	0.00130	-0.00040	4 (4.4)
1975	5758	0.00033	-0.00058	0.00340	0.00340	5 (4.8)
1976	5417	0.00038	-0.00020	0.00270	0.00030	5 (5.1)
1977	5174	0.00046	0.00004	0.00290	0.00290	5 (5.4)
1978	5372	0.00062	0.00052	0.00330	0.00330	5 (5.2)
1979	5413	0.00082	0.00074	0.00520	0.00480	5 (5.2)
1980	5602	0.00094	0.00077	0.00520	0.00490	5 (5.3)
1981	5816	0.00129	0.00105	0.00680	0.00551	5 (5.2)
1982	5753	0.00166	0.00133	0.00590	0.00251	5 (5.3)
1983	5853	0.00207	0.00169	0.00680	0.00411	6 (5.5)
1984	5795	0.00248	0.00202	0.00540	0.00251	6 (5.5)
1985	5832	0.00314	0.00252	0.00800	0.00472	6 (5.7)
1986	5790	0.00385	0.00304	0.00930	0.00412	6 (6.0)
1987	5664	0.00496	0.00402	0.01150	0.00633	6 (6.0)
1988	5602	0.00611	0.00482	0.01120	0.00443	6 (5.9)
1989	5533	0.00753	0.00588	0.00990	0.00402	6 (6.0)
1990	5442	0.00823	0.00618	0.01230	0.00554	6 (6.2)
1991	5560	0.00999	0.00753	0.01280	0.00744	6 (6.1)
1992	5644	0.01124	0.00813	0.01570	0.00776	6 (5.5)
1993	5673	0.01327	0.00945	0.01640	0.00717	6 (5.5)
1994	5753	0.01498	0.01008	0.01640	0.00496	5 (5.3)
1995	5774	0.01689	0.01085	0.01860	0.00748	6 (5.6)
1996	5982	0.01795	0.01050	0.01860	0.00879	6 (5.6)
1997	6164	0.01955	0.01141	0.02100	0.00881	6 (5.6)

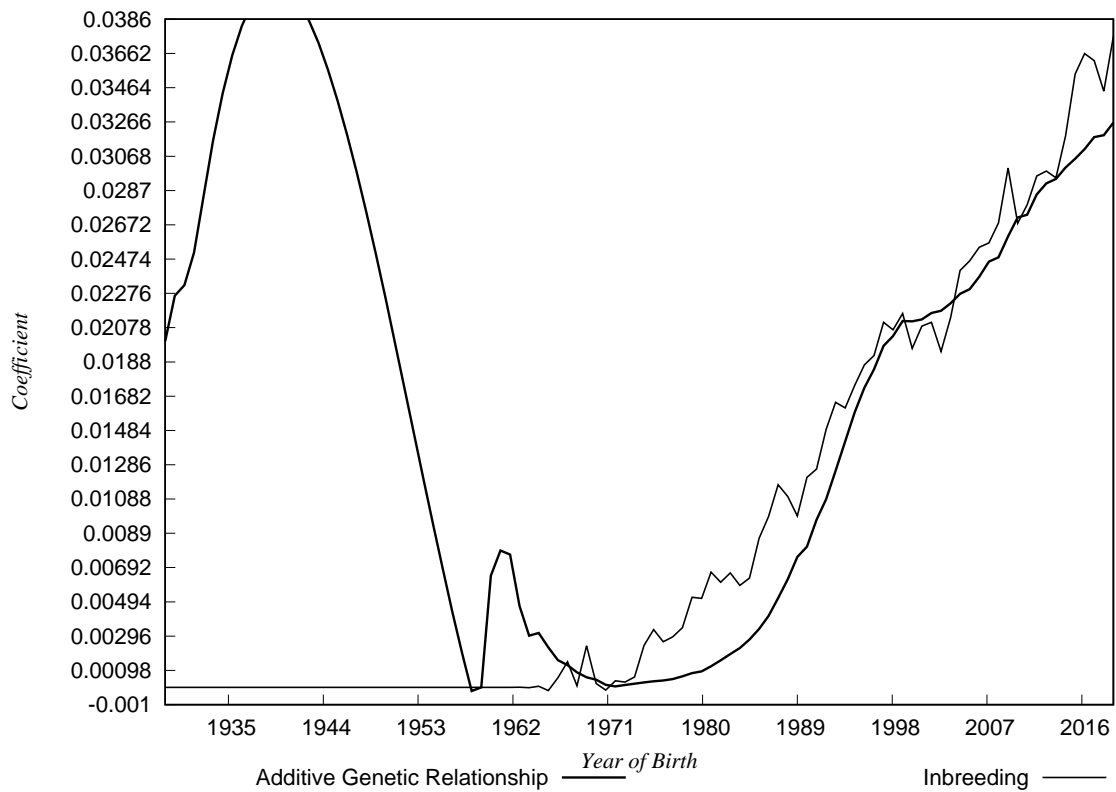
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Year	No Animals	AGR		<i>F</i>		Generation Interval
		Avg	$\Delta f$	Avg	$\Delta F$	() = True GI
1998	6108	0.02022	0.01033	0.02060	0.00790	6 (5.6)
1999	6000	0.02116	0.01004	0.02160	0.00599	6 (5.8)
2000	5959	0.02113	0.00797	0.01950	0.00315	6 (6.0)
2001	5903	0.02132	0.00643	0.02120	0.00488	6 (6.1)
2002	5811	0.02170	0.00489	0.02060	0.00204	6 (6.3)
2003	5476	0.02184	0.00396	0.01950	0.00092	6 (6.4)
2004	5213	0.02252	0.00302	0.02320	0.00225	7 (6.7)
2005	4965	0.02289	0.00272	0.02440	0.00388	7 (6.7)
2006	4760	0.02341	0.00230	0.02520	0.00368	7 (6.9)
2007	4628	0.02451	0.00345	0.02570	0.00632	7 (7.0)
2008	4505	0.02478	0.00355	0.02650	0.00541	7 (7.2)
2009	4433	0.02605	0.00445	0.03000	0.00960	7 (7.1)
2010	4366	0.02719	0.00547	0.02660	0.00724	7 (6.9)
2011	4346	0.02742	0.00501	0.02840	0.00532	7 (7.0)
2012	4328	0.02884	0.00610	0.02970	0.00543	7 (7.2)
2013	4328	0.02915	0.00587	0.02970	0.00462	7 (6.9)
2014	4320	0.02968	0.00530	0.03000	0.00441	7 (7.2)
2015	4346	0.03039	0.00574	0.03440	0.00812	7 (6.8)
2016	4378	0.03085	0.00492	0.03630	0.00649	10 (9.8)
2017	4519	0.03172	0.00466	0.03660	0.01027	7 (-)
2018	4834	0.03186	0.00457	0.03440	0.00618	7 (-)
2019	5494	0.03263	0.00390	0.03760	0.00814	7 (-)

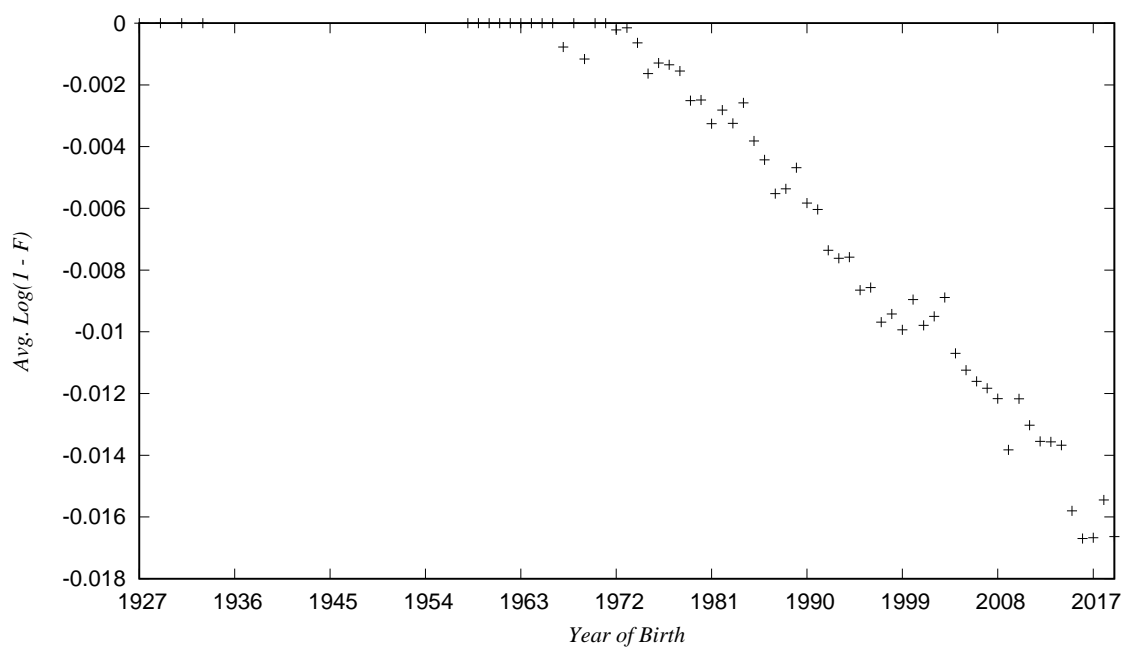
Fixed Time interval used to calculate Delta AGR: 7



Figure 3: Average Additive Genetic Relationships and Inbreeding Coefficients by year of birth

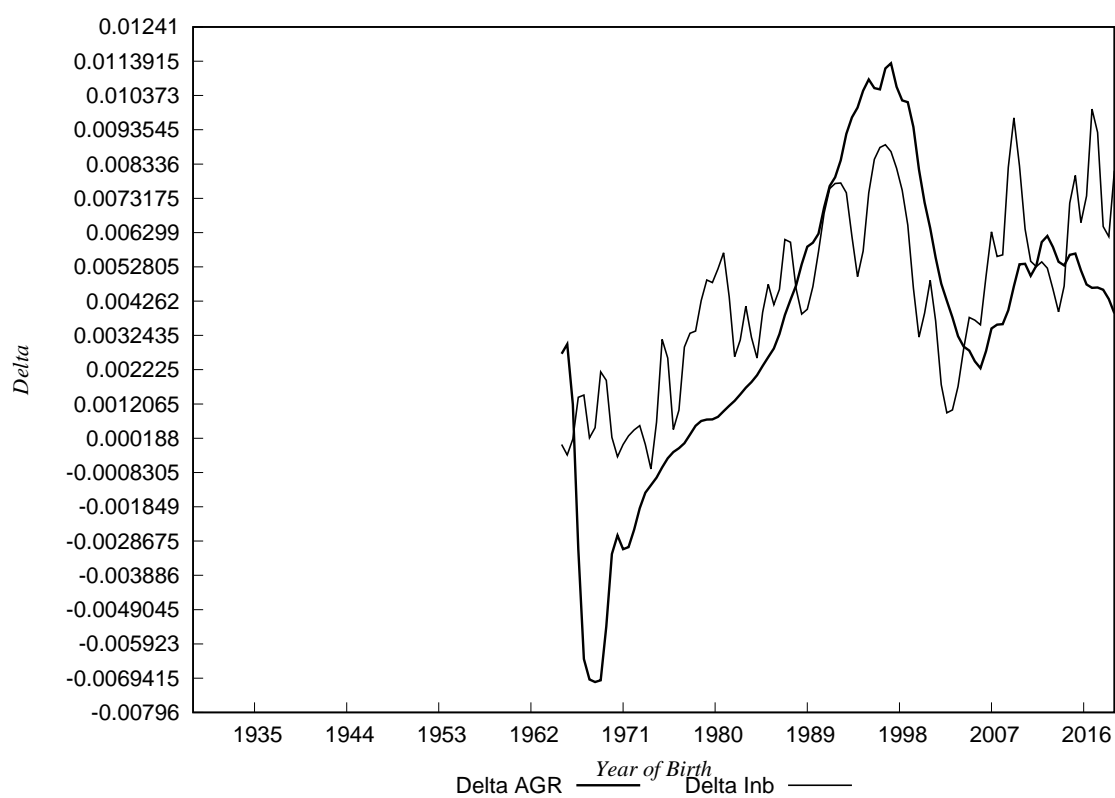


The average rate of change of the additive genetic relationships between 1929 and 2019 for the 51 breed was 0.00033 per year based on the slope of the regression fitted. This result in a  $\Delta f$  per generation of 0.00234. The rate of change of the average inbreeding coefficients based on the slope of the regression between 1929 and 2019 was 0.00052, which represents a  $\Delta F$  per generation of 0.00372. The effective population sizes for the 51 breed, based on  $\Delta f$  and  $\Delta F$  were 214 and 135, respectively.

Figure 4: Average  $\text{Log}(1-F)$  by year of birth for animals born between 1927 and 2019.

*(The rate of inbreeding per generation for the 51 breed,  
based on the Log(1-Inbreeding) is 0.0056 which presents an  $N_e$  of 89.  
Calculations were performed on 144245 animals born between 1927 and 2019.)*

Figure 5: The Rate of Inbreeding and Increase in the Additive Genetic Relationships by year of birth



# PopReport

## A Population Monitoring Report

**Population:** 51  
**Inputfile:** POPREP.TXT  
**Initiated by:** quaglia@anabic.it  
**Submitted at:** 2020-08-26 10:46:54  
**Started at:** 2020-08-26 10:47:01  
**Finished at:** 2020-08-26 11:43:41

**Courtesy:** Department of Animal Breeding and Genetics  
Institute of Farm Animal Genetics (FLI)  
Eildert.Groeneveld@gmx.de  
Höltystasse 10  
D-31535 Mariensee, Germany  
<http://popreport.fli.de>

## Some Notes About Your PopReport Job:

- INFO: This job ran on machine rie-ex-web160 with 12 CPUs and MemTotal: 32950668 kB
- INFO: Your entered dateformat was 'YYYYMMDD', your dateseparator 'undef'.  
144245 input lines processed.  
144245 animals accepted.
- INFO: (concerning Inbreeding Report)  
This table shows the shortening of the number of male and female animals per year for the AGR computations. The original (orig) number of records is shortened (cut) to keep the product of *male \* female* within acceptable limits. See details later in the Inbreeding Report.

