

# PopReport

## A Pedigree Analysis Report

**Population:** 56  
**Inputfile:** POPREP.TXT  
**Initiated by:** quaglia@anabic.it  
**Submitted at:** 2020-08-26 12:13:41  
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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'.  
87937 input lines processed.  
87937 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
1980	651	651	8710	6144
1981	850	850	9681	4706
1982	958	958	10571	4175
1983	1030	1030	11009	3883
1984	1067	1067	11918	3749
1985	1052	1052	12350	3802
1986	1040	1040	12286	3846
1987	989	989	12448	4044
1988	974	974	12423	4107
1989	942	942	12577	4246
1990	860	860	12598	4651
1991	754	754	12326	5305
1992	648	648	12337	6173
1993	525	525	12023	7619
1994	429	429	11536	9324
2010	457	457	10907	8753
2011	504	504	11451	7937
2012	576	576	11807	6944
2013	644	644	12096	6211
2014	709	709	12981	5642
2015	722	722	13501	5540
2016	708	708	14075	5650
2017	688	688	13239	5814
2018	605	605	11186	6612

# Pedigree Analysis Report for Population: 56

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## 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

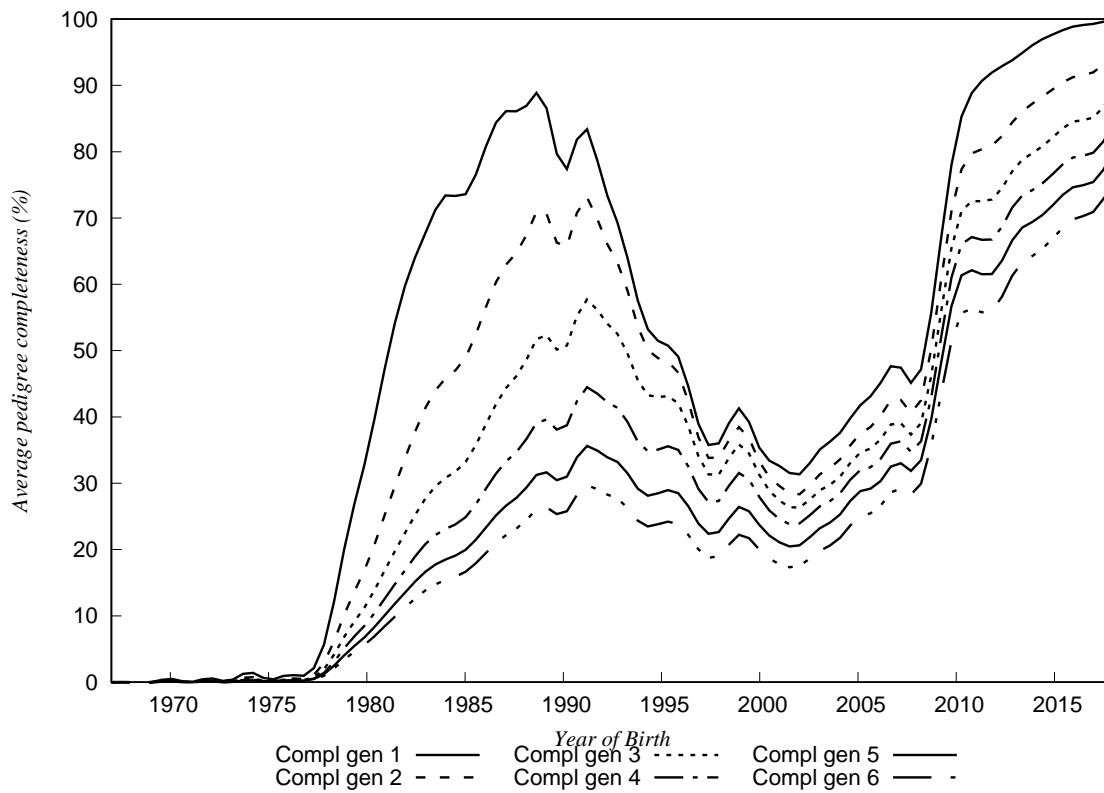
Year	No of Animals	Compl. gen 1	Compl. gen 2	Compl. gen 3	Compl. gen 4	Compl. gen 5	Compl. (%) gen 6(%)
1962	1	0.0	0.0	0.0	0.0	0.0	0.0
1963	1	0.0	0.0	0.0	0.0	0.0	0.0
1964	1	0.0	0.0	0.0	0.0	0.0	0.0
1965	2	0.0	0.0	0.0	0.0	0.0	0.0
1966	10	0.0	0.0	0.0	0.0	0.0	0.0
1967	35	0.0	0.0	0.0	0.0	0.0	0.0
1968	68	0.0	0.0	0.0	0.0	0.0	0.0
1969	71	0.0	0.0	0.0	0.0	0.0	0.0
1970	188	0.5	0.3	0.2	0.1	0.1	0.1
1971	269	0.0	0.0	0.0	0.0	0.0	0.0
1972	515	0.6	0.3	0.2	0.2	0.1	0.1
1973	672	0.2	0.1	0.1	0.0	0.0	0.0
1974	848	1.5	0.8	0.5	0.4	0.3	0.3
1975	975	0.4	0.2	0.2	0.1	0.1	0.1
1976	1217	1.1	0.6	0.4	0.3	0.3	0.2
1977	1704	1.2	0.6	0.4	0.3	0.3	0.2
1978	1550	7.6	3.9	2.6	1.9	1.6	1.3
1979	1834	22.3	11.3	7.6	5.7	4.5	3.8
1980	2081	34.3	17.7	11.8	8.9	7.1	5.9
1981	2145	48.6	26.0	17.4	13.0	10.4	8.7
1982	2215	60.3	34.2	22.8	17.1	13.7	11.4
1983	2214	67.9	41.5	27.8	20.9	16.7	13.9
1984	2496	73.4	45.8	30.8	23.1	18.5	15.4
1985	2251	73.5	48.8	33.1	24.8	19.9	16.6
1986	2005	80.3	56.1	38.5	28.9	23.1	19.3
1987	2256	86.0	62.6	44.0	33.0	26.4	22.0
1988	2175	86.5	66.6	47.9	36.1	28.9	24.1

*Continue...*

Year	No of Animals	Compl. 1 gen	Compl. 2 gen	Compl. 3 gen	Compl. 4 gen	Compl. 5 gen	Compl. (%) 6 gen (%)
1989	2336	88.0	71.4	52.6	39.8	31.8	26.5
1990	2435	77.1	65.0	49.9	38.0	30.4	25.3
1991	1873	83.7	73.0	57.3	44.1	35.3	29.4
1992	1910	75.6	67.6	54.9	42.7	34.3	28.6
1993	1819	67.1	61.6	51.4	40.6	32.6	27.2
1994	1592	55.4	51.8	44.3	35.4	28.5	23.8
1995	1852	51.2	48.7	43.1	35.3	28.7	24.0
1996	1756	48.1	45.7	41.3	34.5	28.1	23.5
1997	1492	37.9	35.9	33.2	28.5	23.4	19.6
1998	1784	36.4	34.2	31.6	27.6	22.9	19.2
1999	1773	41.3	38.5	35.9	31.6	26.5	22.3
2000	1815	35.2	33.1	31.1	27.8	23.6	19.9
2001	1785	32.6	29.6	27.4	24.6	21.1	17.8
2002	2329	31.3	28.3	26.3	23.9	20.6	17.5
2003	2058	34.9	31.2	28.8	26.4	23.1	19.7
2004	1719	37.3	33.3	30.7	28.2	25.0	21.5
2005	1713	41.4	37.2	34.4	31.8	28.6	24.8
2006	1923	44.4	39.5	36.0	33.1	29.8	26.1
2007	2016	48.0	43.0	39.4	36.6	33.2	29.3
2008	1881	45.4	40.9	37.6	35.0	32.2	28.7
2009	2045	61.7	55.8	51.3	47.7	44.1	39.8
2010	1786	82.0	74.6	68.7	64.0	59.5	54.0
2011	2304	89.7	80.1	72.6	67.0	61.9	56.1
2012	2351	92.3	81.3	73.2	67.2	62.0	56.5
2013	2373	94.1	85.0	77.7	72.3	67.4	62.1
2014	2831	96.3	87.5	80.0	74.4	69.6	64.5
2015	2578	97.8	89.6	82.4	76.9	72.2	67.2
2016	2346	98.9	91.3	84.6	79.2	74.7	69.9
2017	1448	99.3	92.0	85.2	79.9	75.5	71.0
2018	215	100.0	94.9	89.2	84.1	80.0	75.7

The average pedigree completeness for animals born within the last 10 years: 1 generations deep = 90.7%. 2 generations deep = 82.3%. 3 generations deep = 75.4%. 4 generations deep = 70.1%. 5 generations deep = 65.4%. 6 generations deep = 60.3%.

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 1967 and 2018 for the 56 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
1962	1	-	-	-	-	-	-	-	-	-	-
1963	1	-	-	-	-	-	-	-	-	-	-
1964	1	-	-	-	-	-	-	-	-	-	-
1965	2	-	-	-	-	-	-	-	-	-	-
1966	10	-	-	-	-	-	-	-	-	-	-
1967	35	-	-	-	-	-	-	-	-	-	-
1968	68	-	-	-	-	-	-	-	-	-	-
1969	71	-	-	-	-	-	-	-	-	-	-
1970	188	-	-	-	-	-	-	-	-	-	-
1971	269	-	-	-	-	-	-	-	-	-	-
1972	515	-	-	-	-	-	-	-	-	-	-
1973	672	-	-	-	-	-	-	-	-	-	-
1974	848	-	-	-	-	-	-	-	-	-	-
1975	975	-	-	-	-	-	-	-	-	-	-
1976	1217	-	-	-	-	-	-	-	-	-	-
1977	1704	-	-	-	-	-	-	-	-	-	-
1978	1549	1	-	-	-	-	-	-	-	-	-
1979	1833	-	-	-	1	-	-	-	-	-	-
1980	2079	-	-	-	2	-	-	-	-	-	-
1981	2129	-	1	-	14	-	-	1	-	-	-
1982	2175	1	15	-	24	-	-	-	-	-	-
1983	2155	-	25	-	34	-	-	-	-	-	-
1984	2370	5	55	2	63	-	-	1	-	-	-
1985	2142	15	53	5	36	-	-	-	-	-	-
1986	1836	11	92	4	60	-	2	-	-	-	-
1987	2011	45	119	14	66	1	-	-	-	-	-
1988	1863	69	157	24	61	-	1	-	-	-	-
1989	1923	113	180	45	67	5	3	-	-	-	-
1990	1951	119	231	51	77	1	4	1	-	-	-
1991	1416	129	195	53	65	9	2	4	-	-	-
1992	1459	152	165	56	51	10	11	4	-	2	-
1993	1362	125	159	80	66	9	15	2	1	-	-
1994	1245	124	87	53	58	12	10	2	1	-	-
1995	1449	126	110	69	71	14	7	5	1	-	-
1996	1451	98	77	71	25	9	19	6	-	-	-
1997	1297	60	49	45	24	12	3	2	-	-	-
1998	1578	65	55	41	20	14	8	2	-	-	1

*Continue...*

Year	Classes										
	1	2	3	4	5	6	7	8	9	10	11
1999	1577	57	54	42	29	9	5	-	-	-	-
2000	1599	53	62	45	19	28	7	2	-	-	-
2001	1642	36	26	37	22	14	2	4	2	-	-
2002	2120	49	59	33	28	33	3	4	-	-	-
2003	1852	77	37	34	28	19	7	3	1	-	-
2004	1555	64	23	37	18	20	1	1	-	-	-
2005	1530	64	32	30	22	23	6	4	2	-	-
2006	1755	51	19	43	26	19	5	5	-	-	-
2007	1843	55	29	30	31	14	12	2	-	-	-
2008	1759	48	17	22	18	11	4	2	-	-	-
2009	1825	86	46	33	21	26	3	5	-	-	-
2010	1484	122	54	38	34	47	6	1	-	-	-
2011	1995	106	85	29	40	44	5	-	-	-	-
2012	2027	123	76	35	46	34	7	3	-	-	-
2013	2017	113	95	41	39	48	18	1	1	-	-
2014	2320	153	110	81	72	76	12	4	2	1	-
2015	2090	146	85	55	71	111	14	6	-	-	-
2016	1889	117	88	81	64	85	20	1	1	-	-
2017	1182	120	34	25	35	46	4	1	1	-	-
2018	178	20	6	6	3	2	-	-	-	-	-

