

PopReport

A Pedigree Analysis Report

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25638 input lines processed.
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Pedigree Analysis Report for Population: 55

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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

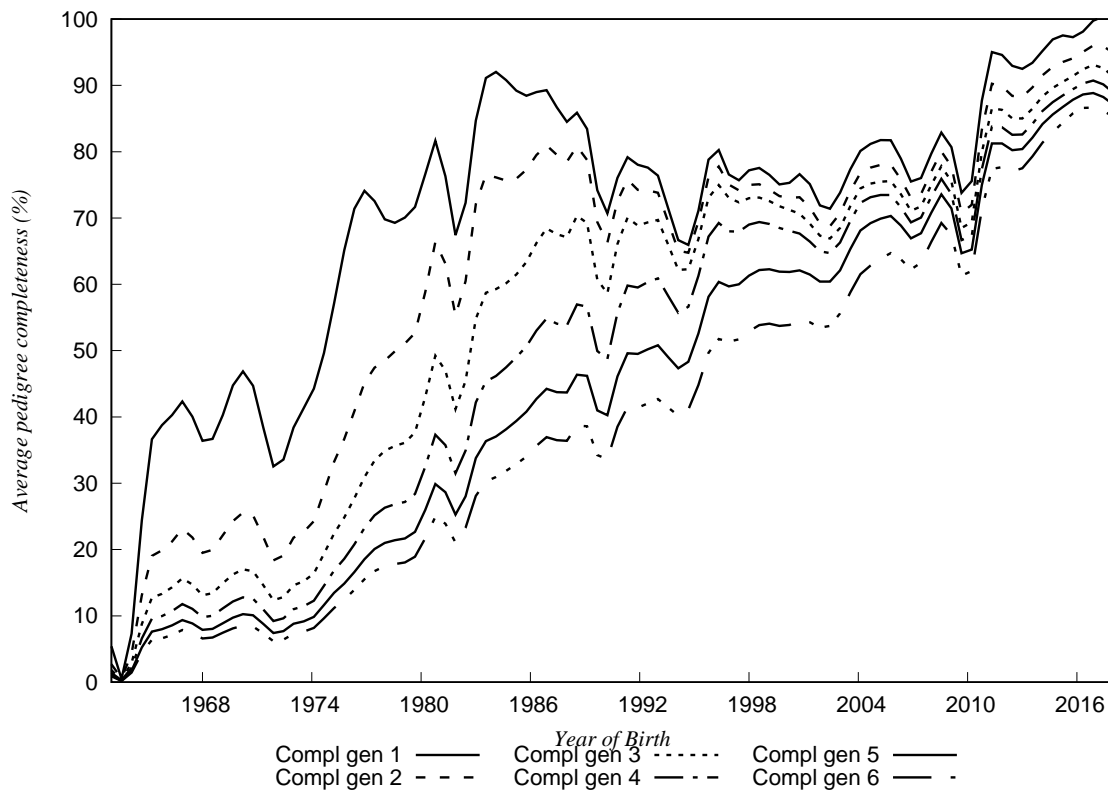
Year	No of Animals	Compl. gen 1	Compl. gen 2	Compl. gen 3	Compl. gen 4	Compl. gen 5	Compl. (%) gen 6(%)
1951	1	0.0	0.0	0.0	0.0	0.0	0.0
1952	1	0.0	0.0	0.0	0.0	0.0	0.0
1954	1	0.0	0.0	0.0	0.0	0.0	0.0
1959	1	0.0	0.0	0.0	0.0	0.0	0.0
1960	4	25.0	12.5	8.3	6.2	5.0	4.2
1961	7	0.0	0.0	0.0	0.0	0.0	0.0
1962	6	16.7	8.3	5.6	4.2	3.3	2.8
1963	55	5.4	2.7	1.8	1.4	1.1	0.9
1964	62	4.8	3.0	2.0	1.5	1.2	1.0
1965	99	33.3	17.5	11.7	8.8	7.0	5.9
1966	123	39.0	20.1	13.5	10.1	8.1	6.7
1967	130	42.3	23.2	15.7	11.8	9.4	7.9
1968	151	36.4	19.5	13.1	9.8	7.9	6.6
1969	170	39.4	21.7	14.6	10.9	8.7	7.3
1970	172	46.5	25.2	16.8	12.6	10.1	8.4
1971	230	42.6	24.2	16.1	12.1	9.7	8.1
1972	361	32.1	18.1	12.2	9.1	7.3	6.1
1973	391	38.4	21.8	14.6	11.0	8.8	7.3
1974	490	43.5	23.7	16.0	12.0	9.6	8.0
1975	449	53.9	31.6	21.3	16.0	12.8	10.6
1976	460	68.0	38.2	25.9	19.4	15.5	13.0
1977	429	74.1	45.8	31.5	23.7	18.9	15.8
1978	477	69.8	48.5	34.9	26.3	21.0	17.5
1979	375	69.9	50.9	36.0	27.1	21.6	18.0
1980	437	74.1	55.6	40.3	30.4	24.3	20.3
1981	534	81.1	66.8	49.7	37.7	30.2	25.2
1982	461	67.0	55.0	41.0	31.4	25.2	21.0

Continue...