Year	No. of Male		No. of Female	
	orig.	cut	orig.	cut
1974	743	743	6102	5384
1975	808	808	7398	4950
1976	882	882	9320	4535
1977	946	946	10781	4228
1978	893	893	11243	4479
1979	883	883	12116	4530
1980	840	840	13368	4762
1981	797	797	14331	5019
1982	809	809	15711	4944
1983	790	790	16306	5063
1984	801	801	17739	4994
1985	794	794	18863	5038
1986	802	802	20536	4988
1987	827	827	21889	4837
1988	840	840	23656	4762
1989	855	855	24741	4678
1990	876	876	25384	4566
1991	849	849	25285	4711
1992	831	831	25309	4813
1993	825	825	25205	4848
1994	809	809	24892	4944
1995	805	805	23886	4969
1996	767	767	22836	5215
1997	737	737	22223	5427
1998	746	746	22050	5362
1999	764	764	21641	5236
2000	771	771	21118	5188
2001	781	781	20792	5122
2002	798	798	21041	5013

Year	No. of Male		No. of Female	
	orig.	cut	orig.	cut
2003	868	868	21743	4608
2004	935	935	22641	4278
2005	1012	1012	23699	3953
2006	1090	1090	24980	3670
2007	1150	1150	25737	3478
2008	1216	1216	26042	3289
2009	1261	1261	25821	3172
2010	1308	1308	25672	3058
2011	1323	1323	25377	3023
2012	1338	1338	24503	2990
2013	1338	1338	23704	2990
2014	1344	1344	22977	2976
2015	1323	1323	22281	3023
2016	1299	1299	21219	3079
2017	1208	1208	19000	3311
2018	1060	1060	15808	3774
2019	864	864	12790	4630

# Monitoring the Population 51

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Developers at FLI:  
Carina Apelt – Implementation of Monitoring Module  
Helmut Lichtenberg – Integration and WEB service  
Eildert Groeneveld – Project Leader

August 26, 2020

## Methods in monitoring breeding populations

A number of methods are available to estimate the effective population size on the basis of pedigrees. When it comes to monitoring animal genetic resources not all methods are equally well suited. Further, depending on the conditions in the population under consideration, different methods may have to be chosen. Issues requiring possibly different methods to be chosen are e.g. sub population

stratification, pedigree completeness, and sampling. Guidelines on the appropriate choice are given below.

Table 1 presents six methods for census and pedigree based  $N_e$  estimates. For details see Groeneveld et al. (2009) and Gutiérrez et al. (2009). Based on the rates computed, the  $N_e$  is estimated as  $N_e = \frac{1}{2 \times \Delta F^*}$  for the pedigree based methods.

**Table 1: Methods for estimating the effective population size  $N_e$**

Method	Source	Formula	Description
$N_e$ -Cens	Wright (1923)	$N_e = 4 * \frac{S_n * D_n}{S_n + D_n} * 0.7$	$S_n$ = number of sires per generation, $D_n$ = number of dams per generation
$N_e$ - $\Delta F_p$	Falconer & Mackay (1996)	$\Delta F_p = \frac{F_t - F_{t-1}}{1 - F_{t-1}}$	$F_t = \circlearrowleft$ inbreeding coefficient of offspring, $F_{t-1} = \circlearrowleft$ inbreeding coefficient of direct parents
$N_e$ - $\Delta F_g$	Falconer & Mackay (1996)	$\Delta F_g = \frac{F_t - F_{t-1}}{1 - F_{t-1}}$	$F_{t-1} = \circlearrowleft$ inbreeding coefficient of the $\circlearrowleft$ parents generation
$N_e$ -Coan	Falconer & Mackay (1996)	$\Delta f_g = \frac{f_t - f_{t-1}}{1 - f_{t-1}}$	$f_t = \circlearrowleft$ additive genetic relationship (AGR) of offspring, $f_{t-1} = \circlearrowleft$ AGR of parents
$N_e$ -Ln	Pérez-Enciso (1995)	$\Delta F_{ln} = (-1)bL$	$b$ = slope from the logarithmic regression of $\ln(1 - F)$ on year of birth, $L$ = generation interval
$N_e$ -Ecg	Gutiérrez et al. (2009)	$\Delta F_i = 1 - \text{ecg}_i \sqrt{1 - F_i}$	$\text{ecg}$ = sum of all known ancestors with $(\frac{1}{2})^n$ , $F_i$ = individual inbreeding coefficient

### Choosing the best method

Given the number of methods available, a decision has to be taken on the choice of the most appropriate method for the population under consideration.

Populations are often monitored for effective population size with the objective to start an action once the size falls below some threshold. This may be the start of a management program or the establishment of a gene bank.

In this situation it is important to obtain an estimate from a method which can respond quickly to changes in population size. Different methods use time windows of different length. Thus, the method with the shortest window is best suited for our monitoring purposes.

There is, however, one other aspect which requires attention before considering the time window: we have two different classes of pedigree based methods: the first is based on inbreeding while the second computes the coancestry of an hypothetical contemporary breeding population. With random mating both are expected to produce the same results. If

however there is a population stratification, i.e. selection within herds with little exchange of breeding stocks, then the average inbreeding will be high but the coancestry across the whole population will be much smaller. In this case the latter method better reflects the loss of genetic diversity in the complete breeding population.

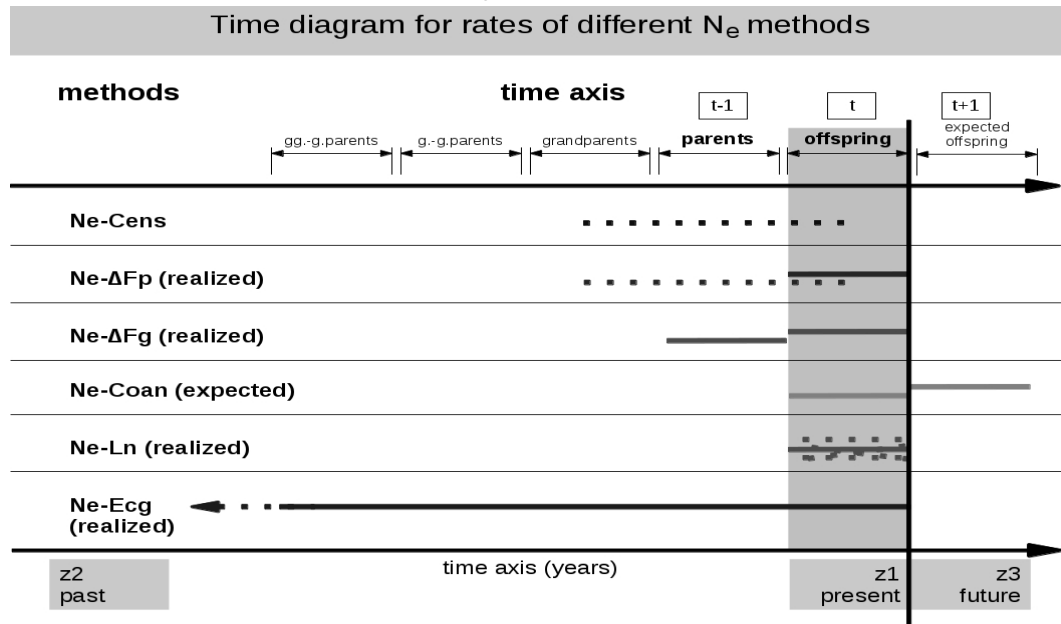
For this reason the decision tree for picking the best method consists of these two major steps:

1. test for population stratification such as selection within herds
2. among the remaining methods chose the one requiring the shortest data history

The choice among the remaining methods is based on the window length required for the  $N_e$  computation. As can be seen from the Figure A the methods require data windows with different lengths and will, thus, respond to rapid changes in population size with different sensitivity. Ordering them according to the window length and putting the least appropriate  $N_e$ -Cens last, gives Table 2.



Figure 1: Data history on which the respective  $N_e$  estimate is based for each of the six  $N_e$ -methods



**Table 2: Order of methods in cascade**

Method	Based on data from
$N_e$ -Ln	animals born in generation $t$
$N_e$ - $\Delta Fp$	animals and their parents born in generation $t$
$N_e$ - $\Delta Fg$	animals born in generation $t$ and $t - 1$
$N_e$ -Coan	animals born in generation $t + 1$ and $t$
$N_e$ -Ecg	animals with their complete ancestors born in generation $t$
$N_e$ -Cens	parents of animals born in generation $t$

Thus,  $N_e$ -Ln will be chosen by default. However, if the side conditions are not met, then the second shortest  $N_e$ - $\Delta Fp$  will be considered, again looking at the side condition, and so on.

The required side conditions are the completeness of  $N_e$  and a relatively stable development of the  $N_e$

from one year to the next. Due to random processes the rate of inbreeding can be negative, resulting in a negative  $N_e$ , which is clearly meaningless and leads to the rejection of the method.

Further, if the  $N_e$  changes drastically from one year to the next, this is also considered dubious.

## Defining the side condition

We are assuming a yearly assessment of the effective population size  $N_e$ . Thus, we are using reporting years, where the most recent year is the relevant one to assess the population size. However, populations can have very different generation intervals. As indicated in Figure 6 the minimum time an  $N_e$  estimate is based on is one generation interval. Above, we have given the reasoning for choosing a method. However, a few more conditions need to be determined. When looking at the  $N_e$  estimates across reporting years, it is clear that they vary pos-

sibly considerably from one year to the next due to sampling. This variation will even lead to negative  $N_e$  estimates which do not make sense. While presenting these in Table 3 and 4 as actual negative numbers we define a side condition that for one generation interval we must not have an undefined or missing estimate. Table 4 shows the actual estimates for one generation interval, one line for each reporting year. Thus, we define **side condition 1** as: "**neither missing nor negative  $N_e$  in any reporting year for the length of one generation interval**". As an example, with a generation interval of 7 years, none of the last 7 years must

have a negative  $N_e$ .

Negative estimates are actually a special case of the more general side condition 2, which addresses variability of the  $N_e$  estimates: if one method has a much smaller variation in  $N_e$  estimates, we would be much more comfortable using this than others that are worse in stability. Thus, side condition 2 determines a threshold as far as variability of the estimates go for a method to be discarded. Here, we have chosen the square root of the residual after fitting a linear regression to the yearly  $N_e$  estimates. The cut off point for rejecting a method is set to  $20 N_e$ . This means that the **side condition 2 sets the standard error of the estimate to  $20 N_e$**  which is actually quite large.

For populations with very short generation intervals, like one year, we would not have a means of assessing the variability of the estimates, because on the basis of side condition 1 we would have only one data point. Thus, a minimum of 4 years, i.e. datapoints are required.

Five of the six methods are based on the rate of inbreeding while  $N_e$ -Coan is based on the additive genetic relationship. A test on population stratification can be made based on the consistent difference in population size between methods  $N_e$ -Coan and  $N_e$ - $\Delta Fg$ . These two means are computed on the respective  $N_e$  across all years as defined above.

Summing up we have introduced:

**side condition 1:** neither missing no negative  $N_e$  estimates over the last number of years of the generation interval length but a minimum of 4 years

**side condition 2:** standard error of the estimate of a linear fit over the reporting years included in side condition 1 must not get larger than  $20 N_e$ .

It must be noted that the side conditions are pure heuristics and that different users may want to use different values.

We even consider it advisable to critically evaluate the selection procedure for an  $N_e$  each time a statement about the population size is made.

## The decision tree in detail

Data for executing the decision tree are given in Table 4. It gives the input data for the decision tree

with as many years as constitute one generation interval. The last line gives the standard error of the estimate from a linear regression of  $N_e$  on years.

Table 5 provides the data used in the side conditions.

The first line in the body of Table 5 gives the difference between  $N_e$ -Coan and  $N_e$ - $\Delta Fg$  which is used to assess population stratification. This is followed by the 6 methods with the completeness and stability column. The last column shows an 'OK', if the side conditions as described above are met. If a user decides that a certain cut off point should be modified, for instance changing the stability value from  $20 N_e$  to 10, this can be done in this table and will likely change the last column. Numbers in red indicate that the current thresholds are not met, while all others are printed in green.

## The cascade

The decision tree can be easily followed on the basis of Table 5. Actually, its entries have already been sorted: the most appropriate methods coming first with the census method being last if all others fail due to not meeting the side conditions.

Thus, executing the decision tree is simple: starting at the top of Table 5 the method which has the first 'yes' in the 'OK' column is the method of choice.

## Population stratification

A comparison of  $N_e$  from inbreeding ( $N_e$ - $\Delta Fg$ ) and coancestry based ( $N_e$ -Coan) will give insight into whether something close to random mating is performed: both estimates should be rather similar. If however  $N_e$ -Coan is substantially larger, selection within herds can be assumed and this parameter be chosen. The investigator will probably be able to either substantiate or discard this claim. Figure 4 will give a quick overview about the situation: in such a case the slope of the  $N_e$ -Coan will be flatter.