## 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

**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 $F$
1962	1	-	-	-	-	-	-	-	-
1963	1	-	-	-	-	-	-	-	-
1964	1	-	-	-	-	-	-	-	-
1965	2	-	-	-	-	-	-	-	-
1966	10	-	-	-	-	-	-	-	-
1967	35	-	-	-	-	-	-	-	-
1968	68	-	-	-	-	-	-	-	-
1969	71	-	-	-	-	-	-	-	-
1970	188	-	-	1	-	-	1	-	-
1971	269	-	-	-	-	-	2	-	-
1972	515	-	-	2	-	-	8	-	-
1973	672	-	-	1	-	-	6	-	-
1974	848	-	-	3	-	-	25	-	-
1975	975	-	-	6	-	-	21	-	-
1976	1217	-	-	10	-	-	89	-	-
1977	1704	-	-	16	-	-	182	-	-
1978	1550	1	0.0000	40	-	-	496	-	-
1979	1834	1	0.0001	131	-	-	925	-	-
1980	2081	2	0.0002	209	-	-	1167	1	0.0001
1981	2145	16	0.0019	273	-	-	1495	1	0.0002
1982	2215	40	0.0036	379	-	-	1643	1	0.0002
1983	2214	60	0.0053	424	-	-	1755	2	0.0003
1984	2496	126	0.0095	430	3	0.0015	2031	4	0.0005
1985	2251	111	0.0078	466	4	0.0014	1851	7	0.0007
1986	2005	172	0.0143	449	4	0.0017	1725	8	0.0008
1987	2256	249	0.0164	481	16	0.0052	2000	20	0.0018
1988	2175	319	0.0203	456	18	0.0063	1926	21	0.0018
1989	2336	432	0.0247	487	35	0.0122	2100	56	0.0046
1990	2435	537	0.0279	451	51	0.0175	2163	77	0.0056
1991	1873	502	0.0344	390	62	0.0245	1626	95	0.0100
1992	1910	512	0.0334	329	68	0.0311	1624	124	0.0119
1993	1819	529	0.0382	265	57	0.0325	1471	157	0.0156
1994	1592	446	0.0335	209	56	0.0378	1194	172	0.0193
1995	1852	521	0.0340	170	54	0.0425	1406	231	0.0216
1996	1756	410	0.0274	146	59	0.0513	1362	308	0.0301
1997	1492	257	0.0206	100	49	0.0565	1009	214	0.0270
1998	1784	270	0.0186	108	60	0.0620	1160	249	0.0256
1999	1773	261	0.0175	112	63	0.0633	1311	259	0.0247
2000	1815	266	0.0199	106	62	0.0673	1393	270	0.0218

*Continue...*

Year	Animal			Sires			Dams		
	Tot No	Inbred No	Avg $F$	Tot No	Inbred No	Avg $F$	Tot No	Inbred No	Avg $F$
2001	1785	189	0.0140	107	62	0.0604	1414	275	0.0236
2002	2329	251	0.0155	122	66	0.0634	1912	336	0.0209
2003	2058	256	0.0160	123	65	0.0632	1782	326	0.0230
2004	1719	229	0.0150	117	56	0.0505	1528	266	0.0194
2005	1713	270	0.0184	122	63	0.0558	1566	265	0.0211
2006	1923	295	0.0156	126	71	0.0586	1776	284	0.0180
2007	2016	312	0.0150	142	84	0.0627	1867	337	0.0213
2008	1881	294	0.0113	135	78	0.0646	1722	288	0.0181
2009	2045	522	0.0186	158	90	0.0564	1923	346	0.0205
2010	1786	616	0.0284	192	100	0.0501	1692	396	0.0238
2011	2304	712	0.0228	254	140	0.0524	2221	431	0.0208
2012	2351	763	0.0230	332	188	0.0456	2260	411	0.0189
2013	2373	921	0.0272	356	211	0.0448	2298	510	0.0225
2014	2831	1252	0.0334	391	233	0.0384	2769	612	0.0195
2015	2578	1280	0.0371	385	241	0.0367	2532	597	0.0216
2016	2346	1345	0.0385	400	267	0.0399	2311	570	0.0195
2017	1448	918	0.0331	350	246	0.0440	1432	337	0.0209
2018	215	150	0.0270	106	74	0.0439	214	61	0.0250

### 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
1962	1	0.0000	0.0000	0.0000	-
1963	1	0.0000	0.0000	0.0000	-
1964	1	0.0000	0.0000	0.0000	-
1965	2	0.0000	0.0000	0.0000	0.0000
1966	10	0.0000	0.0000	0.0000	0.0000
1967	35	0.0000	0.0000	0.0000	0.0000
1968	68	0.0000	0.0000	0.0000	0.0000
1969	71	0.0000	0.0000	0.0000	0.0000
1970	188	0.0000	0.0000	0.0000	0.0000
1971	269	0.0000	0.0000	0.0000	0.0000
1972	515	0.0000	0.0000	0.0000	0.0000
1973	672	0.0000	0.0000	0.0000	0.0000
1974	848	0.0000	0.0000	0.0000	0.0000
1975	975	0.0000	0.0000	0.0000	0.0000
1976	1217	0.0000	0.0000	0.0000	0.0000
1977	1704	0.0000	0.0000	0.0000	0.0000
1978	1550	0.0000	0.0625	0.0000	0.0016
1979	1834	0.0000	0.2500	0.0001	0.0058
1980	2081	0.0000	0.2500	0.0002	0.0077
1981	2145	0.0000	0.3750	0.0019	0.0219
1982	2215	0.0000	0.2500	0.0036	0.0278
1983	2214	0.0000	0.2500	0.0053	0.0333
1984	2496	0.0000	0.3750	0.0095	0.0439
1985	2251	0.0000	0.2500	0.0078	0.0375
1986	2005	0.0000	0.3125	0.0143	0.0506
1987	2256	0.0000	0.2813	0.0164	0.0517
1988	2175	0.0000	0.3125	0.0203	0.0547
1989	2336	0.0000	0.3125	0.0247	0.0593
1990	2435	0.0000	0.3750	0.0279	0.0614
1991	1873	0.0000	0.3750	0.0344	0.0674
1992	1910	0.0000	0.5000	0.0334	0.0685
1993	1819	0.0000	0.4063	0.0382	0.0725
1994	1592	0.0000	0.4375	0.0335	0.0691
1995	1852	0.0000	0.4150	0.0340	0.0699
1996	1756	0.0000	0.3750	0.0274	0.0645
1997	1492	0.0000	0.3574	0.0206	0.0561
1998	1784	0.0000	0.5156	0.0186	0.0558
1999	1773	0.0000	0.3281	0.0175	0.0523
2000	1815	0.0000	0.3750	0.0199	0.0588

*Continue...*

Year	No of Animals	<i>F</i>			
		Min	Max	Avg	Std
2001	1785	0.0000	0.4063	0.0140	0.0514
2002	2329	0.0000	0.3750	0.0155	0.0538
2003	2058	0.0000	0.4063	0.0160	0.0533
2004	1719	0.0000	0.3516	0.0150	0.0495
2005	1713	0.0000	0.4336	0.0184	0.0580
2006	1923	0.0000	0.3906	0.0156	0.0533
2007	2016	0.0000	0.3750	0.0150	0.0516
2008	1881	0.0000	0.3733	0.0113	0.0430
2009	2045	0.0000	0.3984	0.0186	0.0523
2010	1786	0.0000	0.3604	0.0284	0.0645
2011	2304	0.0000	0.3379	0.0228	0.0574
2012	2351	0.0000	0.3750	0.0230	0.0580
2013	2373	0.0000	0.4336	0.0272	0.0643
2014	2831	0.0000	0.4717	0.0334	0.0708
2015	2578	0.0000	0.3984	0.0371	0.0755
2016	2346	0.0000	0.4141	0.0385	0.0751
2017	1448	0.0000	0.4354	0.0331	0.0669
2018	215	0.0000	0.2695	0.0270	0.0518

## 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.

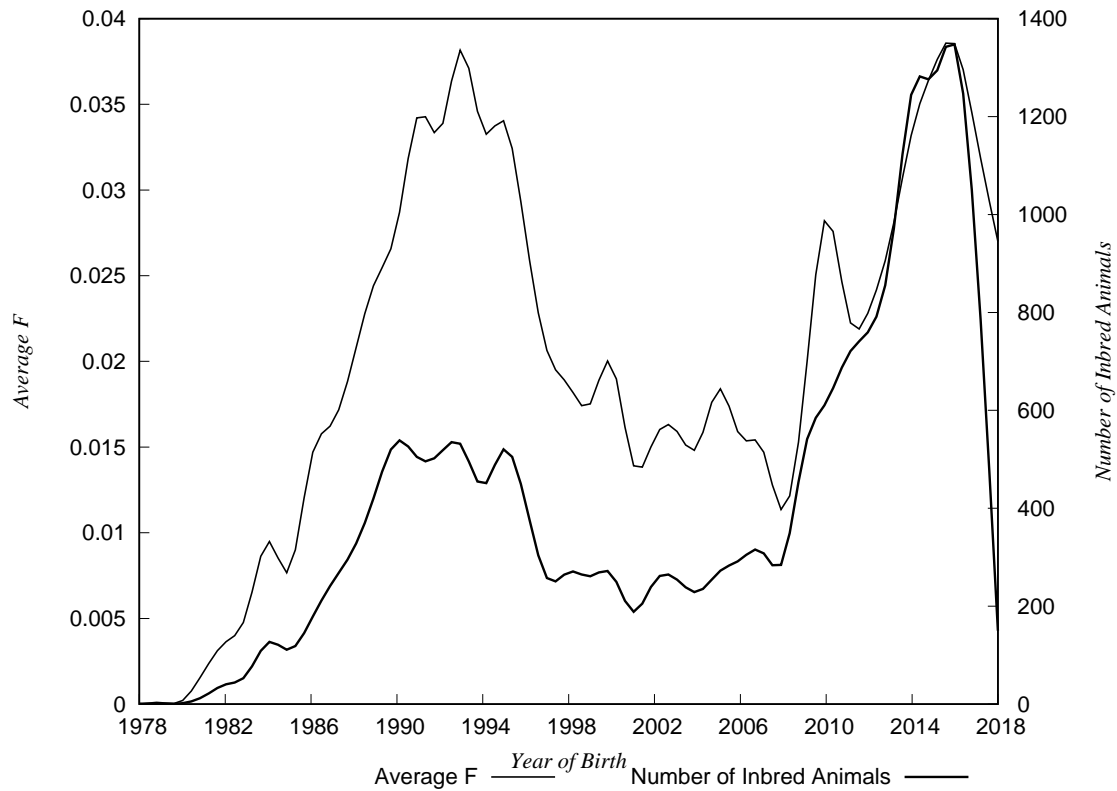
Table 5: Inbreeding coefficients ( $F$ ) of INBRED animals by year

Year	No of Animals	$F$			
		Min	Max	Avg	Std
1978	1	0.0625	0.0625	0.0625	-
1979	1	0.2500	0.2500	0.2500	-
1980	2	0.2500	0.2500	0.2500	0.0000
1981	16	0.1250	0.3750	0.2500	0.0456
1982	40	0.0625	0.2500	0.1984	0.0647
1983	60	0.0313	0.2500	0.1943	0.0654
1984	126	0.0625	0.3750	0.1880	0.0678
1985	111	0.0313	0.2500	0.1581	0.0697
1986	172	0.0313	0.3125	0.1662	0.0682
1987	249	0.0313	0.2813	0.1485	0.0681
1988	319	0.0156	0.3125	0.1381	0.0640
1989	432	0.0313	0.3125	0.1335	0.0672
1990	537	0.0156	0.3750	0.1267	0.0677
1991	502	0.0078	0.3750	0.1283	0.0701
1992	512	0.0078	0.5000	0.1247	0.0782
1993	529	0.0078	0.4063	0.1315	0.0762
1994	446	0.0078	0.4375	0.1195	0.0824
1995	521	0.0039	0.4150	0.1208	0.0829
1996	410	0.0039	0.3750	0.1173	0.0853
1997	257	0.0020	0.3574	0.1198	0.0800
1998	270	0.0039	0.5156	0.1227	0.0886
1999	261	0.0010	0.3281	0.1189	0.0807
2000	266	0.0029	0.3750	0.1355	0.0890
2001	189	0.0020	0.4063	0.1321	0.0967
2002	251	0.0010	0.3750	0.1437	0.0918
2003	256	0.0010	0.4063	0.1286	0.0914
2004	229	0.0002	0.3516	0.1123	0.0867
2005	270	0.0010	0.4336	0.1167	0.0996
2006	295	0.0005	0.3906	0.1016	0.0991
2007	312	0.0002	0.3750	0.0972	0.0963
2008	294	0.0002	0.3733	0.0725	0.0861
2009	522	0.0001	0.3984	0.0729	0.0823
2010	616	0.0001	0.3604	0.0823	0.0874
2011	712	0.0002	0.3379	0.0737	0.0832
2012	763	0.0001	0.3750	0.0710	0.0834
2013	921	0.0001	0.4336	0.0701	0.0874
2014	1252	0.0001	0.4717	0.0756	0.0903
2015	1280	0.0000	0.3984	0.0748	0.0931

Continue...