Year	No of Animals	Compl. 1 gen	Compl. 2 gen	Compl. 3 gen	Compl. 4 gen	Compl. 5 gen	Compl. (%) 6 gen (%)
1983	469	84.7	72.1	54.8	42.2	33.8	28.1
1984	404	92.1	76.3	59.2	46.0	36.9	30.8
1985	411	89.8	75.7	60.9	48.4	38.9	32.5
1986	349	88.5	78.1	64.4	51.5	41.5	34.6
1987	417	89.0	80.9	68.5	54.9	44.3	37.0
1988	368	84.5	78.5	67.1	53.8	43.7	36.4
1989	418	84.7	80.0	70.3	57.4	46.8	39.1
1990	415	70.6	65.9	57.8	47.8	39.4	32.9
1991	456	78.1	74.8	68.7	58.2	48.2	40.3
1992	437	77.8	74.0	68.7	59.5	49.5	41.4
1993	450	76.4	73.8	69.7	60.9	50.8	42.7
1994	371	67.4	65.7	62.7	56.0	47.5	40.3
1995	514	68.3	67.0	64.5	59.0	50.5	43.0
1996	524	80.5	77.7	74.6	68.7	59.6	51.0
1997	405	76.0	74.6	72.7	67.8	59.6	51.3
1998	464	77.2	75.0	73.0	69.0	61.3	52.9
1999	565	76.8	74.5	72.7	69.2	62.3	54.1
2000	597	74.9	73.0	71.4	68.2	61.8	53.7
2001	557	76.5	72.8	70.2	67.3	62.0	54.6
2002	864	71.5	68.9	67.1	64.8	60.3	53.4
2003	768	73.8	70.7	68.5	66.3	62.1	55.6
2004	757	79.7	76.4	74.1	71.9	67.7	61.1
2005	860	81.5	77.8	75.3	73.3	69.6	63.4
2006	749	81.0	77.5	75.1	73.0	70.0	64.6
2007	834	75.2	72.8	70.9	69.2	66.8	62.2
2008	744	79.7	77.0	75.0	73.2	70.8	66.4
2009	704	81.8	78.9	76.6	74.7	72.5	68.4
2010	671	73.0	69.7	67.3	65.4	63.4	60.2
2011	831	91.9	87.3	83.7	81.0	78.5	74.7
2012	617	94.2	89.5	86.0	83.4	81.0	77.5
2013	640	92.5	88.3	85.0	82.6	80.4	77.5
2014	717	94.8	91.2	88.0	85.8	83.8	81.0
2015	637	97.5	93.3	90.2	88.1	86.3	83.8
2016	388	97.4	94.4	91.8	89.8	88.2	86.2
2017	176	100.0	96.1	93.1	90.7	88.8	86.6
2018	13	100.0	94.9	91.3	88.9	87.1	85.3

The average pedigree completeness for animals born within the last 10 years: 1 generations deep = 90.3%. 2 generations deep = 86.4%. 3 generations deep = 83.4%. 4 generations deep = 81.1%. 5 generations deep = 79%. 6 generations deep = 75.9%.