Table 5 shows the decision going from top to bottom. The first line is an evaluation of the  $N_e$ - $\Delta Fg$ . The entry in column 'OK' is set only to 'yes' if the  $N_e$  for the coancestry method  $N_e$ -Coan is numerically larger than for the inbreeding based  $N_e$ - $\Delta Fg$  no matter how big the difference is and if the side conditions completeness and stability are met. This is equally arbitrary than the cut off points chosen for the side conditions 1 and 2. Other values (like a difference of 2) may be equally appropriate.

## Deciding on the final method

Table 5 shows the decision going from top to bottom. The first line with a 'yes' in the 'OK' column represents the method of choice following the rational outlined above. As we go from one line to next, we move from the best choice to the next best. Where we encounter a 'no' under the 'OK' column, a side condition has not been met, and, thus, the method is disregarded. As outlined above, we have the two side conditions 'Completeness' and 'Stability' which are reflected in the two columns with the respective headings in Table 5. The entries to the 'Completeness' column are the pairs 'actually complete' vs 'total number' of years. Thus, '4/8' means that out of the required 8 years 4 estimates were positive.

The 'Stability' column gives the actual  $\sigma$  estimate along with the threshold much like the completeness column. Violations of the constraints are printed in red. A method is only 'OK' if both - and for  $N_e$ -Coan in line 1 all three - constraints are met.

Please note, that the most current year has to be complete as far as data goes. If you can provide data for some months only you should remove this year completely. Otherwise the computation of  $N_e$  might be incorrect.

It also has to be noted that the procedure chosen is heuristic in particular the threshold for the variability of the  $N_e$ . Thus, in the face of additional information on the breed considered a user may find a different choice more appropriate.

In any case, mostly it is important to be sure about the order of the population size and not so much about the value behind the decimal point.

## A word of warning

Figure 2 provides counts per reporting year. The user should study them and relate them to the  $N_e$  estimates. Drastic changes should be reflected in the estimates. Also, in those cases  $N_e$ -Ecg will likely not

be a good procedure as it basically takes an average over the complete pedigree length.

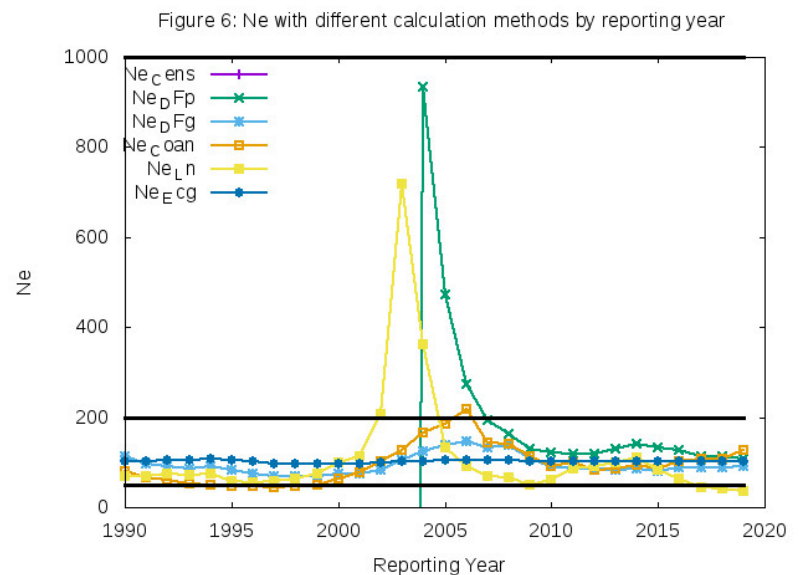
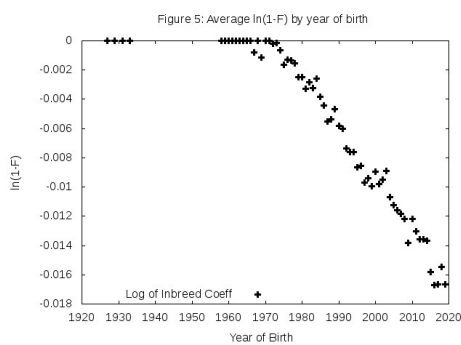
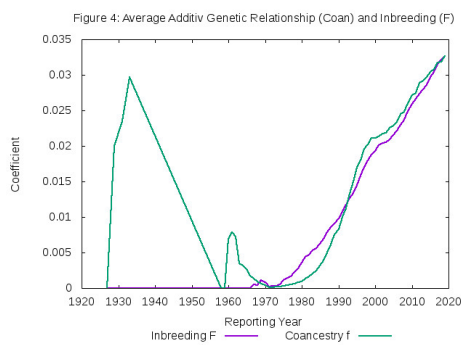
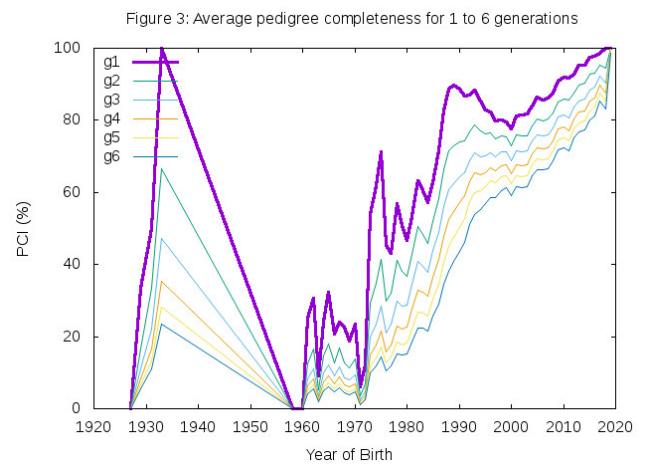
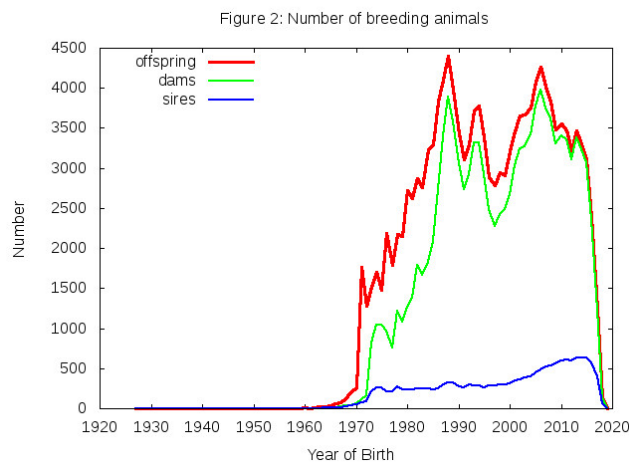
Surprisingly, pedigrees are often quite incomplete which directly impacts on the utility of the methods. To assess the quality of the pedigree Figure 3 should be studied. Incomplete pedigrees will likely overestimate the population size. This will also be reflected by Figure 5 which will look more like a cluster of dots than something that looks like a regression line. Also, Figure 6 gives a visual impression how stable estimates are.

To some degree, the effect of incomplete pedigrees will be accounted for by the side conditions. But it is the obligation of the user to decide at which point an estimate still makes sense in the face of bad pedigrees.

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Breed: 51 • 144245 pedigree records • generation interval: 7 • August 26, 2020



**Table 3: Effective Population Size  $N_e$**

$N_e$ -Method	2019	2018	2017	2016	2015	2014	data history
$N_e$ -Cens	3261	3679	4055	4171	4131	4023	2012 – 2006
$N_e$ - $\Delta F_p$	108	112	114	128	132	140	2019 – 2006
$N_e$ - $\Delta F_g$	91	88	88	89	81	86	2019 – 2006
$N_e$ -Coan	128	109	107	102	87	94	2026 – 2013
$N_e$ -Ln	37	42	44	64	82	110	2019 – 2013
$N_e$ -Ecg	101	101	101	103	102	103	2019 – 1927

**Proposed  $N_e$ :  $N_e$ -Coan (substructure) = 128**

**Note:** The last year is assumed to have complete data!

**Table 4: Decision tree for  $N_e$  calculation**

Year	$N_e$ -Cens	$N_e$ - $\Delta F_p$	$N_e$ - $\Delta F_g$	$N_e$ -Coan	$N_e$ -Ln	$N_e$ -Ecg
2019	3261	108	91	128	37	101
2018	3679	112	88	109	42	101
2017	4055	114	88	107	44	101
2016	4171	128	89	102	64	103
2015	4131	132	81	87	82	102
2014	4023	140	86	94	110	103
2013	3955	131	83	85	99	102
$\sigma$	259.5	5.5	2.4	6.1	10.2	0.7

**Table 5: Decision cascade – side conditions**

Method	Completeness [Years]	Stability [ $\sigma$ ]	Diff	OK
$N_e$ -Coan <sup>a</sup>	14/14	6.1 2.4/20	15.14	yes
$N_e$ -Ln	7/7	10.2/20	-	yes
$N_e$ - $\Delta F_p$	7/7	5.5/20	-	yes
$N_e$ - $\Delta F_g$	7/7	2.4/20	-	yes
$N_e$ -Coan	7/7	6.1/20	-	yes
$N_e$ -Ecg	7/7	0.7/20	-	yes
$N_e$ -Cens	7/7	259.5/20	-	no

<sup>a</sup>Avg  $N_e$ -Coan – Avg  $N_e$ - $\Delta F_g$ :  $101.71 - 86.57 = 15.14$

# PopReport

## A Population Structure Report

**Population:** 51  
**Inputfile:** POPREP.TXT  
**Initiated by:** quaglia@anabic.it  
**Submitted at:** 2020-08-26 10:46:54  
**Started at:** 2020-08-26 10:47:01  
**Finished at:** 2020-08-26 11:43:41

**Courtesy:** Department of Animal Breeding and Genetics  
Institute of Farm Animal Genetics (FLI)  
Eildert.Groeneveld@gmx.de  
Höltystasse 10  
D-31535 Mariensee, Germany  
<http://popreport.fli.de>

## Some Notes About Your PopReport Job:

- INFO: This job ran on machine rie-ex-web160 with 12 CPUs and MemTotal: 32950668 kB
- INFO: Your entered dateformat was 'YYYYMMDD', your dateseparator 'undef'.  
144245 input lines processed.  
144245 animals accepted.
- INFO: (concerning Inbreeding Report)  
This table shows the shortening of the number of male and female animals per year for the AGR computations. The original (orig) number of records is shortened (cut) to keep the product of *male \* female* within acceptable limits. See details later in the Inbreeding Report.

Year	No. of Male		No. of Female	
	orig.	cut	orig.	cut
1974	743	743	6102	5384
1975	808	808	7398	4950
1976	882	882	9320	4535
1977	946	946	10781	4228
1978	893	893	11243	4479
1979	883	883	12116	4530
1980	840	840	13368	4762
1981	797	797	14331	5019
1982	809	809	15711	4944
1983	790	790	16306	5063
1984	801	801	17739	4994
1985	794	794	18863	5038
1986	802	802	20536	4988
1987	827	827	21889	4837
1988	840	840	23656	4762
1989	855	855	24741	4678
1990	876	876	25384	4566
1991	849	849	25285	4711
1992	831	831	25309	4813
1993	825	825	25205	4848
1994	809	809	24892	4944
1995	805	805	23886	4969
1996	767	767	22836	5215
1997	737	737	22223	5427
1998	746	746	22050	5362
1999	764	764	21641	5236
2000	771	771	21118	5188
2001	781	781	20792	5122
2002	798	798	21041	5013

Year	No. of Male		No. of Female	
	orig.	cut	orig.	cut
2003	868	868	21743	4608
2004	935	935	22641	4278
2005	1012	1012	23699	3953
2006	1090	1090	24980	3670
2007	1150	1150	25737	3478
2008	1216	1216	26042	3289
2009	1261	1261	25821	3172
2010	1308	1308	25672	3058
2011	1323	1323	25377	3023
2012	1338	1338	24503	2990
2013	1338	1338	23704	2990
2014	1344	1344	22977	2976
2015	1323	1323	22281	3023
2016	1299	1299	21219	3079
2017	1208	1208	19000	3311
2018	1060	1060	15808	3774
2019	864	864	12790	4630



# Population Structure Report for Population: 51

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## Contents

<b>1</b>	<b>Number of breeding males and females by year</b>	<b>1</b>
<b>2</b>	<b>Age structure of parents by birth year of offspring</b>	<b>4</b>
<b>3</b>	<b>Distribution of parity of dams at birth of offspring</b>	<b>10</b>
<b>4</b>	<b>Generation interval</b>	<b>12</b>
<b>5</b>	<b>Family size</b>	<b>14</b>

## List of Tables

1	Number of sires and dams in reproduction by year of birth of offspring . . . . .	1
2	Age distribution of males in reproduction by year of birth of their offspring . . . . .	4
3	Age distribution of females in reproduction by year of birth of their offspring . . . . .	7
4	Distribution of females by parity number . . . . .	10
5	Generation interval and number of animals by year of birth for different selection paths .	12
6	The maximum and average number of family sizes . . . . .	14

## List of Figures

1	Dams with the most Progeny in the Population . . . . .	16
2	Number of Progeny per Dam . . . . .	17
3	Sires with the most Progeny in the Population . . . . .	18
4	Number of Progeny per Sire . . . . .	19
5	Dams with the most Selected Progeny in the Population . . . . .	20
6	Number of Selected Progeny per Dam . . . . .	21
7	Sires with the most Selected Progeny in the Population . . . . .	22
8	Number of Selected Progeny per Sire . . . . .	23

## 1 Number of breeding males and females by year

The number of breeding animals at a given time determines the genetic structure of the population in subsequent generations. Under simplified conditions ( *e.g.* ratio of males to females is 1:1, random selection, distribution of family size is Poisson, *etc.*), the number of breeding males and females can be used to calculate the effective population size (to be defined later). In the context of this report, an animal only becomes a 'breeding' animal by either having a service record (if available) or show up as a parent in a birth record of an offspring. This may contrast to a situation, where animals get 'selected' with the intent to use them as parents but effectively are never put into service.