Year	No of Animals	$F$			
		Min	Max	Avg	Std
2016	1345	0.0000	0.4141	0.0672	0.0889
2017	918	0.0000	0.4354	0.0521	0.0779
2018	150	0.0000	0.2695	0.0386	0.0583

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 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		
1962	-	-	-	-	-	-
1963	-	-	-	-	-	-
1964	-	-	-	-	-	-
1965	-	-	-	-	-	-
1966	-	-	-	-	-	-
1967	-	-	-	-	-	-
1968	-	-	-	-	-	-
1969	-	-	-	-	-	-
1970	0.0000	0.0000	0.0000	0.0000	0.0000	-
1971	0.0000	0.0000	0.0000	0.0000	0.0000	-
1972	0.0000	0.0000	0.0000	0.0000	0.0000	-
1973	0.0000	0.0000	0.0000	0.0000	0.0000	-
1974	0.0000	0.0000	0.0000	0.0000	0.0000	-
1975	0.0000	0.0000	0.0000	0.0000	0.0000	-
1976	0.0000	0.0000	0.0000	0.0000	0.0000	-
1977	0.0000	0.0000	0.0000	0.0000	0.0000	-
1978	0.0000	0.0000	0.0000	0.0000	0.0000	55728
1979	0.0000	0.0000	0.0000	0.0000	0.0000	13005
1980	0.0001	0.0000	0.0000	0.0000	0.0001	6927
1981	0.0005	0.0000	0.0001	0.0000	0.0004	1215
1982	0.0011	0.0000	0.0001	0.0001	0.0010	477
1983	0.0020	0.0000	0.0001	0.0001	0.0019	257
1984	0.0037	0.0001	0.0002	0.0002	0.0035	141
1985	0.0049	0.0004	0.0003	0.0004	0.0045	111
1986	0.0070	0.0008	0.0004	0.0006	0.0064	78

*Continue...*

Year	Avg $F$		Dams	Parents	$\Delta F$	$N_e$
	Animals	Sires				
1987	0.0094	0.0019	0.0007	0.0013	0.0081	61
1988	0.0121	0.0028	0.0010	0.0019	0.0103	49
1989	0.0154	0.0053	0.0017	0.0035	0.0120	42
1990	0.0188	0.0083	0.0027	0.0054	0.0135	37
1991	0.0229	0.0119	0.0040	0.0078	0.0152	33
1992	0.0258	0.0160	0.0056	0.0107	0.0153	33
1993	0.0293	0.0201	0.0076	0.0136	0.0159	31
1994	0.0315	0.0248	0.0101	0.0170	0.0147	34
1995	0.0333	0.0304	0.0130	0.0209	0.0126	40
1996	0.0335	0.0382	0.0175	0.0267	0.0070	71
1997	0.0315	0.0452	0.0203	0.0308	0.0008	638
1998	0.0289	0.0510	0.0229	0.0342	-0.0054	-92
1999	0.0253	0.0581	0.0247	0.0375	-0.0126	-40
2000	0.0231	0.0642	0.0250	0.0393	-0.0168	-30
2001	0.0196	0.0684	0.0253	0.0401	-0.0214	-23
2002	0.0175	0.0684	0.0236	0.0380	-0.0213	-23
2003	0.0168	0.0656	0.0231	0.0363	-0.0202	-25
2004	0.0163	0.0617	0.0221	0.0341	-0.0185	-27
2005	0.0164	0.0593	0.0216	0.0328	-0.0169	-30
2006	0.0157	0.0567	0.0209	0.0316	-0.0164	-30
2007	0.0159	0.0558	0.0207	0.0315	-0.0162	-31
2008	0.0152	0.0548	0.0202	0.0311	-0.0165	-30
2009	0.0157	0.0550	0.0197	0.0316	-0.0165	-30
2010	0.0178	0.0564	0.0205	0.0337	-0.0164	-30
2011	0.0186	0.0551	0.0205	0.0343	-0.0162	-31
2012	0.0199	0.0523	0.0206	0.0342	-0.0147	-34
2013	0.0221	0.0498	0.0208	0.0339	-0.0122	-41
2014	0.0259	0.0461	0.0209	0.0328	-0.0072	-70
2015	0.0290	0.0433	0.0211	0.0319	-0.0030	-166
2016	0.0306	0.0414	0.0205	0.0308	-0.0002	-2627
2017	0.0321	0.0400	0.0204	0.0301	0.0021	241
2018	0.0338	0.0393	0.0207	0.0299	0.0040	124

### 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	
1962	1	1	1	2	1
1963	2	1	1	2	1
1964	3	1	1	2	1
1965	5	1	1	2	1
1966	15	1	1	2	1
1967	50	1	1	2	1
1968	117	1	1	2	1
1969	187	1	1	2	1
1970	374	2	2	4	3
1971	641	2	4	6	4
1972	1146	4	12	16	8
1973	1783	5	18	23	11
1974	2563	8	43	51	19
1975	3467	13	64	77	30
1976	4496	21	149	170	52
1977	5931	34	325	359	86
1978	6966	57	791	848	149
1979	8128	152	1645	1797	390
1980	9361	266	2634	2900	676
1981	10531	382	3809	4191	972
1982	11529	569	4984	5553	1430
1983	12039	746	6141	6887	1863

*Continue...*

Year	Number of				$N_e$
	Animals	Sires	Dams	Parents	
1984	12985	880	7280	8160	2198
1985	13402	1040	8002	9042	2577
1986	13326	1139	8495	9634	2812
1987	13437	1237	8917	10154	3042
1988	13397	1282	9210	10492	3151
1989	13519	1306	9420	10726	3212
1990	13458	1294	9461	10755	3187
1991	13080	1260	9219	10479	3104
1992	12985	1200	9067	10267	2967
1993	12548	1094	8670	9764	2720
1994	11965	1002	8123	9125	2498
1995	11481	879	7605	8484	2206
1996	10802	736	6980	7716	1864
1997	10421	600	6466	7066	1537
1998	10295	496	6090	6586	1284
1999	10249	428	5926	6354	1118
2000	10472	353	6101	6454	934
2001	10405	305	6178	6483	814
2002	10978	263	6663	6926	708
2003	11544	262	7247	7509	708
2004	11479	263	7570	7833	712
2005	11419	268	7798	8066	725
2006	11527	276	8108	8384	747
2007	11758	300	8401	8701	811
2008	11310	299	8186	8485	808
2009	11297	320	8213	8533	862
2010	11364	348	8234	8582	935
2011	11955	408	8612	9020	1091
2012	12383	500	8888	9388	1325
2013	12740	560	9078	9638	1477
2014	13690	650	9717	10367	1706
2015	14223	715	10095	10810	1870
2016	14783	798	10494	11292	2076
2017	13927	860	10022	10882	2218
2018	11791	819	8879	9698	2100

## 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)

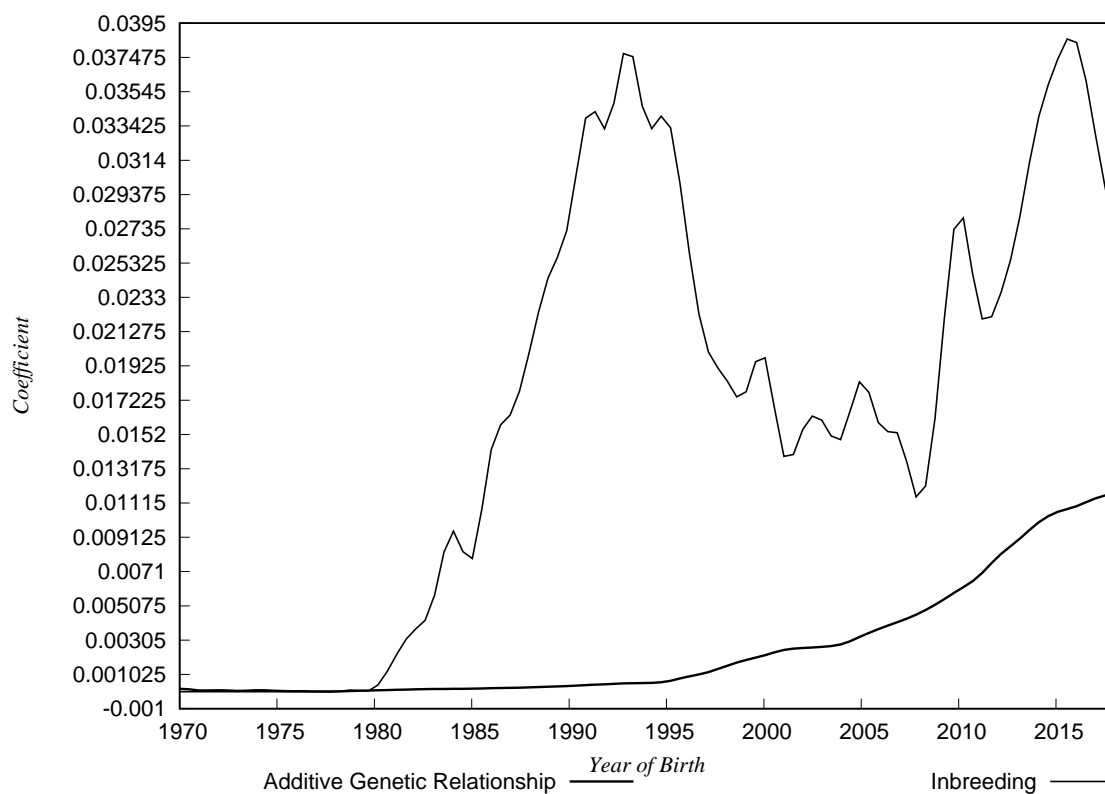
Year	No Animals	AGR		$F$		Generation Interval
		Avg	$\Delta f$	Avg	$\Delta F$	( ) = True GI
1962	1	0.00000	-	0.00000	-	-
1963	2	0.00000	-	0.00000	-	-
1964	3	0.00000	-	0.00000	-	-
1965	5	0.00000	-	0.00000	-	-
1966	15	0.00000	-	0.00000	-	-
1967	50	0.00000	-	0.00000	-	-
1968	117	0.00000	0.00000	0.00000	0.00000	6 (-)
1969	187	0.00000	0.00000	0.00000	0.00000	6 (-)
1970	374	0.00017	0.00017	0.00000	0.00000	6 (-)
1971	641	0.00008	0.00008	0.00000	0.00000	6 (-)

*Continue...*

Year	No Animals	AGR		<i>F</i>		Generation Interval
		Avg	$\Delta f$	Avg	$\Delta F$	() = True GI
1972	1146	0.00009	0.00009	0.00000	0.00000	6 (-)
1973	1783	0.00005	0.00005	0.00000	0.00000	6 (-)
1974	2563	0.00009	0.00009	0.00000	0.00000	2 (2.3)
1975	3467	0.00005	0.00005	0.00000	0.00000	4 (4.2)
1976	4496	0.00003	-0.00014	0.00000	0.00000	4 (3.8)
1977	5931	0.00002	-0.00006	0.00000	0.00000	4 (4.4)
1978	6966	0.00002	-0.00006	0.00000	0.00000	4 (4.4)
1979	8128	0.00005	0.00000	0.00010	0.00010	5 (4.6)
1980	6795	0.00008	-0.00001	0.00020	0.00020	5 (4.8)
1981	5556	0.00011	0.00006	0.00190	0.00190	5 (5.1)
1982	5133	0.00014	0.00011	0.00360	0.00360	5 (5.0)
1983	4913	0.00016	0.00014	0.00530	0.00530	5 (5.2)
1984	4816	0.00017	0.00015	0.00950	0.00950	5 (5.4)
1985	4854	0.00018	0.00013	0.00780	0.00770	6 (5.6)
1986	4886	0.00021	0.00013	0.01430	0.01410	6 (5.7)
1987	5033	0.00023	0.00012	0.01640	0.01453	6 (5.8)
1988	5081	0.00026	0.00012	0.02030	0.01676	6 (5.8)
1989	5188	0.00030	0.00014	0.02470	0.01950	6 (6.0)
1990	5511	0.00034	0.00017	0.02790	0.01858	6 (5.9)
1991	6059	0.00040	0.00021	0.03440	0.02681	6 (5.7)
1992	6821	0.00045	0.00024	0.03340	0.01938	6 (5.9)
1993	8144	0.00050	0.00027	0.03820	0.02216	6 (6.2)
1994	9753	0.00052	0.00026	0.03350	0.01347	6 (6.3)
1995	11481	0.00060	0.00030	0.03400	0.00954	6 (6.4)
1996	10802	0.00087	0.00053	0.02740	-0.00051	7 (6.7)
1997	10421	0.00111	0.00071	0.02060	-0.01429	7 (6.6)
1998	10295	0.00149	0.00104	0.01860	-0.01531	7 (6.6)
1999	10249	0.00185	0.00135	0.01750	-0.02152	7 (6.5)
2000	10472	0.00214	0.00163	0.01990	-0.01407	7 (6.7)
2001	10405	0.00246	0.00186	0.01400	-0.02070	7 (6.8)
2002	10978	0.00258	0.00171	0.01550	-0.01224	7 (6.9)
2003	11544	0.00265	0.00154	0.01600	-0.00470	7 (7.1)
2004	11479	0.00281	0.00132	0.01500	-0.00367	7 (7.0)
2005	11419	0.00328	0.00142	0.01840	0.00092	7 (7.0)
2006	11527	0.00375	0.00162	0.01560	-0.00439	7 (7.0)
2007	11758	0.00417	0.00171	0.01500	0.00101	7 (6.9)
2008	11310	0.00465	0.00208	0.01130	-0.00427	7 (7.2)
2009	11297	0.00528	0.00264	0.01860	0.00264	7 (6.8)
2010	9210	0.00601	0.00320	0.02840	0.01360	7 (6.5)
2011	8441	0.00679	0.00352	0.02280	0.00448	7 (6.6)
2012	7520	0.00796	0.00422	0.02300	0.00752	6 (6.4)
2013	6855	0.00890	0.00474	0.02720	0.01239	6 (6.4)
2014	6351	0.00991	0.00529	0.03340	0.02235	6 (6.3)
2015	6262	0.01059	0.00534	0.03710	0.01885	6 (6.1)
2016	6358	0.01094	0.00496	0.03850	0.01040	7 (6.8)
2017	6502	0.01141	0.00465	0.03310	0.01054	6 (-)
2018	7217	0.01173	0.00381	0.02700	0.00409	6 (-)