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 2018 for the 55 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
1951	1	-	-	-	-	-	-	-	-	-	-
1952	1	-	-	-	-	-	-	-	-	-	-
1954	1	-	-	-	-	-	-	-	-	-	-
1959	1	-	-	-	-	-	-	-	-	-	-
1960	4	-	-	-	-	-	-	-	-	-	-
1961	7	-	-	-	-	-	-	-	-	-	-
1962	6	-	-	-	-	-	-	-	-	-	-
1963	55	-	-	-	-	-	-	-	-	-	-
1964	62	-	-	-	-	-	-	-	-	-	-
1965	98	-	-	-	1	-	-	-	-	-	-
1966	123	-	-	-	-	-	-	-	-	-	-
1967	130	-	-	-	-	-	-	-	-	-	-
1968	151	-	-	-	-	-	-	-	-	-	-
1969	170	-	-	-	-	-	-	-	-	-	-
1970	172	-	-	-	-	-	-	-	-	-	-
1971	230	-	-	-	-	-	-	-	-	-	-
1972	360	-	-	-	1	-	-	-	-	-	-
1973	387	-	1	-	3	-	-	-	-	-	-
1974	489	-	-	-	1	-	-	-	-	-	-
1975	441	2	6	-	-	-	-	-	-	-	-
1976	455	2	3	-	-	-	-	-	-	-	-
1977	424	3	-	-	2	-	-	-	-	-	-
1978	463	12	1	-	1	-	-	-	-	-	-
1979	366	1	3	-	5	-	-	-	-	-	-
1980	425	2	6	-	4	-	-	-	-	-	-
1981	512	1	15	4	2	-	-	-	-	-	-
1982	432	1	19	-	9	-	-	-	-	-	-
1983	460	3	4	1	1	-	-	-	-	-	-
1984	387	9	1	1	6	-	-	-	-	-	-
1985	392	2	8	6	3	-	-	-	-	-	-
1986	329	11	5	-	4	-	-	-	-	-	-
1987	382	15	11	5	2	1	1	-	-	-	-
1988	342	5	7	4	10	-	-	-	-	-	-
1989	377	15	14	5	7	-	-	-	-	-	-
1990	380	17	10	-	8	-	-	-	-	-	-
1991	426	14	12	-	4	-	-	-	-	-	-
1992	393	23	10	4	4	2	1	-	-	-	-

Continue...

Year	Classes										
	1	2	3	4	5	6	7	8	9	10	11
1993	419	12	14	1	3	1	-	-	-	-	-
1994	336	18	9	1	5	2	-	-	-	-	-
1995	454	27	11	10	8	3	1	-	-	-	-
1996	471	28	10	4	8	3	-	-	-	-	-
1997	357	23	8	5	6	5	1	-	-	-	-
1998	396	36	7	8	11	5	-	1	-	-	-
1999	469	47	19	23	4	3	-	-	-	-	-
2000	466	56	40	26	9	-	-	-	-	-	-
2001	461	48	28	13	5	2	-	-	-	-	-
2002	714	67	39	28	7	8	-	1	-	-	-
2003	626	60	33	13	14	20	1	1	-	-	-
2004	607	82	17	16	7	26	2	-	-	-	-
2005	735	64	24	15	2	19	1	-	-	-	-
2006	668	39	13	11	1	13	-	4	-	-	-
2007	777	30	9	6	3	9	-	-	-	-	-
2008	676	31	19	5	1	10	1	1	-	-	-
2009	611	45	16	9	6	17	-	-	-	-	-
2010	594	40	10	7	4	15	-	1	-	-	-
2011	711	53	18	18	1	30	-	-	-	-	-
2012	537	43	18	7	-	11	1	-	-	-	-
2013	536	61	22	5	-	14	-	1	1	-	-
2014	620	63	16	6	1	9	1	1	-	-	-
2015	567	38	14	3	3	11	1	-	-	-	-
2016	337	32	8	4	-	4	2	-	1	-	-
2017	149	18	2	1	-	5	-	-	1	-	-
2018	10	3	-	-	-	-	-	-	-	-	-

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
1951	1	-	-	-	-	-	-	-	-
1952	1	-	-	-	-	-	-	-	-
1954	1	-	-	-	-	-	-	-	-
1959	1	-	-	-	-	-	-	-	-
1960	4	-	-	1	-	-	1	-	-
1961	7	-	-	-	-	-	-	-	-
1962	6	-	-	2	-	-	1	-	-
1963	55	-	-	5	-	-	3	-	-
1964	62	-	-	3	-	-	3	-	-
1965	99	1	0.0025	22	-	-	36	-	-
1966	123	-	-	19	-	-	50	-	-
1967	130	-	-	30	-	-	56	1	0.0045
1968	151	-	-	31	-	-	56	-	-
1969	170	-	-	33	-	-	65	-	-
1970	172	-	-	38	-	-	88	-	-
1971	230	-	-	36	-	-	106	-	-
1972	361	1	0.0007	42	-	-	122	-	-
1973	391	4	0.0022	42	-	-	159	-	-
1974	490	1	0.0005	66	-	-	219	-	-
1975	449	8	0.0019	71	-	-	253	1	0.0010
1976	460	5	0.0011	69	-	-	317	-	-
1977	429	5	0.0016	58	-	-	317	-	-
1978	477	18	0.0025	62	-	-	328	-	-
1979	375	13	0.0048	51	-	-	265	1	0.0005
1980	437	20	0.0046	57	-	-	318	1	0.0004
1981	534	45	0.0069	66	2	0.0019	423	7	0.0025
1982	461	41	0.0109	58	1	0.0011	314	8	0.0037
1983	469	20	0.0030	61	1	0.0010	396	7	0.0023
1984	404	37	0.0069	58	-	-	370	16	0.0038
1985	411	46	0.0085	67	3	0.0008	366	20	0.0053
1986	349	36	0.0078	52	2	0.0033	313	17	0.0040
1987	417	68	0.0123	57	3	0.0037	371	15	0.0028
1988	368	51	0.0130	62	4	0.0081	320	17	0.0029
1989	418	83	0.0147	68	6	0.0056	373	19	0.0040
1990	415	80	0.0129	60	8	0.0070	320	23	0.0054
1991	456	97	0.0109	60	7	0.0085	390	28	0.0047
1992	437	109	0.0159	48	10	0.0153	367	39	0.0072
1993	450	109	0.0117	54	11	0.0160	379	40	0.0060
1994	371	107	0.0148	47	8	0.0141	289	44	0.0096