The number of breeding males and females used in the population in a given year is presented in this table. The table is broken down by birth year with the last column (Number of animals born) giving the total number of animals born for the current breed for that particular year.

It is the objective of this table to provide an overview about the genetic composition of each birth year's batch of new animals: giving the number of sires and dams that produced the current year's crop of offspring. Thus, for 'services' and 'birth' we find under column 'sires' the number of sires involved in the services and births. The same applies to the column 'dams'. Thus, the ratio of 'number of animals born' and the counts in 'birth'

gives the average number of offspring per sire/dam in that year.

The column 'select' goes one step further: firstly, based on the set of animals born in the particular year, it is determined how many of those offspring became parents in later years. Then, for this subset the number of sires and dams are determined and printed under column 'select'. Clearly, this figure has to be less or equal to the corresponding figure under 'births'. Keeping this figure high will help avoid inbreeding.

The description for each column is:

**Services:** The number of sires/dams that participated in services in a given year.

**Births:** The number of sires/dams with offspring in a given year.

**Select:** Those animals born in the given year which became parents later on determine the subset. "Select" gives the number of sires and dams represented in this subset.

The total number of sires and dams is not the sum of the sire and dam columns but rather the total number of sires and dams occurring in all years. This figure will tend to be smaller than the sum from the years, as the same sire or dam may show up in multiple years.

**For example:** For the 51 breed in 1966, 12 sires and 12 dams produced the 58 offspring during this year. In the batch of future parents (select) born in this year 1966 12 sires and 12 dams were represented.

Table 1: Number of sires and dams in reproduction by year of birth of offspring

Year	sires			dams			Number of animals born
	services	births	select	services	births	select	
1929	-	2	2	-	2	2	6
1931	-	3	3	-	3	3	6
1933	-	2	1	-	2	1	2
1960	-	1	1				9
1961	-	1	1	-	1	1	4
1962	-	5	5	-	4	4	13
1963	-	2	2	-	2	2	22
1964	-	7	7	-	6	6	25
1965	-	10	10	-	12	12	34
1966	-	12	12	-	12	12	58
1967	-	16	16	-	18	18	75
1968	-	28	26	-	32	27	124
1969	-	31	27	-	38	34	193

*Continue...*

Year	sires			dams			Number of animals
	services	births	select	services	births	select	born
1970	-	52	44	-	64	54	264
1971	-	73	67	-	110	96	1767
1972	-	91	80	-	159	128	1283
1973	-	212	146	-	816	366	1517
1974	-	265	181	-	1046	456	1697
1975	-	262	184	-	1041	489	1485
1976	-	216	165	-	974	506	2189
1977	-	207	157	-	762	438	1789
1978	-	268	205	-	1219	635	2176
1979	-	237	187	-	1079	560	2146
1980	-	235	185	-	1268	671	2726
1981	-	232	183	-	1375	713	2617
1982	-	253	202	-	1792	968	2877
1983	-	247	185	-	1659	901	2765
1984	-	253	198	-	1831	982	3233
1985	-	230	185	-	2083	1066	3293
1986	-	246	189	-	2739	1274	3827
1987	-	303	237	-	3388	1553	4104
1988	-	317	244	-	3891	1688	4397
1989	-	319	236	-	3577	1616	3977
1990	-	276	217	-	3056	1548	3429
1991	-	261	213	-	2740	1376	3107
1992	-	293	213	-	2915	1408	3299
1993	-	287	231	-	3312	1570	3717
1994	-	285	228	-	3317	1638	3775
1995	-	266	224	-	2916	1476	3387
1996	-	288	232	-	2481	1302	2889
1997	-	281	228	-	2279	1286	2786
1998	-	300	257	-	2421	1374	2943
1999	-	294	231	-	2488	1428	2908
2000	-	306	266	-	2670	1596	3201
2001	-	343	293	-	3029	1760	3459
2002	-	356	311	-	3240	1865	3653
2003	-	379	298	-	3274	1773	3661
2004	-	399	318	-	3423	1770	3751
2005	-	446	351	-	3773	1913	4078
2006	-	480	362	-	3977	1889	4267
2007	-	518	380	-	3753	1736	4018
2008	-	528	360	-	3622	1558	3830
2009	-	554	357	-	3302	1298	3477
2010	-	592	377	-	3411	1269	3559
2011	-	610	336	-	3355	1058	3471
2012	-	598	298	-	3108	882	3219
2013	-	634	220	-	3380	587	3468
2014	-	634	150	-	3234	328	3297
2015	-	629	49	-	3072	92	3113
2016	-	568	7	-	2365	7	2391
2017	-	399	-	-	1235	-	1249

*Continue...*

Year	sires			dams			Number of animals
	services	births	select	services	births	select	born
2018	-	65	-	-	131	-	131
2019	-	5	-	-	5	-	5
Total	-	5338	3898	-	72509	37052	144245

## 2 Age structure of parents by birth year of offspring

This section gives a quick overview of the age structure of breeding males and females by birth year of offspring as summarized in the Tables. The animals of interest or cohort is *the total number of animals born in a given year*. The second row in the header of tables lists the different age groups (in *years*) for male and female parents. It should be noted that parents greater or equal to 16 years of age were grouped together i.e.

age group  $\geq 16$  years. The values in the body of table are the number of male/female parents in a given age-year subgroup. A dash (“-”) in the table indicates that there were no animals of a particular age group in a given year. The last column presents the average age of all male/female parents.

**For example:** For the 51 breed in 1968, 2 two year-old males were used in reproduction while 4 three year-old males were used. The average age of males that produced offspring during 1968 was 1.5 year.

Table 2: Age distribution of males in reproduction by year of birth of their offspring

Year	age of males in year																Avg
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	$\geq 16$	
1929	2	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	1.0
1931	3	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	1.0
1933	2	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	1.0
1960	1	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	1.0
1961	1	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	1.0
1962	4	-	-	-	-	-	-	-	-	-	-	-	-	-	-	1	7.2
1963	2	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	1.0
1964	5	1	1	-	-	-	-	-	-	-	-	-	-	-	-	-	1.4
1965	7	-	1	-	-	-	-	-	-	-	-	-	-	-	-	2	8.4
1966	11	1	-	-	-	-	-	-	-	-	-	-	-	-	-	-	1.1
1967	13	1	2	-	-	-	-	-	-	-	-	-	-	-	-	-	1.3
1968	21	2	4	1	-	-	-	-	-	-	-	-	-	-	-	-	1.5
1969	23	-	3	2	1	-	1	-	-	-	-	-	-	-	-	1	3.0
1970	35	6	3	-	-	2	2	1	1	-	-	-	-	-	-	2	3.5
1971	45	6	5	6	2	-	2	1	2	1	2	-	-	-	-	1	3.0
1972	44	16	7	6	4	4	-	5	1	3	-	-	-	-	-	1	3.2
1973	37	119	21	8	5	5	3	2	6	1	3	-	-	-	-	2	3.0
1974	38	97	70	17	5	7	6	7	1	7	3	4	-	-	-	3	3.7
1975	22	87	62	41	11	5	6	5	5	3	7	1	2	-	1	4	4.2
1976	18	70	39	30	23	5	5	3	3	9	1	3	1	2	-	4	4.6
1977	13	52	65	25	20	8	4	3	2	2	6	2	2	1	1	1	4.1

*Continue...*

Year	age of males in year																Avg
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	≥ 16	
1978	36	50	68	51	24	12	4	4	3	4	2	5	2	1	–	2	3.9
1979	14	60	48	38	27	18	8	3	2	4	3	3	4	1	1	3	4.4
1980	22	50	53	31	29	18	7	8	3	1	2	5	–	3	–	3	4.3
1981	13	60	54	38	22	18	8	5	3	2	–	1	3	–	2	3	4.0
1982	15	61	69	34	26	15	14	6	4	2	–	–	1	2	–	4	4.0
1983	14	67	50	46	32	15	12	1	2	1	4	–	–	–	1	2	3.8
1984	14	60	65	41	32	19	9	5	4	1	1	–	1	–	–	1	3.8
1985	22	43	57	41	24	17	11	6	4	1	–	–	–	1	–	3	3.9
1986	11	56	56	46	29	15	13	10	4	4	–	–	–	–	–	2	4.0
1987	19	75	56	52	36	21	12	14	6	5	4	–	–	–	–	3	4.2
1988	22	71	64	42	36	24	21	8	8	5	5	5	1	–	–	5	4.5
1989	14	84	63	50	32	23	17	6	6	8	3	5	4	2	–	2	4.3
1990	10	77	60	41	27	18	17	7	7	3	4	2	1	1	–	1	4.1
1991	12	74	58	43	23	18	14	4	2	7	3	1	1	–	–	1	3.9
1992	11	92	60	44	29	20	12	7	6	5	3	2	2	–	–	–	3.9
1993	10	86	74	46	29	18	8	4	4	2	2	1	1	1	–	1	3.7
1994	12	79	72	50	33	16	10	3	4	1	2	1	1	–	1	–	3.7
1995	7	77	56	47	39	17	10	6	3	1	–	1	–	1	1	–	3.8
1996	10	90	67	48	35	20	11	2	3	–	1	–	–	–	1	–	3.6
1997	6	76	75	51	30	21	12	4	2	2	–	2	–	–	–	–	3.7
1998	7	71	74	59	38	23	10	9	2	1	2	1	3	–	–	–	3.9
1999	15	59	58	66	38	32	10	8	3	2	1	1	–	1	–	–	4.0
2000	7	86	45	45	48	31	19	12	7	5	–	–	–	–	1	–	4.2
2001	6	89	76	36	38	44	21	7	8	6	6	2	1	–	–	3	4.4
2002	7	91	66	63	30	29	25	18	9	9	2	4	–	–	–	3	4.4
2003	13	82	70	65	42	24	28	18	11	4	8	4	5	1	1	3	4.7
2004	13	91	90	55	45	36	15	15	9	12	6	4	3	3	–	2	4.5
2005	10	100	86	71	61	37	31	8	12	10	5	4	5	2	3	1	4.5
2006	13	104	100	76	51	47	25	22	7	11	7	3	6	4	1	3	4.6
2007	11	117	118	85	57	42	29	16	10	5	6	10	3	2	5	2	4.5
2008	8	114	114	83	72	38	30	16	14	7	4	7	6	3	2	10	4.7
2009	12	112	118	88	67	59	24	20	19	8	7	–	2	7	1	10	4.7
2010	9	118	104	102	77	61	46	22	17	8	5	6	1	1	3	12	4.8



*Continue...*

Year	age of males in year																Avg
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	≥ 16	
2011	15	96	102	98	91	67	41	32	22	14	6	4	6	–	–	16	5.1
2012	6	120	96	83	69	72	43	29	26	14	8	9	3	5	–	15	5.3
2013	13	117	126	77	71	63	52	39	23	17	9	6	2	1	4	14	5.2
2014	12	97	110	114	61	60	55	38	31	13	15	6	5	2	–	15	5.3
2015	6	103	119	87	94	44	41	43	33	20	6	9	3	2	2	17	5.4
2016	12	96	104	86	52	64	37	30	26	21	10	–	6	3	3	18	5.5
2017	5	62	74	69	48	36	35	13	15	10	9	4	–	2	2	15	5.6
2018	1	16	17	10	7	3	4	2	1	–	2	2	–	–	–	–	4.2
2019	–	1	2	1	1	–	–	–	–	–	–	–	–	–	–	–	3.4
Total	842	3788	3377	2535	1823	1311	880	557	406	282	185	130	87	55	37	217	4.1

**For example:** For the 51 breed in 1971, 2 two year-old females were used in reproduction while 2 three year-old females were used. The average age of females that produced offspring during 1971 was 1.6 year.

Table 3: Age distribution of females in reproduction by year of birth of their offspring

Year	age of females in year																
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	≥ 16	Avg
1929	2	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	1.0
1931	3	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	1.0
1933	2	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	1.0
1961	1	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	1.0
1962	4	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	1.0
1963	2	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	1.0
1964	6	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	1.0
1965	12	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	1.0
1966	12	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	1.0
1967	17	-	-	-	1	-	-	-	-	-	-	-	-	-	-	-	1.2
1968	30	-	1	1	-	-	-	-	-	-	-	-	-	-	-	-	1.2
1969	35	1	1	-	-	-	1	-	-	-	-	-	-	-	-	-	1.2
1970	59	1	3	-	1	-	-	-	-	-	-	-	-	-	-	-	1.2
1971	101	2	2	2	-	-	1	-	1	-	-	-	-	-	-	1	1.6
1972	150	-	6	-	1	-	1	-	1	-	-	-	-	-	-	-	1.2
1973	756	24	17	5	6	1	1	-	-	2	1	-	-	-	-	3	1.3
1974	535	142	314	25	8	7	2	6	-	2	1	-	1	1	-	2	2.1
1975	359	134	313	192	11	8	7	4	4	1	2	1	-	1	1	3	2.7
1976	358	138	171	181	97	7	6	6	4	-	2	2	1	-	-	1	2.7
1977	115	120	123	141	154	79	15	3	4	-	3	-	2	1	-	2	3.8
1978	418	139	168	139	112	132	77	10	8	4	4	5	-	-	1	2	3.3
1979	234	188	208	111	98	90	90	44	5	5	3	1	-	1	1	-	3.6
1980	211	174	244	186	126	97	77	73	40	14	9	6	3	4	-	4	4.2
1981	202	189	228	195	153	119	89	75	61	33	15	8	3	-	2	3	4.4
1982	220	260	276	220	260	186	115	106	56	45	28	8	7	1	2	2	4.5
1983	130	221	250	244	184	185	156	91	80	51	32	14	8	1	4	8	5.0
1984	80	214	296	287	222	183	188	143	84	53	35	21	9	8	2	6	5.2
1985	98	276	246	327	258	211	190	169	136	82	34	23	18	5	3	7	5.3
1986	128	378	399	314	364	333	256	188	161	95	60	37	10	7	2	7	5.2

Continue...