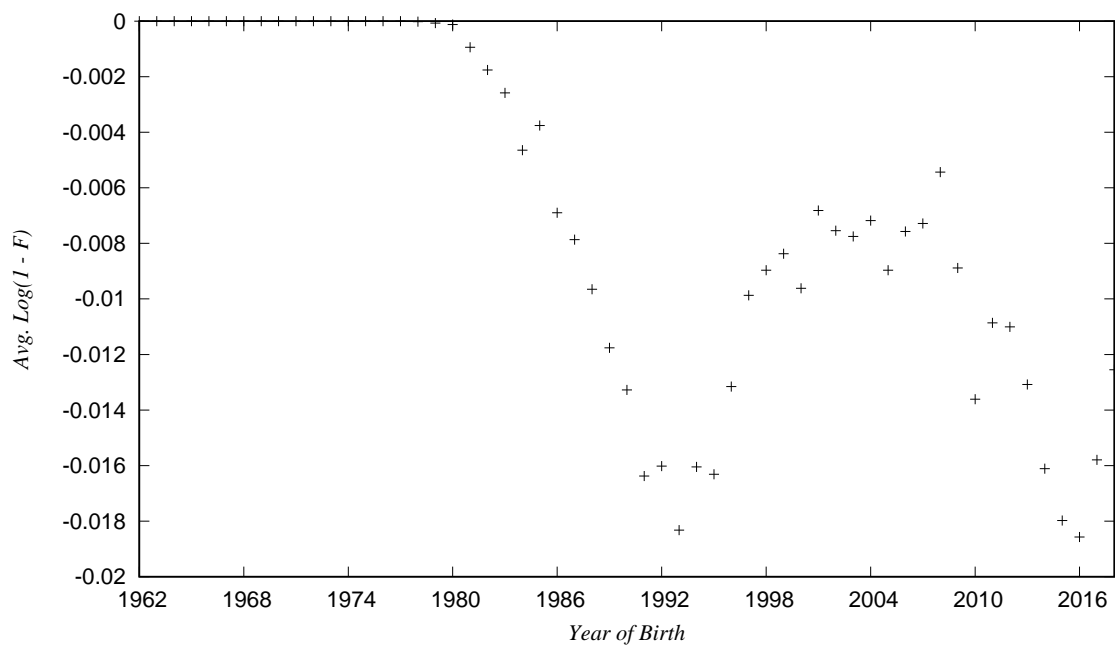
Fixed Time interval used to calculate Delta AGR: 6

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



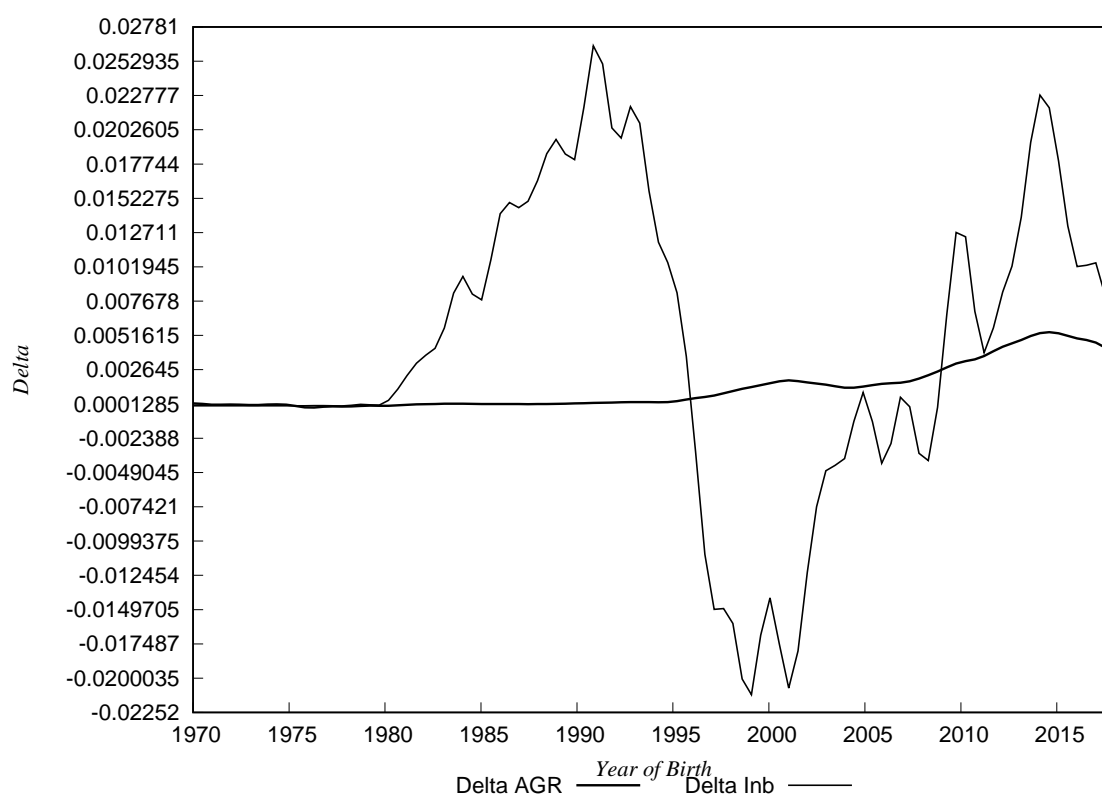
The average rate of change of the additive genetic relationships between 1970 and 2018 for the 56 breed was 0.00021 per year based on the slope of the regression fitted. This result in a  $\Delta f$  per generation of 0.00129. The rate of change of the average inbreeding coefficients based on the slope of the regression between 1970 and 2018 was 0.00065, which represents a  $\Delta F$  per generation of 0.00401. The effective population sizes for the 56 breed, based on  $\Delta f$  and  $\Delta F$  were 387 and 125, respectively.



Figure 4: Average  $\text{Log}(1-F)$  by year of birth for animals born between 1962 and 2018.

*(The rate of inbreeding per generation for the 56 breed, based on the Log(1-Inbreeding) is 0.0042 which presents an  $N_e$  of 120. Calculations were performed on 87937 animals born between 1962 and 2018.)*

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



# PopReport

## A Population Monitoring Report

**Population:** 56  
**Inputfile:** POPREP.TXT  
**Initiated by:** quaglia@anabic.it  
**Submitted at:** 2020-08-26 12:13:41  
**Started at:** 2020-08-26 12:14:01  
**Finished at:** 2020-08-27 08:20:52

**Courtesy:** Department of Animal Breeding and Genetics  
Institute of Farm Animal Genetics (FLI)  
Eildert.Groeneveld@gmx.de  
Höltystrasse 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'.  
87937 input lines processed.  
87937 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
1980	651	651	8710	6144
1981	850	850	9681	4706
1982	958	958	10571	4175
1983	1030	1030	11009	3883
1984	1067	1067	11918	3749
1985	1052	1052	12350	3802
1986	1040	1040	12286	3846
1987	989	989	12448	4044
1988	974	974	12423	4107
1989	942	942	12577	4246
1990	860	860	12598	4651
1991	754	754	12326	5305
1992	648	648	12337	6173
1993	525	525	12023	7619
1994	429	429	11536	9324
2010	457	457	10907	8753
2011	504	504	11451	7937
2012	576	576	11807	6944
2013	644	644	12096	6211
2014	709	709	12981	5642
2015	722	722	13501	5540
2016	708	708	14075	5650
2017	688	688	13239	5814
2018	605	605	11186	6612

# Monitoring the Population 56

Department of Animal Breeding and Genetics  
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August 27, 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)	$\Delta F_p = \frac{F_t - F_{t-1}}{1 - F_{t-1}}$	$F_t = \odot$ inbreeding coefficient of offspring, $F_{t-1} = \odot$ inbreeding coefficient of direct parents
$N_e$ - $\Delta F_g$	Falconer & Mackay (1996)	$\Delta F_g = \frac{F_t - F_{t-1}}{1 - F_{t-1}}$	$F_{t-1} = \odot$ inbreeding coefficient of the $\odot$ parents generation
$N_e$ -Coan	Falconer & Mackay (1996)	$\Delta f_g = \frac{f_t - f_{t-1}}{1 - f_{t-1}}$	$f_t = \odot$ additive genetic relationship (AGR) of offspring, $f_{t-1} = \odot$ 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)	$\Delta F_i = 1 - \text{ecg}_i^{-1} \sqrt{1 - F_i}$	$\text{ecg}$ = 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

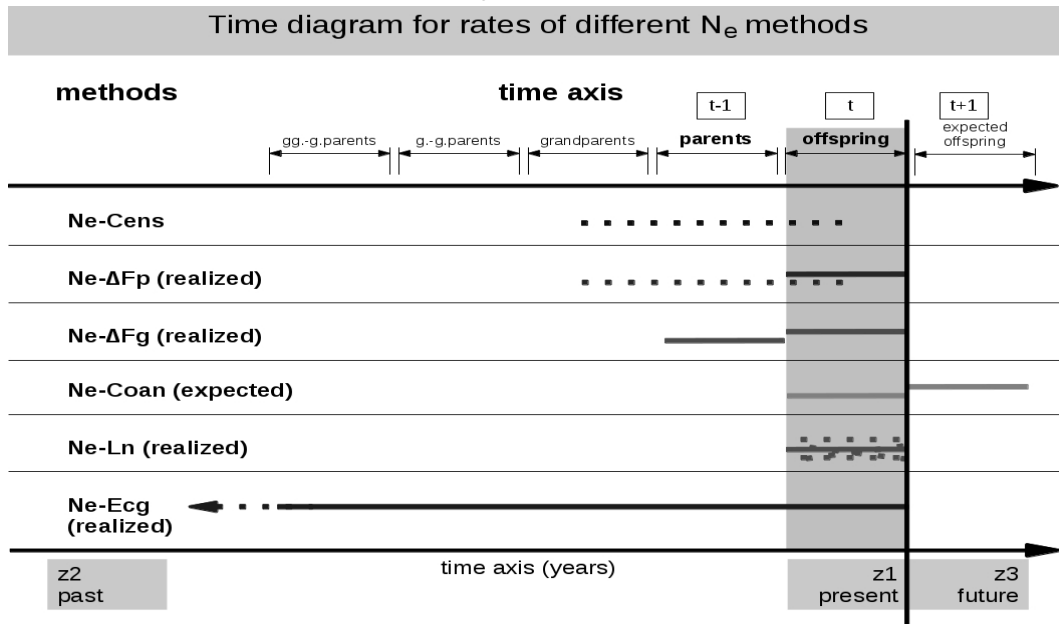


Table 2: Order of methods in cascade

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.

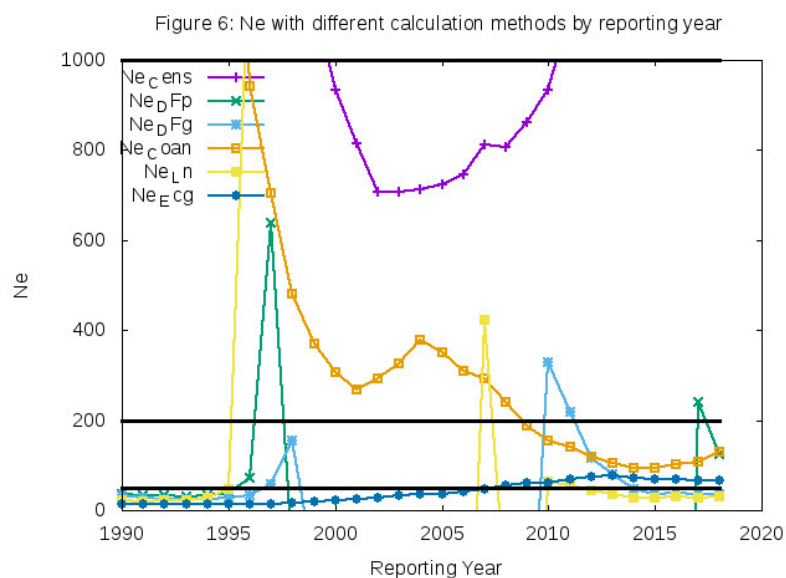
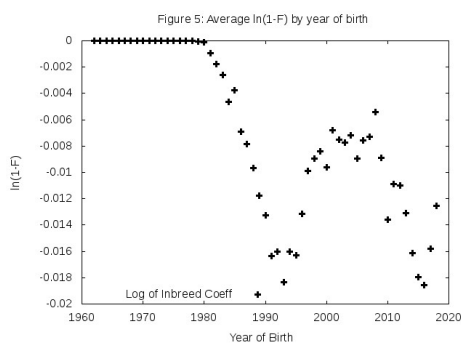
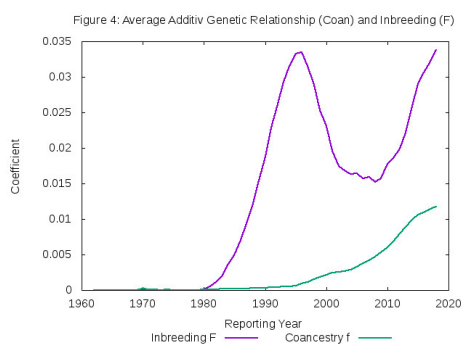
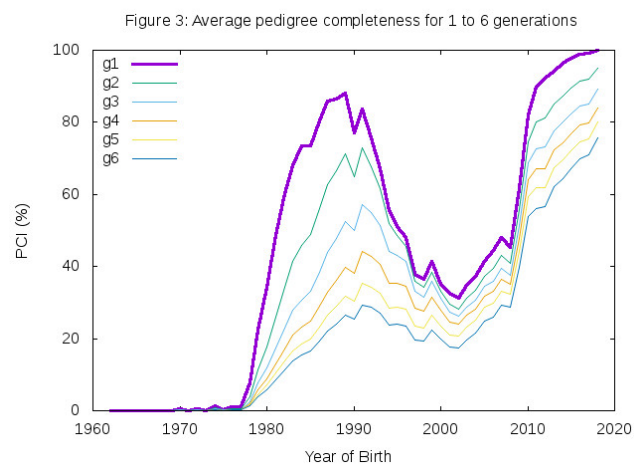
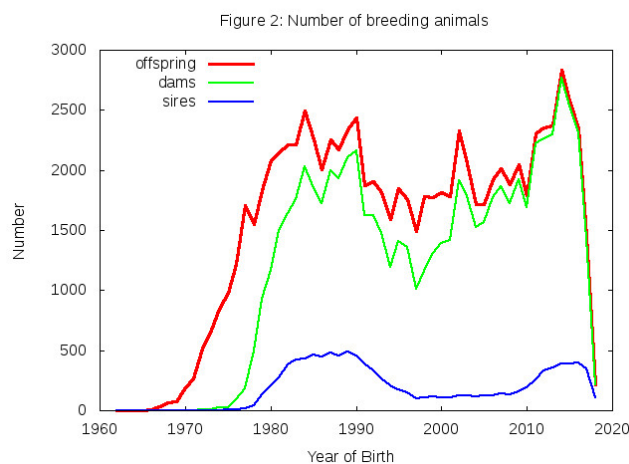
Surprisingly, pedigrees are often quite incomplete which directly impacts on the utility of the methods. To assess the quality of the pedigree Figure 3 should be studied. Incomplete pedigrees will likely overestimate the population size. This will also be reflected by Figure 5 which will look more like 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.