Year	age of females in year																
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	≥ 16	Avg
1987	85	481	494	432	401	414	360	205	196	139	90	47	28	3	5	8	5.4
1988	79	608	551	556	411	420	398	314	197	135	99	57	41	14	5	6	5.4
1989	49	510	548	445	437	380	340	279	263	133	76	49	40	16	4	8	5.5
1990	18	440	474	412	368	304	276	235	191	147	84	55	28	10	7	7	5.5
1991	21	390	399	383	360	301	237	173	146	135	102	34	31	11	7	10	5.5
1992	24	414	434	427	346	329	263	227	149	103	84	58	26	18	4	9	5.5
1993	28	405	460	449	428	390	310	251	194	137	89	67	57	16	15	16	5.7
1994	18	422	434	420	383	401	329	275	190	152	105	89	46	25	11	17	5.9
1995	17	408	374	339	355	334	280	229	215	125	87	64	33	26	17	13	5.9
1996	18	356	359	283	238	263	258	191	152	137	87	53	39	25	12	10	5.9
1997	4	296	327	298	243	248	170	197	165	111	75	58	41	19	19	8	6.0
1998	10	290	326	332	302	203	206	189	156	145	103	64	41	23	20	11	6.1
1999	9	241	312	310	350	254	212	205	179	144	110	69	45	24	10	14	6.2
2000	8	283	315	298	341	314	283	200	162	147	113	92	66	30	9	9	6.3
2001	14	349	346	324	349	352	319	242	212	135	129	100	70	45	21	22	6.3
2002	23	337	400	348	317	331	347	279	216	161	155	131	81	59	21	34	6.5
2003	12	409	362	358	344	316	316	271	271	180	145	103	86	49	25	27	6.4
2004	8	440	427	412	341	316	272	275	272	212	143	108	66	61	28	42	6.4
2005	13	481	473	416	424	324	315	308	256	232	187	124	78	63	41	38	6.4
2006	13	449	465	520	426	406	325	306	233	232	222	158	69	60	34	59	6.5
2007	14	467	463	423	431	391	305	267	229	201	172	148	96	56	28	62	6.4
2008	22	465	452	417	376	385	310	261	202	175	172	122	109	69	39	46	6.4
2009	19	387	414	366	352	352	343	251	202	160	138	120	60	56	42	40	6.4
2010	8	363	395	423	380	347	341	303	218	170	133	128	62	60	29	51	6.5
2011	10	346	369	426	392	340	307	261	221	200	159	90	77	57	40	60	6.6
2012	8	278	345	364	357	351	295	251	184	184	157	111	83	58	26	56	6.7
2013	15	288	350	436	394	356	344	289	218	207	150	121	85	51	27	49	6.6
2014	11	314	328	350	350	344	354	289	216	180	162	124	78	62	26	46	6.7
2015	12	289	270	298	314	313	313	280	271	199	154	134	85	67	36	37	7.0
2016	5	211	243	297	244	237	219	214	189	154	103	83	54	60	21	31	6.8
2017	4	116	156	137	129	106	97	99	97	76	84	54	32	16	15	17	6.8
2018	–	13	13	12	15	15	13	9	14	6	3	7	8	1	–	2	6.9
2019	–	–	–	–	–	2	1	1	–	1	–	–	–	–	–	–	7.4

*Continue...*

Year	age of females in year																
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	≥ 16	Avg
Total	4879	14147	15344	14281	12954	11777	10330	8544	6921	5342	4101	2948	1903	1240	662	916	7.1

### 3 Distribution of parity of dams at birth of offspring

The rate of genetic progress in the population depends among other things on the turnover of breeding stock. In general, under artificial breeding, animals that stay in the population longer tend to leave more offspring. Thus, the distribution of parity of dams over time may be informative about the rate of turnover in the population. The distribution of

breeding females in different parity groups in a given year is presented in the Table. Dams with parity  $\geq 16$  are often few in the population and they are conveniently placed together in one group i.e.  $\geq 16$  group. In this instance, the *cohort is defined as the total number of animals born in a given year.*

**For example:** For breed 51 in 1969, 2 females were in their second parity while in 1972, 2 were in their third parity.

Table 4: Distribution of females by parity number

Year	parity number										
	1	2	3	4	5	6	7	8	9	10	11
1929	2	–	–	–	–	–	–	–	–	–	–
1931	3	–	–	–	–	–	–	–	–	–	–
1933	2	–	–	–	–	–	–	–	–	–	–
1961	1	–	–	–	–	–	–	–	–	–	–
1962	4	–	–	–	–	–	–	–	–	–	–
1963	2	–	–	–	–	–	–	–	–	–	–
1964	6	–	–	–	–	–	–	–	–	–	–
1965	12	–	–	–	–	–	–	–	–	–	–
1966	12	–	–	–	–	–	–	–	–	–	–
1967	18	–	–	–	–	–	–	–	–	–	–
1968	31	1	–	–	–	–	–	–	–	–	–
1969	36	2	–	–	–	–	–	–	–	–	–
1970	61	4	–	–	–	–	–	–	–	–	–
1971	106	4	–	–	–	–	–	–	–	–	–
1972	155	2	2	–	–	–	–	–	–	–	–
1973	780	37	–	1	–	–	–	–	–	–	–
1974	897	146	6	–	–	–	–	–	–	–	–
1975	835	175	34	–	1	–	–	–	–	–	–
1976	772	178	28	6	–	–	–	–	–	–	–
1977	505	197	53	10	1	–	–	–	–	–	–
1978	936	211	62	16	6	–	–	–	–	–	–
1979	785	209	69	14	3	–	–	–	–	–	–
1980	903	262	83	21	2	2	–	–	–	–	–
1981	971	289	87	29	6	3	–	–	–	–	–
1982	1308	345	109	33	3	1	–	–	–	–	–
1983	1176	345	91	38	10	2	–	–	–	–	–
1984	1309	365	116	33	15	–	1	–	–	–	–
1985	1432	477	137	30	15	5	–	–	–	–	–
1986	2000	538	142	43	14	7	1	–	–	–	–
1987	2423	682	207	57	20	11	2	–	–	–	–
1988	2762	846	207	66	16	3	1	2	–	–	–
1989	2351	852	275	75	24	5	3	–	1	–	–
1990	1990	725	259	64	17	7	3	1	–	–	–
1991	1715	693	240	70	25	6	–	2	1	–	–
1992	1857	705	242	73	28	10	1	–	–	1	–

*Continue...*

Year	parity number										
	1	2	3	4	5	6	7	8	9	10	11
1993	2098	788	306	88	27	11	3	–	–	–	1
1994	2016	835	318	112	30	9	2	3	–	–	–
1995	1773	764	254	97	22	8	2	1	2	–	–
1996	1427	668	268	77	37	4	5	–	–	–	–
1997	1348	573	229	85	28	17	2	–	1	–	–
1998	1450	616	234	90	20	15	4	1	–	–	–
1999	1459	652	247	89	29	5	10	2	–	–	–
2000	1624	645	260	94	39	9	1	2	–	–	–
2001	1829	756	296	94	39	14	5	2	–	–	–
2002	1940	799	325	128	32	19	1	–	–	–	–
2003	1898	854	337	125	47	12	4	1	2	–	–
2004	2037	832	347	122	62	18	6	1	2	1	–
2005	2179	978	383	159	52	23	4	2	1	1	–
2006	2290	1030	442	143	57	18	7	1	–	2	–
2007	2116	968	416	166	71	18	8	4	–	–	–
2008	2032	920	401	170	61	32	7	6	–	–	–
2009	1853	878	356	132	61	16	3	3	3	–	–
2010	1932	875	397	135	54	28	6	1	–	–	–
2011	1875	889	367	140	48	24	11	3	2	–	–
2012	1715	839	335	136	56	18	11	3	–	2	–
2013	1878	912	378	139	53	19	9	2	–	–	–
2014	1813	805	389	145	56	21	4	5	3	–	–
2015	1692	811	324	155	56	26	5	3	1	1	–
2016	1326	614	256	108	31	17	10	2	2	1	–
2017	679	330	128	64	22	8	4	3	1	1	1
2018	70	37	12	8	1	3	–	–	–	–	–
2019	2	–	1	2	–	–	–	–	–	–	–
Total	72509	27958	10455	3682	1297	474	146	56	22	10	2

## 4 Generation interval

Generation interval is one of the key factors affecting the rate of genetic progress and therefore the genetic structure of the population. As a general rule, the shorter the generation interval the rapid is the genetic change in the population holding other factors constant. Generation interval can be defined as the average age of the parents at the *birth of their selected offspring* (Falconer & Mackay, 1996). In the calculation of generation interval, an offspring is considered selected if it has produced at least one progeny. Computation of the generation interval for a given year was carried out as follows:

1. All animals born in a given year were considered (subset 1)
2. Animals in subset 1 that become parents in the later years were identified (subset 2)

3. The parents of animals in subset 2 were identified (subset 3)
4. The generation interval was calculated as the average age of the animals in subset 3 at birth of their offspring in subset 2.

In livestock, transfer of genes from parents to offspring occurs through four selection paths i.e. sires to sons, sires to daughters, dams to sons and dams to daughters. Thus, the generation interval were computed for the four selection paths and is expressed in *years*. Furthermore, generation interval was calculated separately for the males and females. The values in the body of the table are the average generation intervals for a given selection path followed by the number of animals within that path. The overall generation interval for the entire population is also provided in the table.

**For example:** For the 51 breed the Generation interval (average age of parents when their selected offspring were born) for the selection path between sire to son (ss) was 2.0 year in 1966. This values was calculated based on the avarage ages of 6 selected sons, born during 1966. During the same year the generation intervals for the sire to daughter (sd), dam to son (ds) and dam to daughter (dd) selection paths were 2.1, 2.0 and 2.0 year, respectively. During 1966, the generation interval for the males was 2.0 year and 2.0 year for the female born during this year. The generation interval in 1966 for all four selection paths together, or for the population in total (pop), was 2.0 year, based on the average age of parents of 12 selected offspring.

Table 5: Generation interval and number of animals by year of birth for different selection paths

(*ss=sire to son, Nss=number of selected males for ss, sd=sire to daughter, Nsd=number of females for sd, ms=dams to sons, Nms=number of males for ms, md=dams to daughters and Nmd=number of females for md, male=avg age of sires, Nmale=number of sires where age is known, female=avg age of dams, Nfemale=number of dams where age is known, pop=interval for the population, Npop=number of selected offspring*)

Year	Generation interval and number of animal													
	ss	Nss	sd	Nsd	ms	Nms	md	Nmd	male	Nmale	female	Nfemale	pop	Npop
1929	2.0	1	2.0	1	2.0	1	2.0	1	2.0	2	2.0	2	2.0	2
1962	12.2	3	2.0	2	2.0	2	2.0	2	8.1	5	2.0	4	5.0	5
1964	2.9	3	2.0	4	2.0	3	2.0	3	2.4	7	2.0	6	2.2	7
1965	14.1	6	8.9	5	2.0	7	2.0	5	11.7	11	2.0	12	6.4	12
1966	2.0	6	2.1	6	2.0	6	2.0	6	2.0	12	2.0	12	2.0	12
1967	2.4	4	2.1	14	2.8	4	2.0	14	2.2	18	2.2	18	2.2	18
1968	2.2	8	2.2	18	2.0	8	2.1	19	2.2	26	2.1	27	2.1	27
1969	2.5	8	4.7	25	2.1	7	2.0	27	4.2	33	2.0	34	3.1	35
1970	2.8	7	7.4	48	2.2	7	2.1	48	6.8	55	2.1	55	4.4	57
1971	8.4	8	5.9	89	7.3	8	2.1	88	6.1	97	2.5	96	4.3	98
1972	5.5	15	6.7	112	2.0	15	2.1	113	6.6	127	2.1	128	4.3	129
1973	5.3	67	6.0	303	3.5	66	2.3	303	5.9	370	2.5	369	4.2	371

*Continue...*

Year	Generation interval and number of animal													
	ss	Nss	sd	Nsd	ms	Nms	md	Nmd	male	Nmale	female	Nfemale	pop	Npop
1974	5.6	80	5.8	380	2.8	80	2.9	378	5.8	460	2.9	458	4.4	460
1975	5.0	68	6.3	426	3.2	68	3.5	425	6.1	494	3.4	493	4.8	494
1976	9.4	52	6.4	454	3.9	52	3.4	455	6.7	506	3.5	507	5.1	508
1977	5.2	62	6.6	380	4.7	63	4.3	379	6.4	442	4.4	442	5.4	443
1978	5.5	80	6.3	565	4.6	80	4.2	565	6.2	645	4.2	645	5.2	646
1979	5.1	75	6.3	496	3.8	75	4.3	489	6.1	571	4.2	564	5.2	573
1980	6.2	87	5.6	583	4.9	87	4.9	588	5.7	670	4.9	675	5.3	676
1981	5.5	83	5.3	634	5.2	83	4.9	636	5.3	717	5.0	719	5.2	720
1982	5.1	85	5.6	897	5.5	85	5.0	893	5.5	982	5.0	978	5.3	983
1983	5.8	70	5.4	835	5.7	71	5.5	836	5.5	905	5.5	907	5.5	909
1984	5.0	85	5.3	910	5.9	85	5.6	908	5.3	995	5.6	993	5.5	1000
1985	6.0	81	5.6	970	6.1	82	5.8	992	5.6	1051	5.8	1074	5.7	1075
1986	5.5	82	6.2	1189	6.0	81	5.8	1199	6.2	1271	5.8	1280	6.0	1281
1987	5.9	104	6.1	1445	5.7	105	5.9	1458	6.1	1549	5.9	1563	6.0	1564
1988	5.7	85	6.0	1607	5.9	85	5.9	1611	5.9	1692	5.9	1696	5.9	1700
1989	5.7	93	6.0	1520	5.7	93	6.1	1533	6.0	1613	6.1	1626	6.0	1627
1990	4.9	102	6.4	1441	5.4	105	6.1	1453	6.3	1543	6.1	1558	6.2	1562
1991	5.4	81	6.1	1268	5.4	81	6.1	1301	6.1	1349	6.1	1382	6.1	1383
1992	4.2	83	4.9	1300	5.8	84	6.1	1330	4.8	1383	6.1	1414	5.5	1415
1993	4.2	99	4.6	1451	5.6	99	6.4	1483	4.6	1550	6.3	1582	5.5	1582
1994	4.3	107	4.3	1483	6.2	107	6.4	1538	4.3	1590	6.4	1645	5.3	1646
1995	4.5	103	4.8	1322	5.9	103	6.4	1387	4.8	1425	6.4	1490	5.6	1492
1996	4.1	79	4.7	1172	6.0	79	6.4	1231	4.7	1251	6.3	1310	5.6	1312
1997	4.3	89	4.6	1169	6.3	89	6.5	1203	4.6	1258	6.5	1292	5.6	1295
1998	4.2	98	4.5	1249	6.0	98	6.7	1286	4.5	1347	6.6	1384	5.6	1389
1999	4.7	108	4.8	1226	6.3	108	6.7	1326	4.8	1334	6.6	1434	5.8	1438
2000	4.3	110	5.1	1386	6.2	110	6.8	1494	5.1	1496	6.7	1604	6.0	1609
2001	4.6	123	5.4	1516	6.0	123	6.8	1647	5.4	1639	6.8	1770	6.1	1778
2002	4.9	124	5.4	1593	6.2	124	7.1	1753	5.4	1717	7.0	1877	6.3	1882
2003	5.1	149	5.8	1481	7.0	149	6.9	1631	5.7	1630	6.9	1780	6.4	1783
2004	5.7	153	6.3	1488	7.1	153	6.9	1626	6.3	1641	7.0	1779	6.7	1787
2005	6.2	161	6.6	1640	7.1	161	6.8	1763	6.6	1801	6.8	1924	6.7	1936
2006	6.2	169	6.9	1572	7.0	169	7.0	1732	6.8	1741	7.0	1901	6.9	1905
2007	7.4	156	7.0	1413	6.7	156	6.8	1587	7.1	1569	6.8	1743	7.0	1748
2008	6.7	165	7.5	1291	6.8	165	7.0	1403	7.4	1456	6.9	1568	7.2	1576
2009	6.4	156	7.4	1081	6.9	156	6.8	1150	7.3	1237	6.9	1306	7.1	1308
2010	6.2	179	7.3	1059	6.6	179	6.8	1102	7.1	1238	6.7	1281	6.9	1281
2011	5.6	150	7.5	898	6.3	150	6.8	912	7.2	1048	6.7	1062	7.0	1070
2012	5.9	166	7.7	700	6.8	166	7.0	720	7.4	866	6.9	886	7.2	892
2013	5.8	134	7.3	450	6.8	134	6.9	454	7.0	584	6.9	588	6.9	588
2014	6.5	102	8.2	222	6.8	102	6.7	226	7.7	324	6.7	328	7.2	329
2015	7.0	33	8.3	58	6.1	33	5.7	59	7.8	91	5.8	92	6.8	92
2016	6.5	6	23.0	2	7.4	6	4.1	1	10.6	8	6.9	7	9.8	8
Total	5.5	-	5.9	-	6.0	-	6.2	-	5.9	-	6.2	-	6.1	-



## 5 Family size

Family size refers to the number of offspring of an individual that become breeding individuals in the next generation (Falconer & Mackay, 1996). Under *ideal conditions* as specified by Falconer & Mackay (1996), parents have an equal chance of contributing offspring to the next generation. In practice, particularly in production animals, genetic contribution of the parents is not the same. Unequal contribution leads to differences or variation in family size.

The consequence of increased variation in family size is an increase in the rate of inbreeding and the reduction in the effective population size ( $N_e = 1/2\Delta F$  where  $N_e$  is the effective population size and  $\Delta F$  is the rate of inbreeding per generation).

The variance of family size can be minimized, i.e. regressed to zero as the number of offspring become equal for all parents. The Table presents the summary statistics for family size (i.e. the maximum

and average) for the male and female parents. Offspring have been categorized into four groups as follows:

**All offspring:** all offspring born in the population.

**Selected offspring:** offspring that have a service record.

**Selected sons:** male offspring that have a service record.

**Selected daughters:** female offspring that have a service record.

In addition, the distribution of family size is also presented. The most influential individuals in the population are also identified (Figures 1 to 8). The information is presented separately for sires and dams considering *all* and *selected offspring*.

Table 6: The maximum and average number of family sizes

Year	All offspring				Selected offspring				Selected sons				Selected daughters			
	sires		dams		sires		dams		sires		dams		sires		dams	
	max	avg	max	avg	max	avg	max	avg	max	avg	max	avg	max	avg	max	avg
1927	3	2.5	3	2.0	3	2.5	3	2.0	2	2.0	1	1.0	3	3.0	2	2.0
1929	53	33.7	4	3.3	35	18.3	4	3.0	5	2.3	2	1.7	30	24.0	3	2.0
1931	78	32.0	4	3.0	47	17.7	3	2.0	8	4.5	-	-	39	14.7	3	2.0
1958	1	1.0	-	-	1	1.0	-	-	-	-	-	-	1	1.0	-	-
1959	5	5.0	1	1.0	2	2.0	1	1.0	1	1.0	1	1.0	1	1.0	-	-
1960	3	1.8	5	2.2	3	1.8	3	1.4	2	1.5	1	1.0	2	1.3	2	1.3
1961	83	42.0	1	1.0	52	26.5	1	1.0	8	8.0	-	-	44	22.5	1	1.0
1962	56	29.0	2	1.4	33	17.4	2	1.3	6	5.0	1	1.0	29	15.4	1	1.0
1963	30	14.3	4	1.9	22	9.1	3	1.5	9	3.0	2	1.1	13	7.4	3	1.4
1964	155	21.5	3	1.5	82	12.0	3	1.5	6	2.6	2	1.2	76	13.7	3	1.4
1965	65	18.8	3	1.6	40	11.2	3	1.4	13	4.4	1	1.0	35	9.5	2	1.3
1966	109	21.5	6	1.9	64	13.6	5	1.5	12	5.6	2	1.1	56	11.5	5	1.5
1967	655	37.8	5	1.7	292	19.7	4	1.5	16	3.1	2	1.3	276	21.2	4	1.4
1968	28	5.3	6	1.6	16	3.3	6	1.4	10	2.5	3	1.3	14	2.8	4	1.3
1969	67	8.1	4	1.4	38	4.4	4	1.3	9	2.6	2	1.2	35	3.8	4	1.2
1970	129	8.4	7	1.7	89	5.1	6	1.4	25	4.0	4	1.3	64	4.4	4	1.3
1971	80	7.8	7	1.4	32	4.9	5	1.3	6	1.7	3	1.1	26	4.7	4	1.3
1972	119	8.1	6	1.4	64	5.1	5	1.3	13	2.4	3	1.1	51	4.7	5	1.2
1973	95	10.2	6	1.4	66	7.0	5	1.3	25	2.5	2	1.1	41	6.4	5	1.3
1974	78	8.5	6	1.5	35	5.4	6	1.4	5	1.6	3	1.3	34	5.2	6	1.3
1975	217	14.1	9	1.6	100	8.4	8	1.4	10	2.5	5	1.3	96	7.9	5	1.3
1976	413	19.9	8	1.5	218	12.2	5	1.3	27	3.8	4	1.3	191	11.4	5	1.2
1977	545	17.9	8	1.5	265	10.9	6	1.3	18	3.1	4	1.2	247	10.7	5	1.3
1978	558	32.1	9	1.5	277	20.2	7	1.3	22	3.3	3	1.2	255	19.0	5	1.3
1979	1150	32.8	7	1.5	536	20.4	6	1.4	27	3.8	3	1.2	509	19.3	5	1.3

*Continue...*

Year	All offspring				Selected offspring				Selected sons				Selected daughters			
	sires		dams		sires		dams		sires		dams		sires		dams	
	max	avg	max	avg	max	avg	max	avg	max	avg	max	avg	max	avg	max	avg
1980	823	28.5	11	1.6	422	17.4	10	1.4	33	3.2	6	1.3	389	16.8	6	1.3
1981	1378	34.8	9	1.6	535	19.2	6	1.3	20	3.5	2	1.2	515	19.2	6	1.3
1982	879	34.8	7	1.6	322	17.7	6	1.4	8	1.9	4	1.3	319	17.7	5	1.3
1983	738	43.3	9	1.6	373	25.2	7	1.4	16	4.8	3	1.2	359	23.6	6	1.3
1984	973	23.7	9	1.6	448	13.0	6	1.3	15	2.5	3	1.1	433	12.7	6	1.3
1985	489	25.9	8	1.6	202	16.1	7	1.4	14	2.7	5	1.2	202	15.6	6	1.4
1986	79	12.6	8	1.6	44	8.5	6	1.4	15	2.9	3	1.1	38	7.7	5	1.4
1987	258	16.6	9	1.6	126	11.0	7	1.4	13	2.3	5	1.4	126	10.5	6	1.4
1988	458	21.5	10	1.6	215	13.6	8	1.5	23	3.2	3	1.2	195	13.4	6	1.4
1989	1031	39.0	9	1.7	475	22.0	8	1.4	30	5.2	3	1.1	445	20.9	7	1.4
1990	2672	50.5	11	1.7	1255	29.0	8	1.5	135	7.6	4	1.3	1120	26.8	7	1.4
1991	575	35.2	8	1.7	307	19.3	6	1.5	7	2.2	3	1.2	301	19.7	6	1.4
1992	1086	40.9	9	1.7	570	22.6	8	1.5	55	6.0	4	1.2	515	21.1	7	1.4
1993	1445	43.0	8	1.7	753	22.8	7	1.5	60	6.0	4	1.2	693	21.1	7	1.4
1994	1480	36.5	8	1.8	731	21.6	7	1.5	75	6.0	4	1.2	656	20.8	6	1.5
1995	1616	54.1	8	1.8	849	31.8	7	1.5	92	5.6	4	1.3	757	30.4	5	1.4
1996	68	13.0	10	1.9	46	8.2	9	1.6	11	2.5	6	1.2	36	7.5	6	1.5
1997	1037	51.8	8	1.8	590	29.4	6	1.5	42	7.1	3	1.2	548	27.4	5	1.4
1998	921	26.1	8	1.8	423	15.2	7	1.5	33	3.7	5	1.3	393	14.1	5	1.4
1999	1164	29.4	10	1.8	580	16.8	8	1.4	44	4.0	5	1.3	536	15.7	5	1.3
2000	564	21.2	8	1.8	231	11.2	6	1.4	22	3.7	4	1.2	209	10.0	6	1.3
2001	390	18.9	11	1.8	143	10.1	6	1.4	13	2.5	4	1.2	135	9.8	6	1.3
2002	958	27.4	10	1.7	294	11.7	7	1.3	28	3.1	3	1.2	266	11.0	5	1.3
2003	553	23.4	10	1.7	256	10.3	8	1.3	34	4.2	4	1.2	222	9.6	6	1.2
2004	530	15.4	7	1.7	165	6.0	5	1.3	25	2.5	3	1.2	140	5.3	5	1.2
2005	88	15.8	9	1.7	34	6.2	4	1.2	11	2.7	4	1.3	32	5.5	3	1.2
2006	855	18.1	7	1.5	220	6.4	5	1.2	32	3.1	3	1.1	188	5.6	4	1.2
2007	738	16.2	6	1.5	190	5.6	5	1.1	32	2.9	4	1.1	158	5.1	3	1.1
2008	649	16.9	6	1.5	109	5.1	3	1.2	30	2.8	3	1.2	79	4.5	2	1.1
2009	344	11.9	5	1.4	47	3.5	3	1.1	10	2.3	3	1.1	37	3.0	3	1.1
2010	51	9.0	4	1.3	18	2.6	2	1.1	9	2.1	2	1.1	9	2.0	2	1.1
2011	245	8.9	4	1.2	25	2.3	2	1.0	11	1.8	2	1.1	14	2.0	1	1.0
2012	231	7.2	4	1.2	3	1.4	1	1.0	2	1.1	1	1.0	2	1.3	1	1.0
2013	18	4.0	3	1.1	1	1.0	1	1.0	1	1.0	1	1.0	1	1.0	1	1.0
2014	134	5.7	2	1.0	-	-	1	1.0	-	-	-	-	-	-	1	1.0
2015	31	2.8	1	1.0	-	-	-	-	-	-	-	-	-	-	-	-
2016	1	1.0	1	1.0	-	-	-	-	-	-	-	-	-	-	-	-
Total	2672	21.2	11	1.6	1255	12.7	10	1.4	135	3.3	6	1.2	1120	12.2	7	1.3