## References

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- [Pérez-Enciso, 1995] Pérez-Enciso, M. (1995). Use of the uncertain relationship matrix to compute effective population size. *J. Anim. Breed. Genet.*, 112:327–332.
- [Wright, 1923] Wright, S. (1923). Mendelian analysis of the pure breeds of livestock. *J. Hered.*, (14):339–348.

Breed: 56 • 87937 pedigree records • generation interval: 6 • August 27, 2020



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

$N_e$ -Method	2018	2017	2016	2015	2014	2013	data history
$N_e$ -Cens	2100	2218	2076	1870	1706	1477	2012 – 2007
$N_e$ - $\Delta F_p$	124	241	-2627	-166	-70	-41	2018 – 2007
$N_e$ - $\Delta F_g$	35	36	38	37	46	79	2018 – 2007
$N_e$ -Coan	131	108	101	94	95	105	2024 – 2013
$N_e$ -Ln	31	27	30	29	28	36	2018 – 2013
$N_e$ -Ecg	65	67	69	70	72	76	2018 – 1962

**Proposed  $N_e$ :  $N_e$ -Coan (substructure) = 131**

**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
2018	2100	124	35	131	31	65
2017	2218	241	36	108	27	67
2016	2076	-2627	38	101	30	69
2015	1870	-166	37	94	29	70
2014	1706	-70	46	95	28	72
2013	1477	-41	79	105	36	76
$\sigma$	114.2	1217.3	11.9	10.9	3.2	0.8

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

Method	Completeness [Years]	Stability [ $\sigma$ ]	Diff	OK
$N_e$ -Coan <sup>a</sup>	12/12	10.9 11.9/20	60.50	yes
$N_e$ -Ln	6/6	3.2/20	-	yes
$N_e$ - $\Delta F_p$	2/6	1217.3/20	-	no
$N_e$ - $\Delta F_g$	6/6	11.9/20	-	yes
$N_e$ -Coan	6/6	10.9/20	-	yes
$N_e$ -Ecg	6/6	0.8/20	-	yes
$N_e$ -Cens	6/6	114.2/20	-	no

<sup>a</sup>Avg  $N_e$ -Coan – Avg  $N_e$ - $\Delta F_g$ : 105.67 - 45.17 = 60.50

# PopReport

## A Population Structure Report

**Population:** 56  
**Inputfile:** POPREP.TXT  
**Initiated by:** quaglia@anabic.it  
**Submitted at:** 2020-08-26 12:13:41  
**Started at:** 2020-08-26 12:14:01  
**Finished at:** 2020-08-27 08:20:52

**Courtesy:** Department of Animal Breeding and Genetics  
Institute of Farm Animal Genetics (FLI)  
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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'.  
87937 input lines processed.  
87937 animals accepted.
- INFO: (concerning Inbreeding Report)  
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2016	708	708	14075	5650
2017	688	688	13239	5814
2018	605	605	11186	6612

# Population Structure Report for Population: 56

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## 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 56 breed in 1977, 16 sires and 182 dams produced the 1704 offspring during this year. In the batch of future parents (select) born in this year 1977 16 sires and 122 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	
1970	-	1	1	-	1	1	188
1972	-	2	2	-	8	4	515
1973	-	1	1	-	6	6	672
1974	-	3	3	-	25	16	848
1975	-	6	2	-	21	11	975
1976	-	10	8	-	89	56	1217
1977	-	16	16	-	182	122	1704
1978	-	40	33	-	496	299	1550
1979	-	131	107	-	925	578	1834
1980	-	209	178	-	1167	716	2081
1981	-	273	232	-	1495	880	2145
1982	-	379	308	-	1643	887	2215

*Continue...*

Year	sires			dams			Number of animals
	services	births	select	services	births	select	born
1983	-	424	327	-	1755	900	2214
1984	-	430	322	-	2031	936	2496
1985	-	466	351	-	1851	883	2251
1986	-	449	332	-	1725	851	2005
1987	-	481	347	-	2000	915	2256
1988	-	456	306	-	1926	780	2175
1989	-	487	337	-	2100	927	2336
1990	-	451	301	-	2163	899	2435
1991	-	390	259	-	1626	661	1873
1992	-	329	217	-	1624	684	1910
1993	-	265	173	-	1471	607	1819
1994	-	209	142	-	1194	567	1592
1995	-	170	138	-	1406	651	1852
1996	-	146	117	-	1362	669	1756
1997	-	100	83	-	1009	523	1492
1998	-	108	93	-	1160	626	1784
1999	-	112	94	-	1311	704	1773
2000	-	106	94	-	1393	681	1815
2001	-	107	92	-	1414	725	1785
2002	-	122	100	-	1912	962	2329
2003	-	123	104	-	1782	851	2058
2004	-	117	100	-	1528	802	1719
2005	-	122	97	-	1566	814	1713
2006	-	126	105	-	1776	889	1923
2007	-	142	124	-	1867	904	2016
2008	-	135	114	-	1722	861	1881
2009	-	158	140	-	1923	991	2045
2010	-	192	158	-	1692	816	1786
2011	-	254	203	-	2221	939	2304
2012	-	332	239	-	2260	793	2351
2013	-	356	202	-	2298	562	2373
2014	-	391	171	-	2769	322	2831
2015	-	385	102	-	2532	161	2578
2016	-	400	14	-	2311	15	2346
2017	-	350	-	-	1432	-	1448
2018	-	106	-	-	214	-	215
Total	-	3523	2674	-	43603	21024	87937

## 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 56 breed in 1977, 3 two year-old males were used in reproduction while 3 three year-old males were used. The average age of males that produced offspring during 1977 was 1.8 year.

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

Year	age of males in year																
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	$\geq 16$	Avg
1970	1	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	1.0
1972	1	1	-	-	-	-	-	-	-	-	-	-	-	-	-	-	1.5
1973	-	1	-	-	-	-	-	-	-	-	-	-	-	-	-	-	2.0
1974	1	2	-	-	-	-	-	-	-	-	-	-	-	-	-	-	1.7
1975	5	-	1	-	-	-	-	-	-	-	-	-	-	-	-	-	1.3
1976	5	3	-	-	-	1	1	-	-	-	-	-	-	-	-	-	2.4
1977	9	3	3	-	1	-	-	-	-	-	-	-	-	-	-	-	1.8
1978	14	16	3	4	-	1	-	1	1	-	-	-	-	-	-	-	2.4
1979	37	47	25	9	6	2	2	1	-	2	-	-	-	-	-	-	2.5
1980	38	70	55	28	7	4	3	1	1	1	1	-	-	-	-	-	2.7
1981	40	75	75	45	23	5	4	6	-	-	-	-	-	-	-	-	3.0
1982	49	89	98	76	36	18	5	3	3	2	-	-	-	-	-	-	3.2
1983	41	128	95	75	47	19	6	6	2	5	-	-	-	-	-	-	3.3
1984	41	81	129	66	50	33	14	6	4	3	3	-	-	-	-	-	3.6
1985	45	107	86	117	49	27	19	8	2	2	3	1	-	-	-	-	3.6
1986	37	88	99	81	70	35	20	10	6	-	1	-	2	-	-	-	3.8
1987	50	85	99	103	61	44	24	6	7	1	1	-	-	-	-	-	3.7
1988	42	79	97	90	80	26	25	10	5	1	1	-	-	-	-	-	3.8
1989	48	94	99	92	60	49	17	15	8	3	1	1	-	-	-	-	3.8
1990	45	88	90	80	73	37	22	6	3	2	4	-	-	-	-	1	3.8
1991	29	82	91	76	47	31	14	8	4	4	1	3	-	-	-	-	3.8

*Continue...*

Year	age of males in year																
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	≥ 16	Avg
1992	21	55	90	81	37	29	7	5	2	–	2	–	–	–	–	–	3.7
1993	10	40	62	62	40	21	18	4	3	1	1	3	–	–	–	–	4.1
1994	12	22	36	47	42	25	8	10	2	3	1	–	1	–	–	–	4.4
1995	14	27	33	22	33	13	11	5	7	2	1	2	–	–	–	–	4.3
1996	12	27	23	26	20	15	7	4	5	3	1	1	1	–	1	–	4.4
1997	3	23	25	12	12	7	8	5	2	1	1	–	–	1	–	–	4.2
1998	13	16	24	17	15	9	7	3	–	1	2	–	–	–	1	–	4.0
1999	9	27	19	23	13	7	6	5	1	–	–	–	1	–	–	1	3.9
2000	4	18	26	19	15	11	6	3	1	1	–	–	1	–	–	1	4.2
2001	2	17	17	30	11	17	9	3	–	–	1	–	–	–	–	–	4.3
2002	4	19	25	20	19	10	11	9	2	1	1	1	–	–	–	–	4.5
2003	2	19	22	21	20	14	7	7	4	3	–	2	1	–	1	–	4.9
2004	1	15	21	25	16	11	11	7	6	2	1	–	–	1	–	–	4.9
2005	3	18	19	16	20	17	9	10	6	2	1	–	–	1	–	–	5.0
2006	3	18	23	22	15	17	12	7	4	3	1	1	–	–	–	–	4.8
2007	6	22	29	24	18	12	11	7	6	3	2	–	–	2	–	–	4.7
2008	2	23	29	26	19	12	8	6	6	1	–	2	–	–	1	–	4.5
2009	10	28	26	30	19	19	10	6	5	1	–	1	1	–	–	2	4.4
2010	10	46	30	23	33	16	13	8	6	3	–	1	1	–	–	2	4.4
2011	8	77	53	24	20	29	17	6	6	6	4	–	1	1	1	1	4.2
2012	22	74	99	49	22	19	21	8	5	4	5	1	1	–	–	2	3.9
2013	9	56	108	86	37	19	10	15	4	1	1	6	–	–	1	3	4.1
2014	16	67	70	92	76	28	15	7	6	4	1	1	4	1	–	3	4.3
2015	12	76	70	55	73	52	23	9	5	1	1	1	2	1	–	4	4.4
2016	16	77	70	65	49	60	35	14	4	3	1	1	1	–	1	3	4.4
2017	16	74	74	50	42	31	31	18	6	2	2	–	1	–	–	3	4.3
2018	4	19	31	22	10	11	4	3	2	–	–	–	–	–	–	–	3.9
Total	822	2139	2299	1931	1356	863	511	281	152	78	47	29	19	8	7	26	4.1

**For example:** For the 56 breed in 1975, 2 two year-old females were used in reproduction while 4 three year-old females were used. The average age of females that produced offspring during 1975 was 3.5 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
1970	1	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	1.0
1971	1	–	1	–	–	–	–	–	–	–	–	–	–	–	–	–	2.0
1972	7	1	–	–	–	–	–	–	–	–	–	–	–	–	–	–	1.1
1973	4	–	1	1	–	–	–	–	–	–	–	–	–	–	–	–	1.8
1974	17	1	4	2	–	1	–	–	–	–	–	–	–	–	–	–	1.8
1975	6	2	4	2	2	2	2	1	–	–	–	–	–	–	–	–	3.5
1976	25	10	13	13	15	6	4	2	1	–	–	–	–	–	–	–	3.4
1977	35	17	30	33	28	14	11	5	3	5	–	1	–	–	–	–	4.0
1978	96	46	78	75	74	51	33	17	12	11	3	–	–	–	–	–	4.1
1979	307	45	100	99	109	82	74	39	31	20	9	8	–	–	2	–	4.0
1980	244	82	146	114	126	135	133	76	48	26	16	13	5	3	–	–	4.6
1981	207	57	164	201	193	183	150	128	100	52	27	11	12	5	5	–	5.3
1982	190	83	160	184	222	200	184	144	128	69	40	21	10	6	–	2	5.5
1983	182	95	186	166	229	232	181	144	129	93	61	33	13	6	2	3	5.7
1984	195	105	226	233	196	216	235	202	151	109	79	38	22	10	8	6	5.9
1985	90	106	170	200	230	203	205	199	167	108	78	43	31	9	7	5	6.3
1986	77	109	164	187	221	185	177	161	143	110	86	47	30	14	5	9	6.4
1987	57	91	184	240	206	229	240	197	168	128	89	63	55	30	11	12	6.7
1988	30	80	180	255	239	236	199	196	154	128	97	60	28	15	14	15	6.7
1989	19	148	229	213	250	231	207	184	189	133	108	82	54	23	17	13	6.7
1990	33	142	236	213	251	236	240	191	157	164	103	74	61	31	16	15	6.7
1991	12	130	180	187	189	156	168	148	110	94	93	68	39	22	16	14	6.7
1992	8	132	192	173	170	155	146	162	134	116	66	63	41	35	17	14	6.8
1993	9	124	192	169	168	142	141	118	116	91	59	56	34	21	20	11	6.6
1994	5	73	162	142	114	134	123	106	110	78	57	33	25	18	5	9	6.6
1995	15	104	141	171	192	141	120	128	107	77	69	60	33	20	15	13	6.7
1996	10	97	143	138	167	168	117	118	103	82	70	58	38	15	18	20	6.8
1997	11	81	103	110	96	115	114	93	74	56	52	32	22	24	11	15	6.8
1998	12	76	125	122	118	108	124	133	88	77	54	46	29	17	14	17	6.9

*Continue...*

Year	age of females in year																
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	≥ 16	Avg
1999	18	109	136	118	119	126	127	141	128	78	61	48	40	21	22	19	7.0
2000	14	111	141	148	137	148	121	115	137	112	72	49	35	22	16	15	6.9
2001	16	86	161	150	145	158	132	98	97	109	97	64	38	27	21	15	7.0
2002	23	125	211	227	176	199	163	210	145	117	100	69	47	41	28	31	6.9
2003	11	75	182	241	208	176	180	159	119	115	95	73	55	46	22	25	7.0
2004	16	108	125	163	154	149	146	142	115	96	86	66	46	47	29	40	7.3
2005	14	87	197	191	146	161	124	122	135	107	79	54	52	43	23	31	7.0
2006	8	102	188	226	177	191	154	159	121	120	96	70	45	37	21	61	7.2
2007	29	80	170	188	263	160	153	169	174	110	103	86	67	35	35	45	7.3
2008	22	93	138	135	173	185	165	153	144	120	96	82	76	49	29	62	7.7
2009	20	157	196	171	188	202	190	158	129	126	109	68	72	60	31	46	7.2
2010	13	117	212	152	146	148	161	157	125	96	95	78	42	47	46	57	7.4
2011	30	160	209	219	192	173	161	194	217	134	127	106	93	72	40	94	7.6
2012	30	155	264	230	236	186	146	156	170	168	116	90	89	69	53	102	7.5
2013	20	127	238	237	213	248	169	170	166	155	147	112	81	78	63	74	7.6
2014	24	248	319	256	277	233	261	179	163	159	150	148	105	87	61	99	7.3
2015	30	249	261	230	223	211	215	212	155	114	140	115	127	73	74	103	7.5
2016	30	178	241	284	258	173	209	171	158	121	91	80	89	78	53	97	7.3
2017	13	121	142	171	179	125	110	111	75	89	57	33	52	42	42	70	7.2
2018	2	13	22	37	14	23	15	16	13	16	16	10	2	3	3	9	7.1
Total	2288	4538	7267	7417	7429	6936	6430	5884	5109	4089	3249	2411	1835	1301	915	1288	7.2

### 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 56 in 1976, 4 females were in their second parity while in 1978, 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
1970	1	–	–	–	–	–	–	–	–	–	–
1971	2	–	–	–	–	–	–	–	–	–	–
1972	8	–	–	–	–	–	–	–	–	–	–
1973	6	–	–	–	–	–	–	–	–	–	–
1974	25	–	–	–	–	–	–	–	–	–	–
1975	21	–	–	–	–	–	–	–	–	–	–
1976	86	4	–	–	–	–	–	–	–	–	–
1977	178	5	1	–	–	–	–	–	–	–	–
1978	474	29	2	1	–	–	–	–	–	–	–
1979	856	75	7	–	–	–	–	–	–	–	–
1980	1007	166	12	3	–	–	–	–	–	–	–
1981	1187	277	46	2	–	–	–	–	–	–	–
1982	1225	358	69	5	–	–	–	–	–	–	–
1983	1250	400	99	15	3	–	–	–	–	–	–
1984	1417	479	135	24	6	1	–	–	–	–	–
1985	1238	467	130	27	3	1	1	–	–	–	–
1986	1162	409	127	27	8	–	–	–	–	–	–
1987	1349	472	138	42	5	1	–	–	–	–	–
1988	1324	430	132	37	9	–	–	–	–	–	–
1989	1362	522	174	40	14	1	–	–	–	–	–
1990	1368	557	172	59	9	2	–	–	–	–	–
1991	973	432	166	39	15	3	–	–	–	–	–
1992	974	452	145	48	4	3	1	–	–	–	–
1993	909	382	126	40	10	5	–	–	–	–	–
1994	716	320	122	29	7	–	1	–	–	–	–
1995	878	338	143	36	12	–	2	1	–	–	–
1996	819	359	139	34	12	1	–	–	1	–	–
1997	594	271	102	40	8	1	1	–	–	–	–
1998	728	279	103	37	12	4	–	–	–	–	–
1999	783	327	137	49	15	4	1	–	–	–	–
2000	932	289	116	42	9	6	–	–	–	–	–
2001	953	299	117	37	7	2	1	1	–	–	–
2002	1329	396	134	37	14	3	3	–	–	–	–
2003	1195	387	133	50	16	3	–	–	–	–	–
2004	986	354	115	52	10	9	1	1	–	–	–

*Continue...*

Year	parity number										
	1	2	3	4	5	6	7	8	9	10	11
2005	1031	360	123	36	12	1	1	1	1	–	–
2006	1185	405	131	38	13	4	1	–	–	–	–
2007	1165	441	175	64	15	6	3	1	–	–	–
2008	1022	449	164	64	16	7	1	1	–	–	–
2009	1164	485	176	63	26	4	3	2	–	–	–
2010	951	443	190	67	28	13	2	1	1	–	–
2011	1283	573	228	100	28	11	3	1	1	1	–
2012	1288	587	248	91	31	9	4	2	1	1	1
2013	1263	612	255	114	43	17	3	1	–	–	1
2014	1573	709	296	121	43	21	7	2	1	–	–
2015	1306	710	309	124	52	22	8	2	1	–	–
2016	1198	599	311	127	47	15	8	6	1	1	–
2017	732	382	173	94	33	9	5	2	2	1	–
2018	127	50	22	10	4	1	–	–	–	–	–
Total	43603	16340	5843	1965	599	190	61	25	10	4	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 56 breed the Generation interval (average age of parents when their selected offspring were born) for the selection path between sire to son (ss) was 2.6 year in 1978. This values was calculated based on the avarage ages of 8 selected sons, born during 1978. 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 3.3, 4.6 and 4.4 year, respectively. During 1978, the generation interval for the males was 3.2 year and 4.5 year for the female born during this year. The generation interval in 1978 for all four selection paths together, or for the population in total (pop), was 4.4 year, based on the average age of parents of 308 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,Nmale=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
1974	2.2	2	2.1	7	1.9	3	2.3	13	2.1	9	2.3	16	2.3	16
1975	2.0	1	2.0	1	4.5	2	4.4	9	2.0	2	4.4	11	4.2	12
1976	2.0	2	3.4	7	2.0	2	3.9	55	3.1	9	3.9	57	3.8	58
1977	2.0	3	2.5	19	4.3	12	4.4	112	2.4	22	4.4	124	4.4	126
1978	2.6	8	3.3	75	4.6	29	4.4	275	3.2	83	4.5	304	4.4	308
1979	2.9	52	3.3	226	4.6	88	4.7	495	3.3	278	4.7	583	4.6	591
1980	3.7	44	3.4	432	5.6	72	5.2	655	3.5	476	5.2	727	4.8	759
1981	3.6	108	3.8	555	5.7	149	5.8	744	3.8	663	5.8	893	5.1	920
1982	3.8	102	3.8	653	6.2	119	5.9	772	3.8	755	5.9	891	5.0	918
1983	4.0	95	3.9	689	6.4	112	6.0	793	3.9	784	6.1	905	5.2	920
1984	4.2	109	4.3	749	6.4	126	6.3	821	4.3	858	6.3	947	5.4	966
1985	4.2	105	4.2	705	7.1	118	6.8	770	4.2	810	6.8	888	5.6	904

*Continue...*

Year	Generation interval and number of animal													
	ss	Nss	sd	Nsd	ms	Nms	md	Nmd	male	Nmale	female	Nfemale	pop	Npop
1986	4.7	117	4.4	681	6.2	127	6.9	729	4.5	798	6.8	856	5.7	858
1987	4.4	141	4.4	757	7.1	146	7.2	772	4.4	898	7.1	918	5.8	931
1988	4.2	130	4.4	635	7.0	131	7.1	650	4.4	765	7.1	781	5.8	787
1989	4.8	123	4.5	778	7.3	124	7.3	807	4.5	901	7.3	931	6.0	937
1990	4.0	72	4.2	728	7.2	78	7.1	823	4.2	800	7.1	901	5.9	905
1991	4.1	46	4.1	594	7.1	48	7.2	615	4.1	640	7.2	663	5.7	663
1992	4.5	37	4.1	570	7.0	40	7.4	645	4.1	607	7.4	685	5.9	688
1993	4.8	32	4.9	484	6.8	34	7.1	573	4.9	516	7.1	607	6.2	608
1994	4.8	36	5.0	406	7.7	37	7.2	532	5.0	442	7.2	569	6.3	572
1995	4.7	33	4.9	435	8.2	33	7.2	618	4.9	468	7.2	651	6.4	654
1996	5.0	38	5.5	404	7.1	38	7.3	634	5.4	442	7.3	672	6.7	672
1997	5.3	37	4.7	297	7.3	37	7.4	488	4.8	334	7.4	525	6.6	529
1998	4.8	19	4.7	388	6.9	19	7.4	608	4.7	407	7.4	627	6.6	631
1999	4.0	32	4.4	404	7.3	32	7.4	676	4.4	436	7.4	708	6.5	709
2000	4.4	33	4.7	353	8.4	33	7.5	649	4.7	386	7.6	682	6.7	685
2001	5.0	28	4.9	309	7.1	28	7.4	701	4.9	337	7.4	729	6.8	731
2002	4.5	25	5.2	424	8.1	25	7.4	941	5.2	449	7.5	966	6.9	969
2003	4.4	38	5.2	385	9.3	38	7.7	817	5.1	423	7.7	855	7.1	856
2004	4.9	31	5.2	375	8.3	31	7.6	777	5.2	406	7.7	808	7.0	812
2005	5.0	43	5.7	384	7.2	43	7.5	774	5.6	427	7.5	817	7.0	821
2006	5.1	31	5.0	465	6.8	31	7.7	866	5.0	496	7.6	897	7.0	899
2007	5.5	45	4.9	490	8.9	45	7.6	865	5.0	535	7.7	910	6.9	915
2008	5.0	67	5.1	427	8.3	67	8.0	799	5.1	494	8.0	866	7.2	870
2009	4.9	135	5.0	565	7.9	135	7.6	861	5.0	700	7.7	996	6.8	1003
2010	4.8	125	5.1	623	7.7	125	7.6	696	5.0	748	7.6	821	6.5	823
2011	5.1	83	4.9	802	8.9	83	8.0	862	4.9	885	8.1	945	6.6	946
2012	4.8	99	4.7	664	7.6	99	8.1	698	4.7	763	8.1	797	6.4	806
2013	4.6	101	4.5	453	7.9	101	8.1	468	4.6	554	8.1	569	6.4	572
2014	5.4	92	4.6	230	7.6	92	8.0	231	4.8	322	7.9	323	6.3	325
2015	4.9	77	5.0	80	6.8	77	7.7	84	5.0	157	7.3	161	6.1	161
2016	3.9	8	4.6	7	8.1	8	11.0	7	4.2	15	9.4	15	6.8	15
Total	4.5	-	4.6	-	7.0	-	7.1	-	4.6	-	7.1	-	6.2	-

## 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 ( $Ne = 1/2\Delta F$  where  $Ne$  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
1968	13	12.5	5	1.4	11	9.5	3	1.3	-	-	2	1.1	11	9.5	3	1.2
1970	7	6.5	4	1.4	6	4.0	3	1.2	-	-	2	1.1	6	4.0	3	1.2
1971	1	1.0	4	1.4	1	1.0	3	1.3	-	-	1	1.0	1	1.0	3	1.2
1972	28	13.6	7	1.5	14	7.2	4	1.3	1	1.0	2	1.0	13	6.6	4	1.3
1973	62	19.7	5	1.5	37	10.3	4	1.3	2	1.4	2	1.0	36	9.3	4	1.3
1974	34	12.5	6	1.5	28	9.5	5	1.3	3	2.0	2	1.1	25	10.3	5	1.3
1975	58	16.4	5	1.5	28	9.8	5	1.3	10	2.8	2	1.0	23	8.3	5	1.2
1976	65	12.5	5	1.6	37	7.3	5	1.3	12	2.1	3	1.0	25	6.7	5	1.3
1977	84	12.7	6	1.6	35	8.1	5	1.3	10	2.1	2	1.0	35	7.1	4	1.3
1978	46	11.1	7	1.6	25	6.4	5	1.4	6	1.6	2	1.0	23	5.9	5	1.3
1979	55	9.9	6	1.6	32	6.2	5	1.3	5	1.5	2	1.1	30	5.8	5	1.3
1980	60	11.8	6	1.5	33	6.1	5	1.3	3	1.3	2	1.0	32	5.8	4	1.3
1981	70	10.0	9	1.6	28	6.3	6	1.3	5	1.6	2	1.0	28	5.8	6	1.3
1982	65	10.4	6	1.6	32	6.0	5	1.3	6	1.5	2	1.0	29	5.6	5	1.3
1983	75	11.8	6	1.6	36	6.3	4	1.3	7	1.5	2	1.0	34	6.1	4	1.3
1984	51	11.3	5	1.5	26	5.3	4	1.3	4	1.3	2	1.0	25	4.9	4	1.3
1985	44	11.6	6	1.5	27	5.9	6	1.3	11	1.4	2	1.0	26	5.5	6	1.3
1986	78	11.3	6	1.6	52	7.1	6	1.3	5	1.5	2	1.0	52	6.9	5	1.3
1987	71	11.1	8	1.6	39	6.4	6	1.4	4	1.4	4	1.2	36	6.4	5	1.3
1988	67	12.1	6	1.6	30	6.4	5	1.4	3	1.2	2	1.1	30	6.2	5	1.3
1989	72	11.8	6	1.6	45	6.8	6	1.5	5	1.4	3	1.1	41	6.8	5	1.4
1990	52	11.1	9	1.6	32	7.1	6	1.4	10	2.0	2	1.1	31	6.7	6	1.4
1991	123	12.2	7	1.6	95	10.0	6	1.4	17	2.7	1	1.0	78	9.4	5	1.4
1992	104	17.7	6	1.6	77	10.9	5	1.4	10	3.5	3	1.2	67	10.2	4	1.4
1993	161	21.9	8	1.6	96	11.0	7	1.4	19	4.4	2	1.2	77	10.1	7	1.4