Figure 1: Dams with the most Progeny in the Population

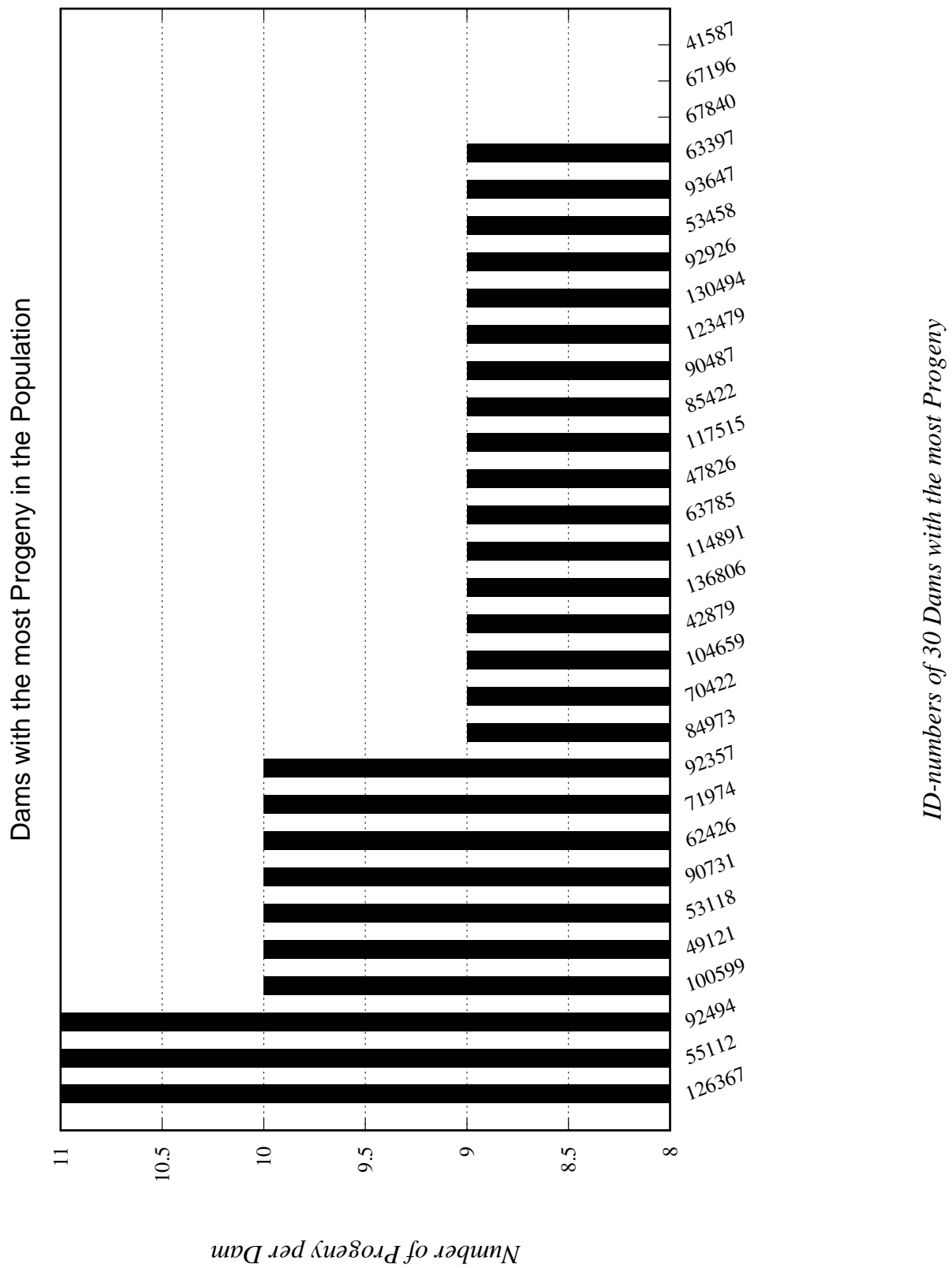


Figure 2: Number of Progeny per Dam

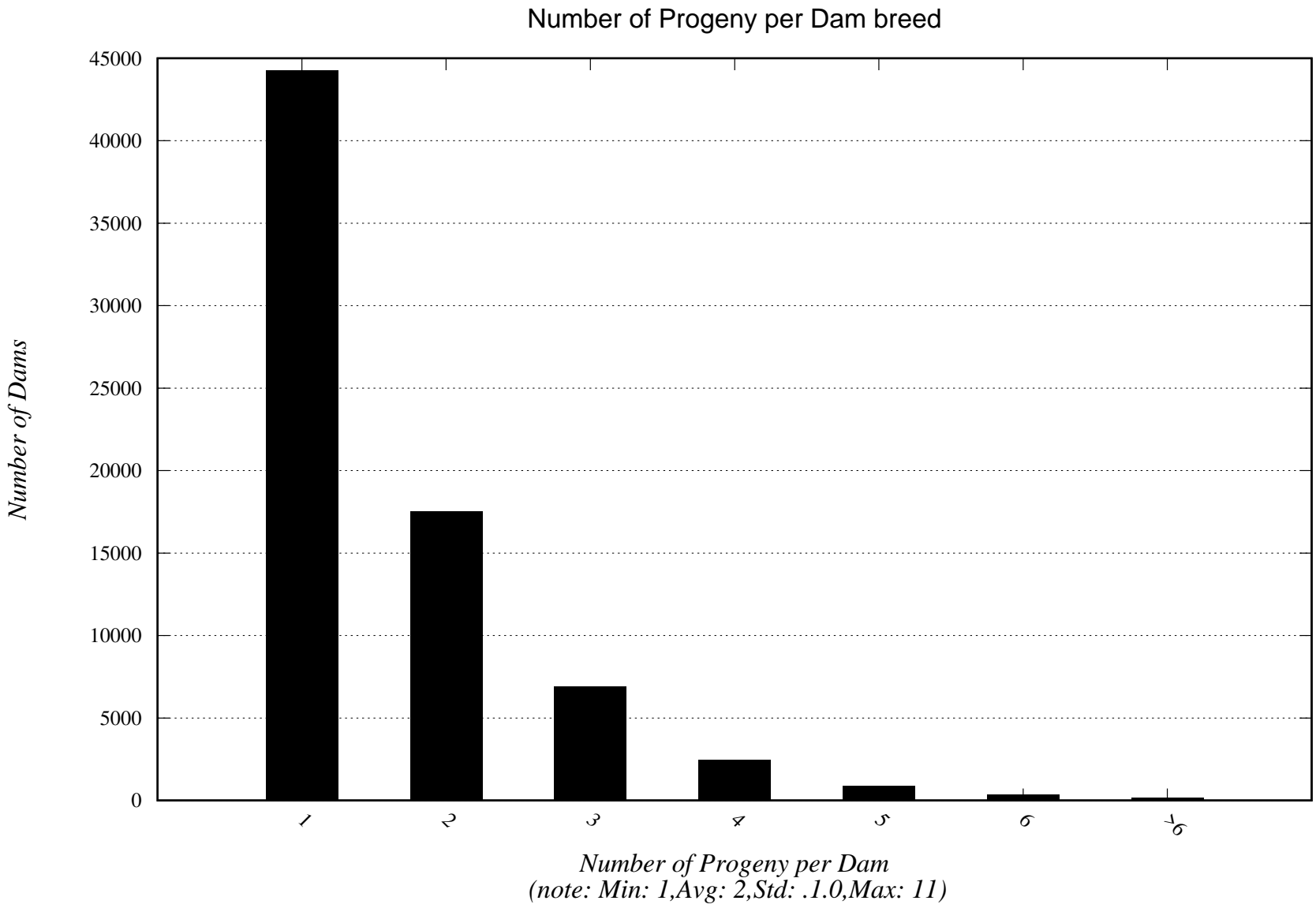


Figure 3: Sires with the most Progeny in the Population

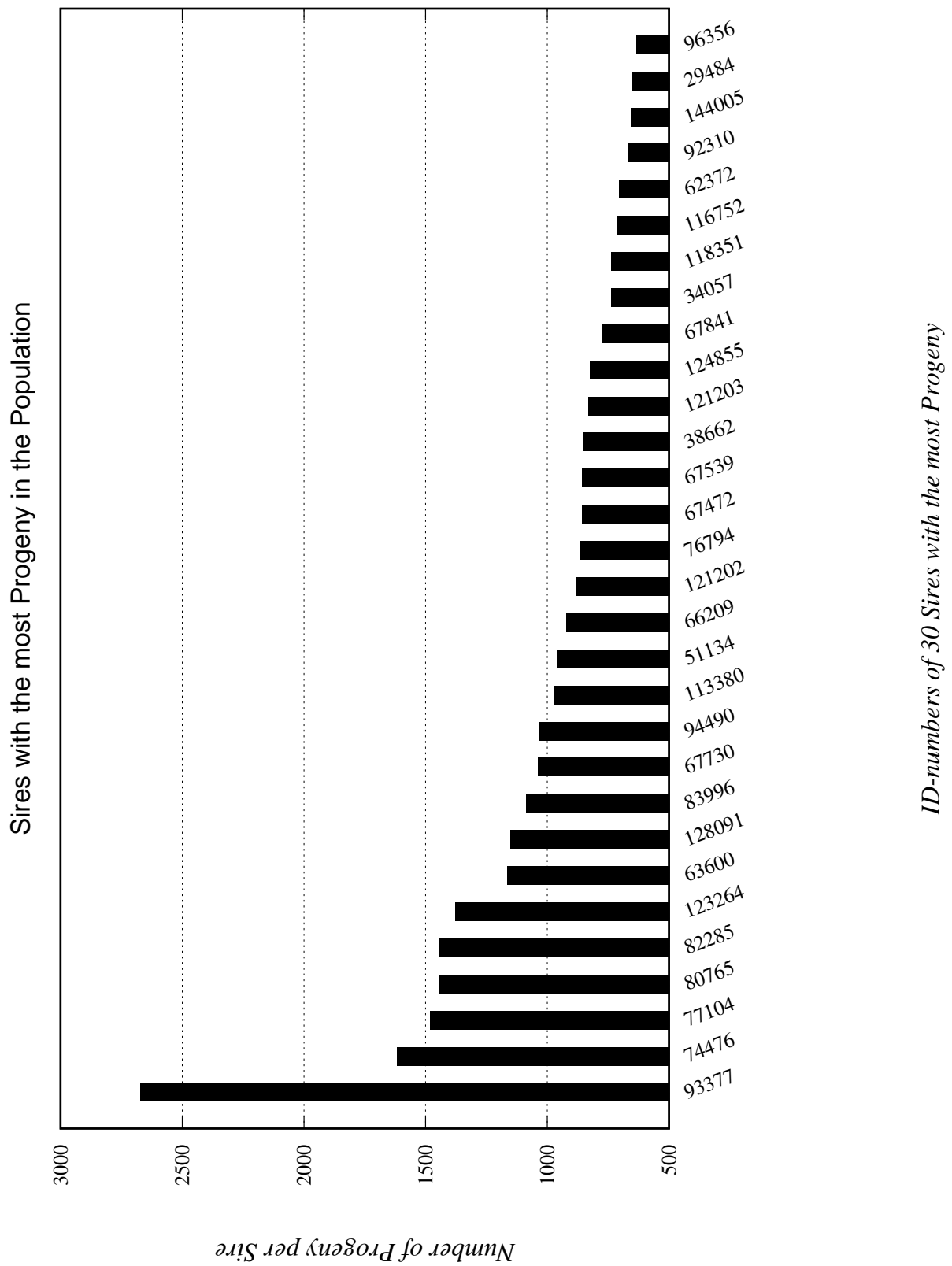


Figure 4: Number of Progeny per Sire

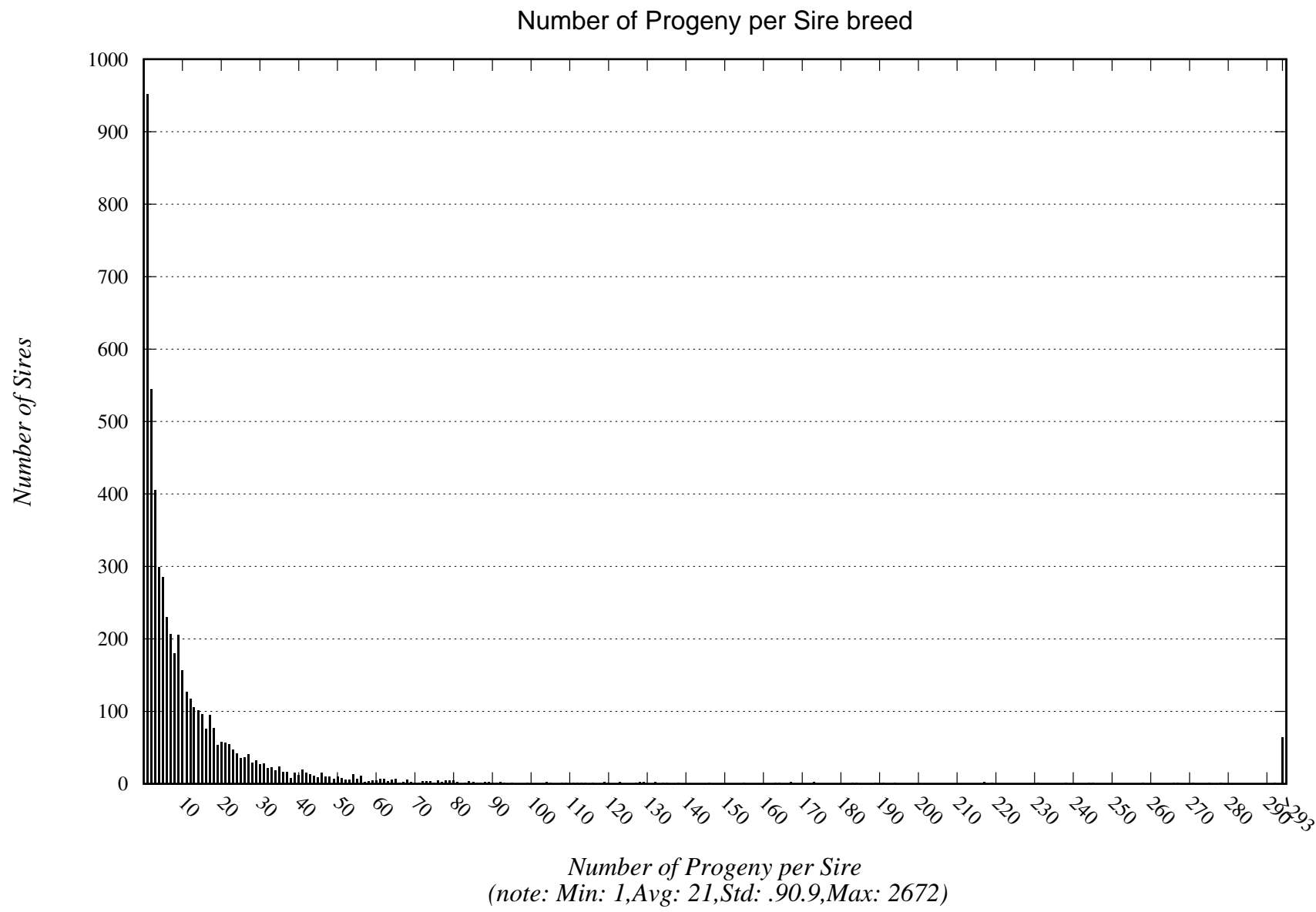