*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
1994	70	19.1	7	1.6	54	14.7	6	1.5	9	3.1	2	1.1	53	14.5	6	1.4
1995	134	22.0	8	1.7	88	16.9	7	1.5	5	2.2	4	1.4	87	15.9	5	1.4
1996	110	24.1	11	1.7	49	13.5	7	1.5	8	2.9	3	1.2	42	13.4	6	1.4
1997	87	25.9	8	1.7	55	14.9	6	1.5	12	2.9	3	1.3	47	14.2	6	1.4
1998	123	34.9	7	1.7	81	22.8	6	1.5	13	4.6	3	1.3	69	20.7	6	1.4
1999	79	23.7	8	1.7	60	13.6	7	1.4	7	3.1	3	1.3	57	12.6	5	1.4
2000	173	25.3	9	1.8	116	15.5	7	1.5	29	4.4	3	1.2	87	13.8	6	1.4
2001	160	30.3	9	1.7	97	16.5	7	1.4	24	3.9	3	1.2	73	14.8	4	1.3
2002	90	26.2	10	1.7	64	14.3	5	1.4	3	1.8	4	1.4	61	13.3	4	1.3
2003	93	27.6	8	1.7	47	15.3	5	1.4	11	3.5	2	1.2	43	13.9	5	1.3
2004	103	38.9	10	1.8	67	20.5	7	1.3	18	4.0	3	1.3	64	18.6	4	1.3
2005	198	46.3	8	1.8	69	21.7	6	1.4	23	5.8	4	1.2	46	18.0	5	1.3
2006	101	29.2	6	1.7	52	13.2	4	1.2	22	4.5	2	1.1	30	10.5	4	1.2
2007	151	31.7	7	1.6	50	12.6	5	1.2	20	4.7	3	1.2	40	10.4	5	1.2
2008	135	31.9	9	1.6	40	9.2	5	1.2	9	2.9	3	1.2	40	8.0	3	1.1
2009	116	24.7	6	1.5	26	5.9	3	1.1	13	2.5	2	1.1	20	5.0	2	1.1
2010	76	20.6	5	1.4	23	3.8	2	1.1	5	1.5	2	1.2	23	3.4	2	1.1
2011	63	17.3	4	1.3	11	2.7	2	1.1	7	2.3	2	1.0	8	2.3	2	1.0
2012	52	13.4	4	1.2	7	1.9	1	1.0	3	1.6	1	1.0	5	1.7	1	1.0
2013	39	9.5	4	1.1	5	1.6	1	1.0	2	1.3	1	1.0	3	1.6	1	1.0
2014	38	5.8	2	1.1	1	1.0	-	-	1	1.0	-	-	-	-	-	-
2015	17	3.5	1	1.0	-	-	-	-	-	-	-	-	-	-	-	-
2016	2	1.1	1	1.0	-	-	-	-	-	-	-	-	-	-	-	-
Total	198	14.9	11	1.6	116	8.0	7	1.4	29	2.0	4	1.1	87	7.5	7	1.3

Figure 1: Dams with the most Progeny in the Population

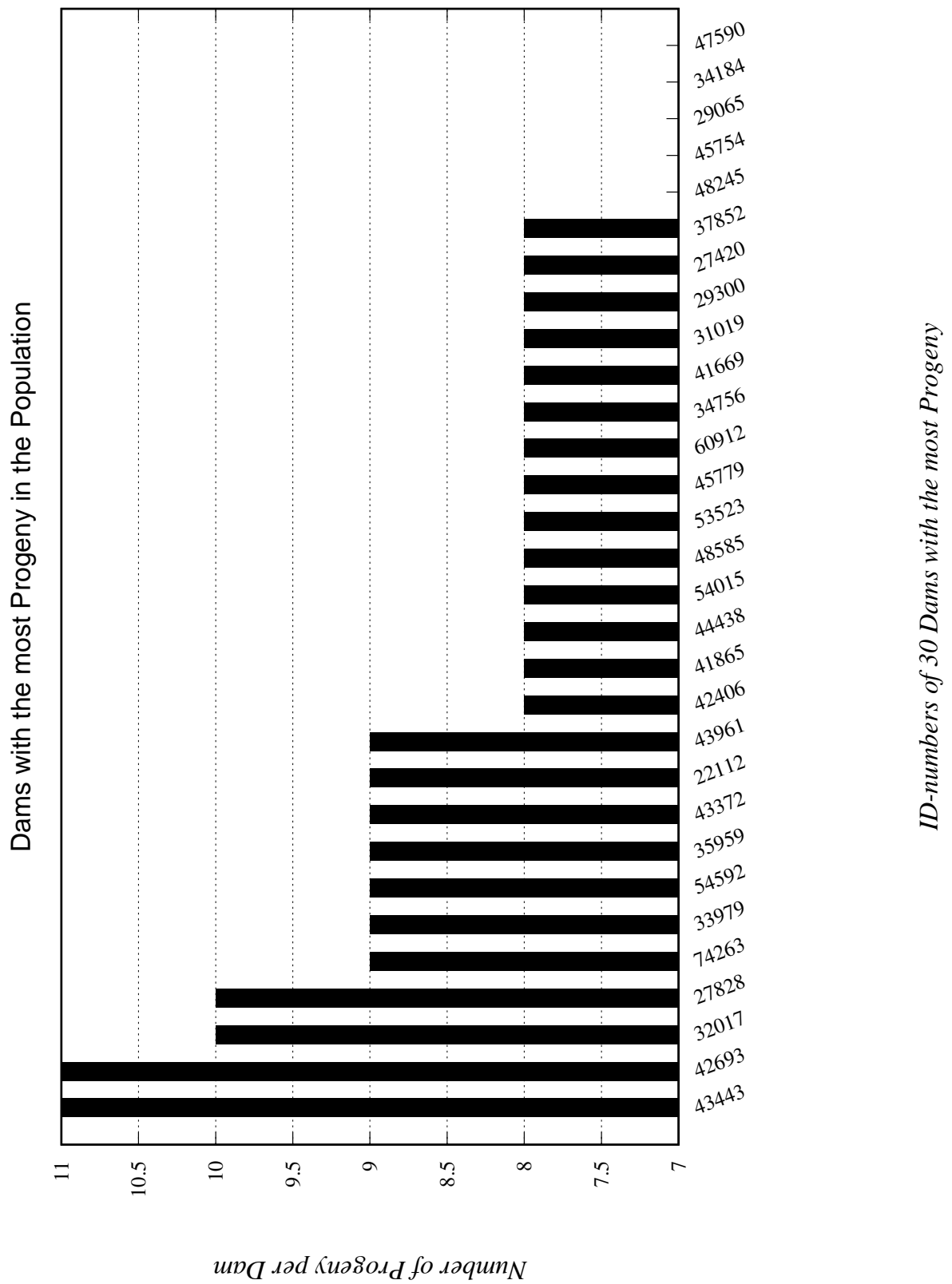


Figure 2: Number of Progeny per Dam

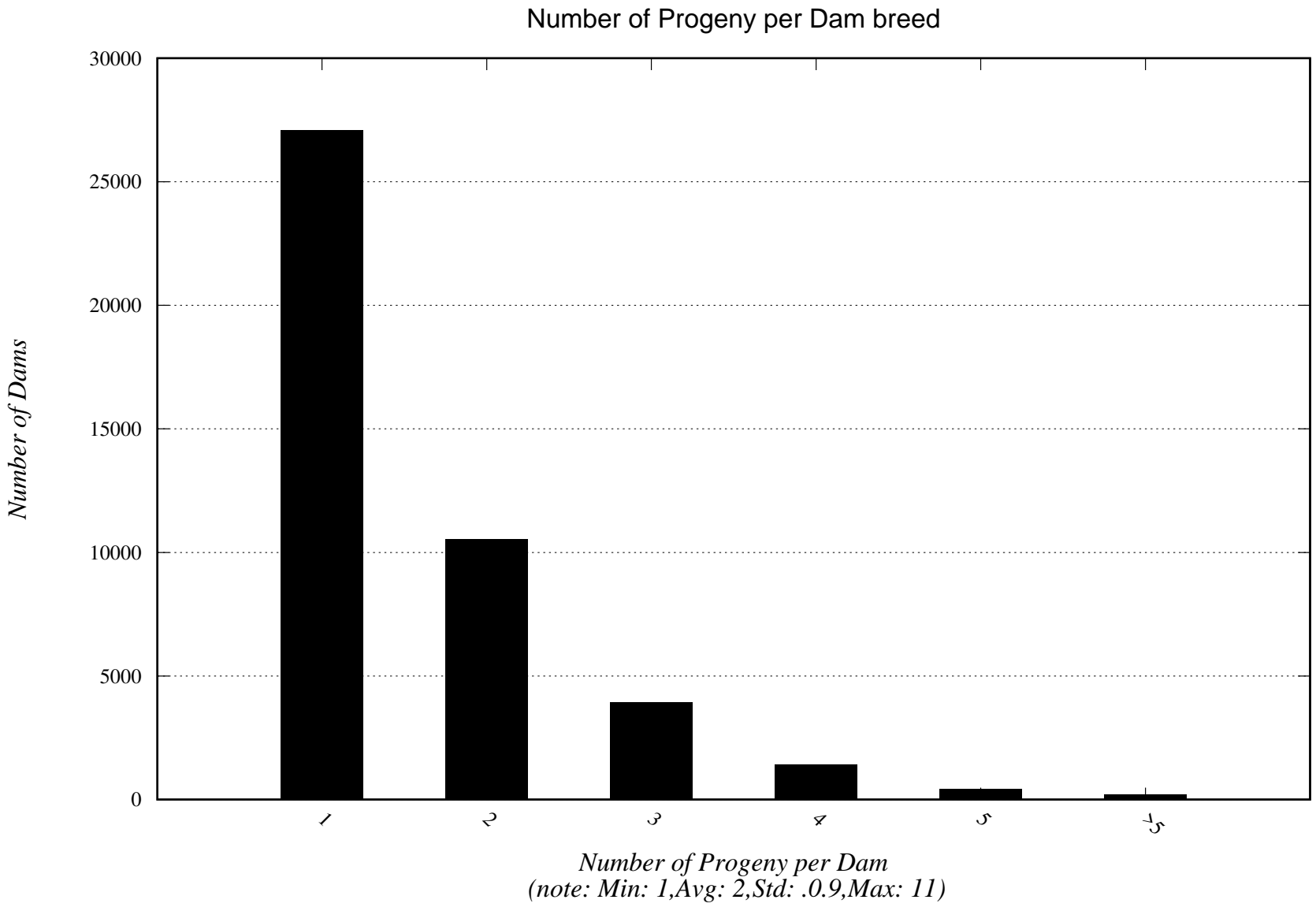


Figure 3: Sires with the most Progeny in the Population

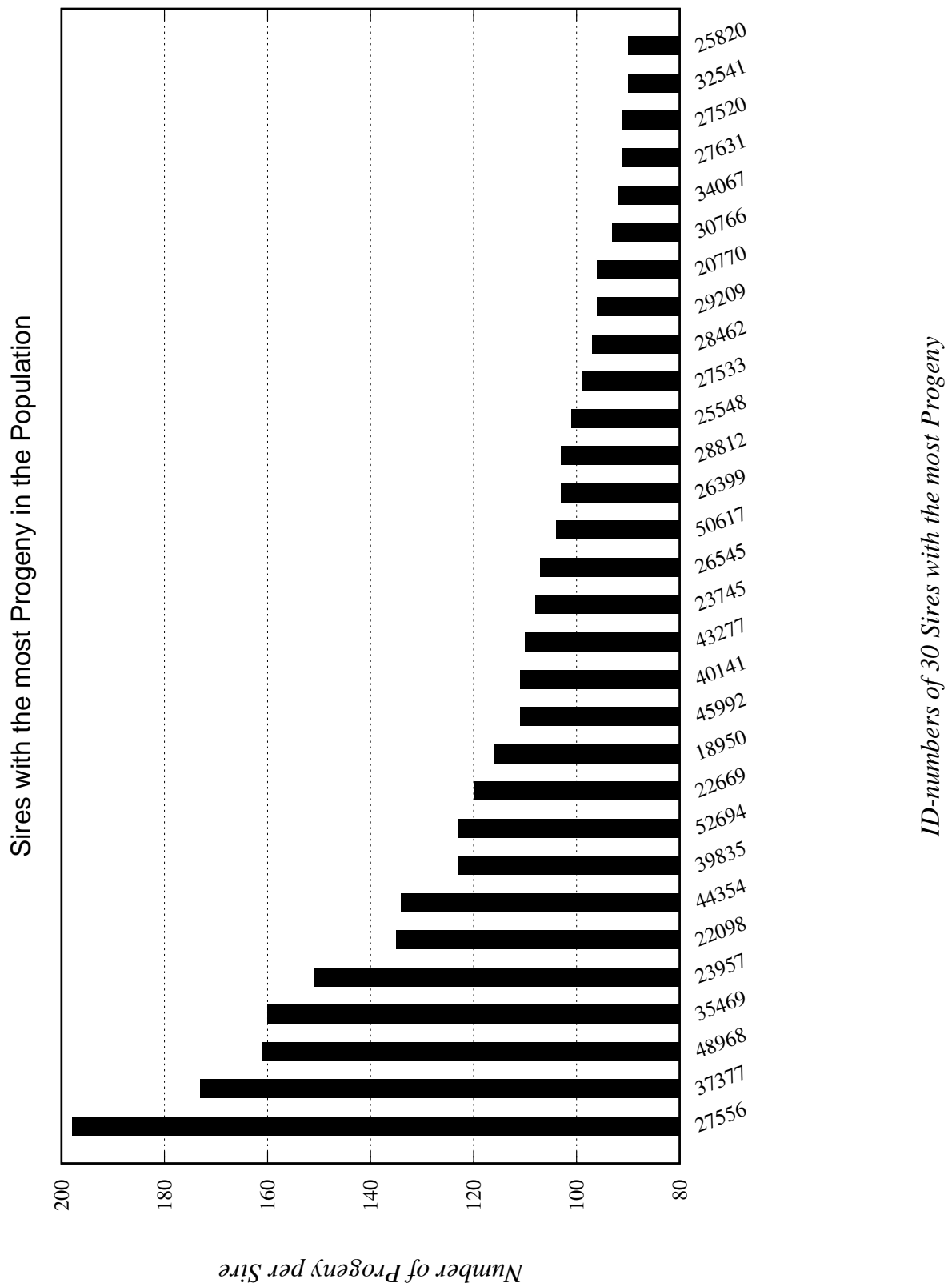


Figure 4: Number of Progeny per Sire

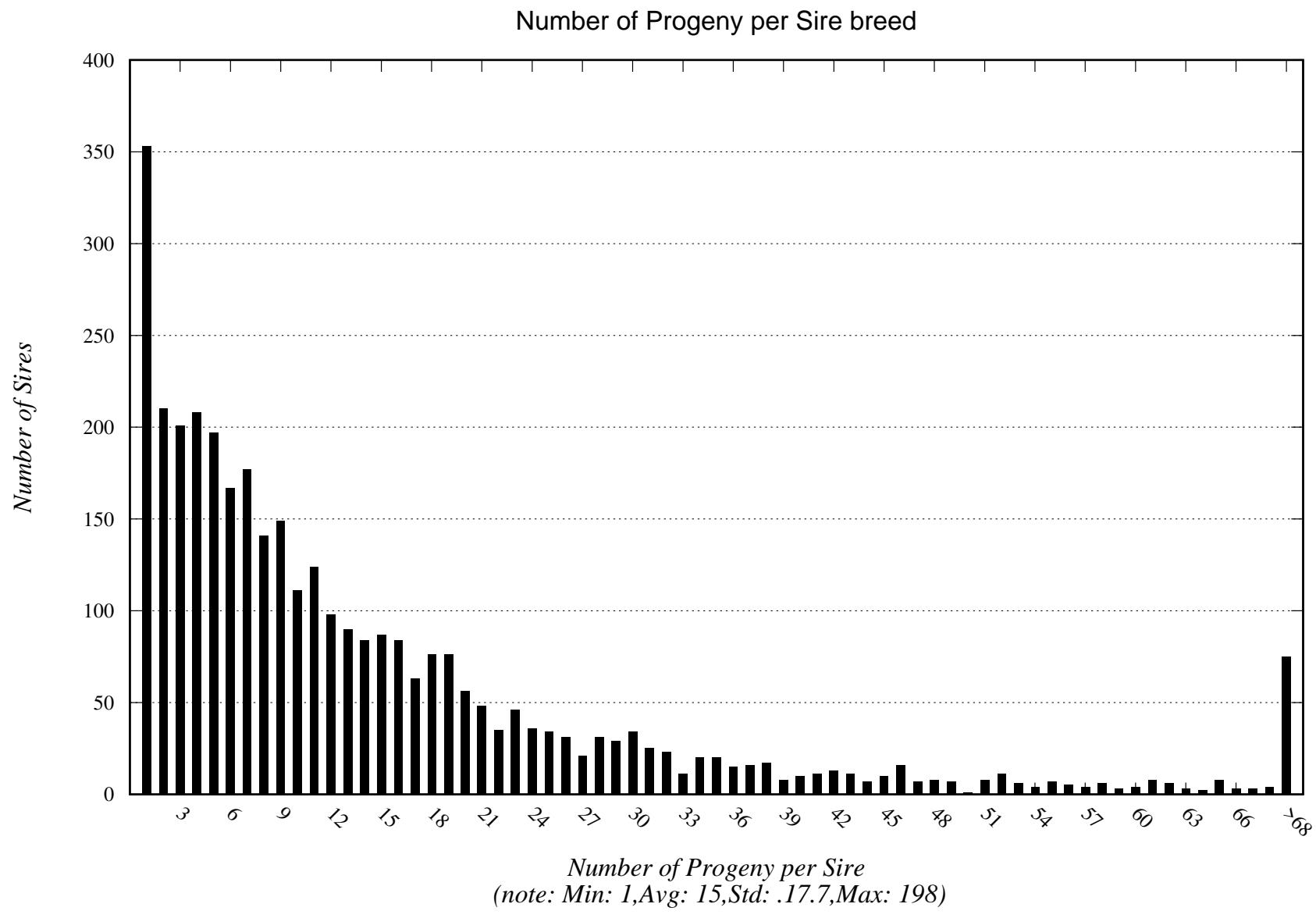






Figure 6: Number of Selected Progeny per Dam

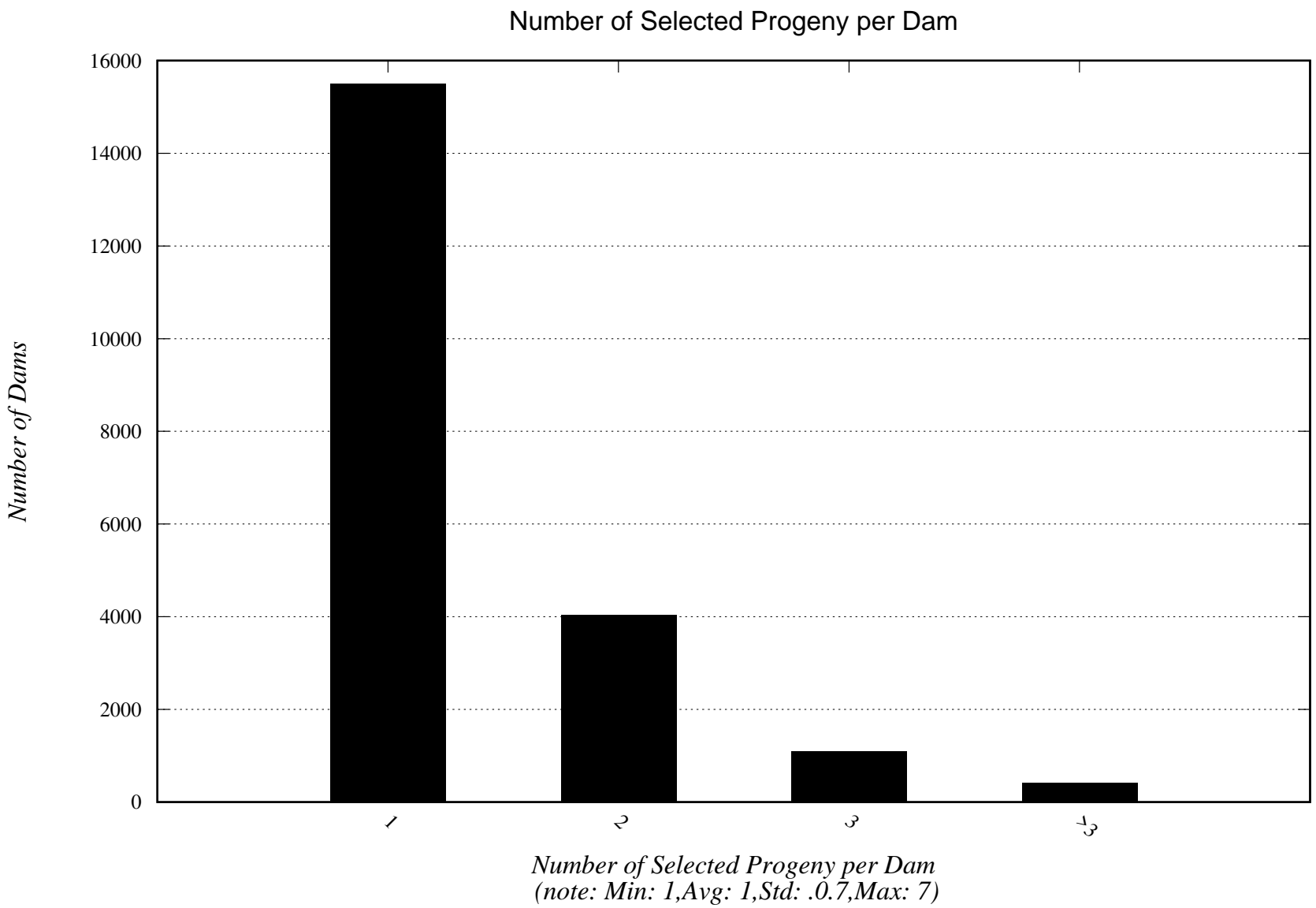


Figure 7: Sires with the most Selected Progeny in the Population

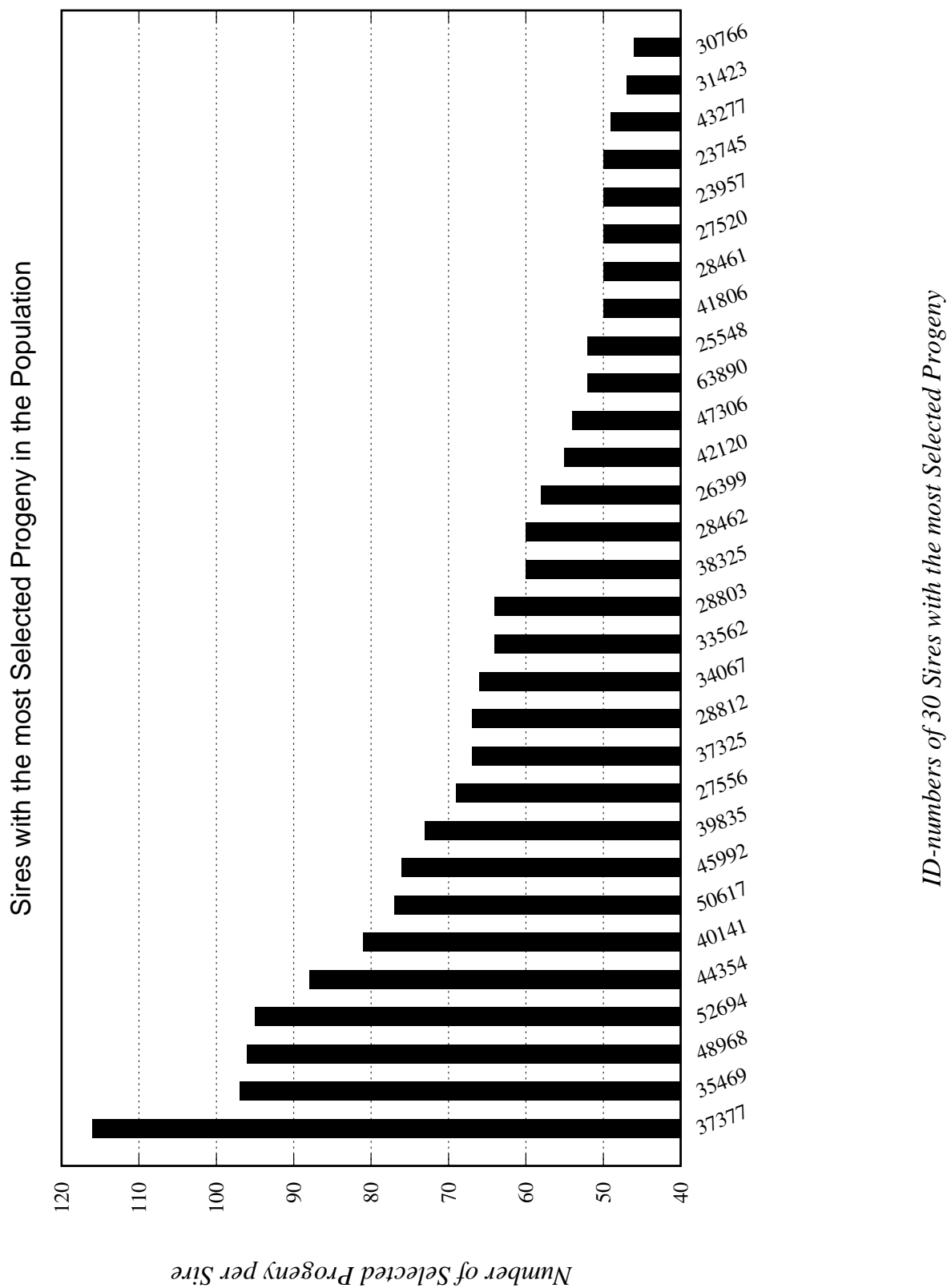


Figure 8: Number of Selected Progeny per Sire