Figure 5: Dams with the most Selected Progeny in the Population

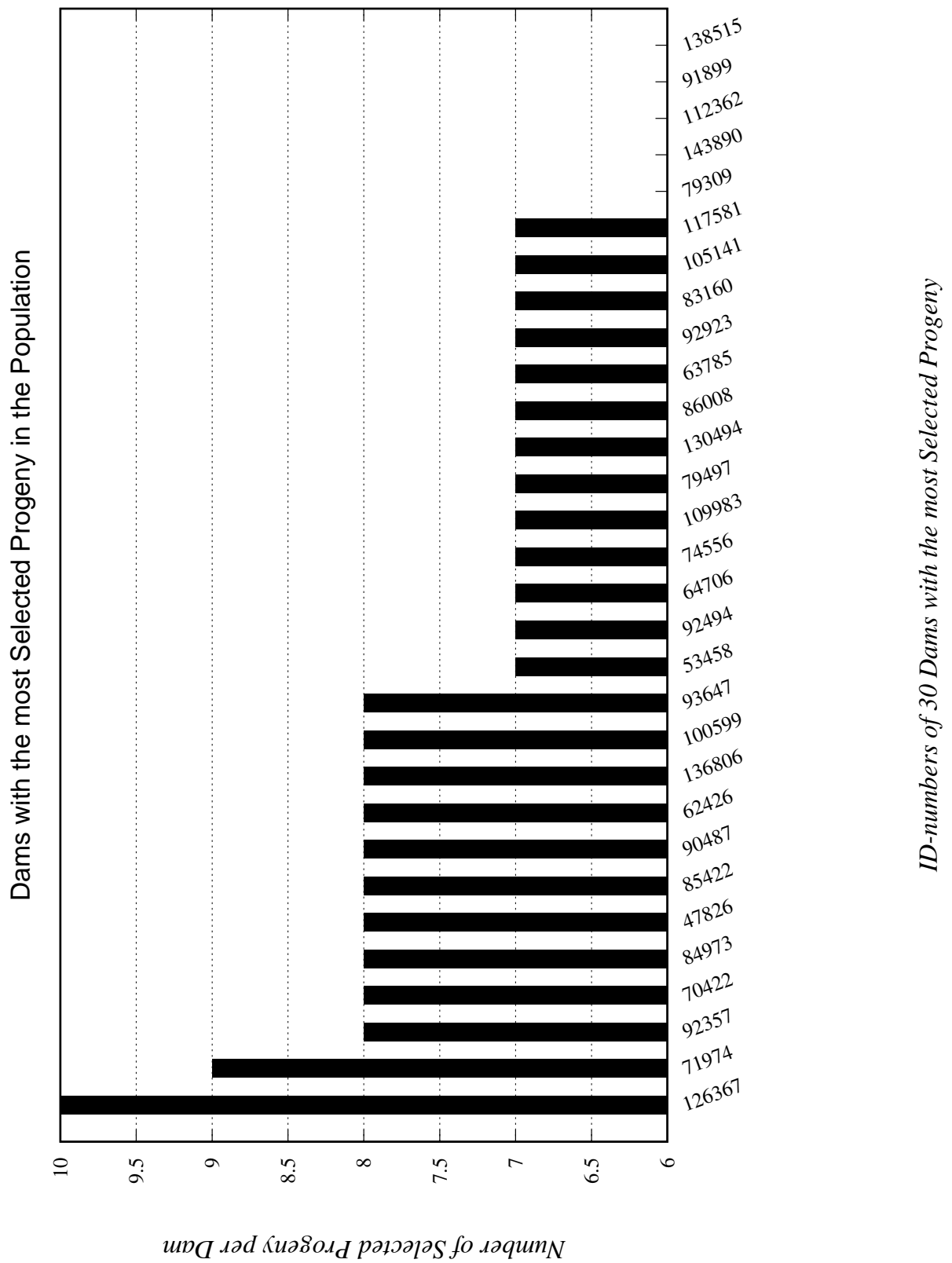


Figure 6: Number of Selected Progeny per Dam

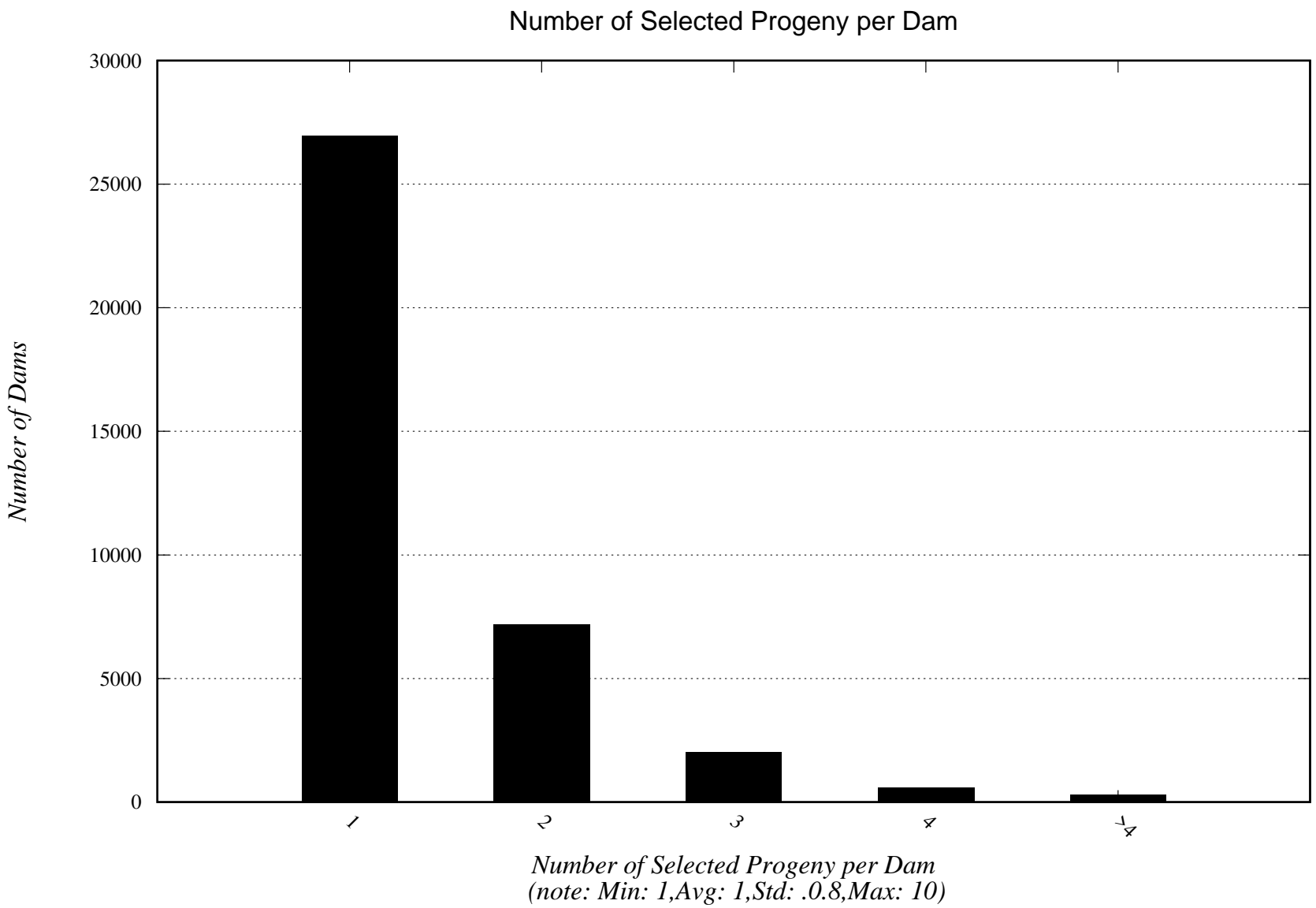




Figure 7: Sires with the most Selected Progeny in the Population

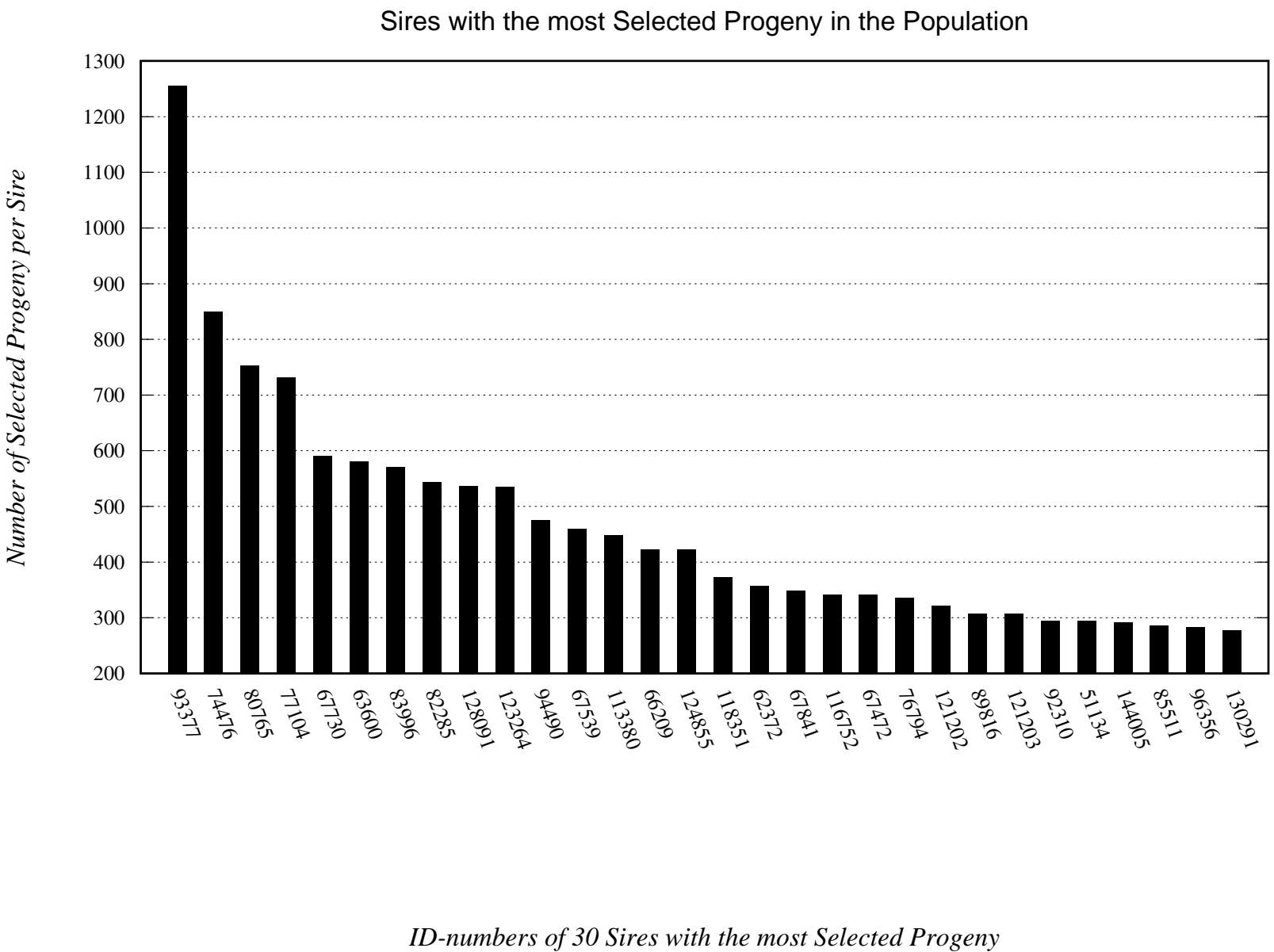


Figure 8: Number of Selected Progeny per Sire