Continue...

Year	Animal			Sires			Dams		
	Tot No	Inbred No	Avg F	Tot No	Inbred No	Avg F	Tot No	Inbred No	Avg F
1995	514	173	0.0200	50	12	0.0141	392	72	0.0125
1996	524	222	0.0181	57	14	0.0185	430	78	0.0089
1997	405	186	0.0220	58	16	0.0093	315	74	0.0122
1998	464	228	0.0263	55	23	0.0077	370	90	0.0119
1999	565	329	0.0267	63	28	0.0084	458	140	0.0153
2000	597	357	0.0331	68	30	0.0096	485	150	0.0143
2001	557	303	0.0248	79	42	0.0140	462	153	0.0148
2002	864	476	0.0261	95	58	0.0179	799	247	0.0148
2003	768	429	0.0308	96	68	0.0224	715	255	0.0172
2004	757	465	0.0315	100	77	0.0230	720	303	0.0208
2005	860	563	0.0246	103	81	0.0232	819	362	0.0188
2006	749	490	0.0227	107	87	0.0254	724	345	0.0239
2007	834	524	0.0160	116	98	0.0277	796	402	0.0236
2008	744	500	0.0188	113	97	0.0249	729	386	0.0257
2009	704	496	0.0248	117	103	0.0270	685	368	0.0260
2010	671	402	0.0225	107	93	0.0290	659	369	0.0246
2011	831	601	0.0296	145	133	0.0226	815	506	0.0259
2012	617	466	0.0245	118	109	0.0219	603	378	0.0233
2013	640	497	0.0300	126	119	0.0254	628	409	0.0319
2014	717	582	0.0253	128	123	0.0220	708	473	0.0252
2015	637	534	0.0245	122	119	0.0236	633	458	0.0223
2016	388	339	0.0285	91	90	0.0283	385	283	0.0260
2017	176	152	0.0325	60	59	0.0342	174	125	0.0189
2018	13	11	0.0257	10	10	0.0489	13	9	0.0137

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
1951	1	0.0000	0.0000	0.0000	-
1952	1	0.0000	0.0000	0.0000	-
1954	1	0.0000	0.0000	0.0000	-
1959	1	0.0000	0.0000	0.0000	-
1960	4	0.0000	0.0000	0.0000	0.0000
1961	7	0.0000	0.0000	0.0000	0.0000
1962	6	0.0000	0.0000	0.0000	0.0000
1963	55	0.0000	0.0000	0.0000	0.0000
1964	62	0.0000	0.0000	0.0000	0.0000
1965	99	0.0000	0.2500	0.0025	0.0251
1966	123	0.0000	0.0000	0.0000	0.0000
1967	130	0.0000	0.0000	0.0000	0.0000
1968	151	0.0000	0.0000	0.0000	0.0000
1969	170	0.0000	0.0000	0.0000	0.0000
1970	172	0.0000	0.0000	0.0000	0.0000
1971	230	0.0000	0.0000	0.0000	0.0000
1972	361	0.0000	0.2500	0.0007	0.0132
1973	391	0.0000	0.2500	0.0022	0.0227
1974	490	0.0000	0.2500	0.0005	0.0113
1975	449	0.0000	0.1250	0.0019	0.0149
1976	460	0.0000	0.1250	0.0011	0.0109
1977	429	0.0000	0.2500	0.0016	0.0178
1978	477	0.0000	0.2500	0.0025	0.0162
1979	375	0.0000	0.2500	0.0048	0.0310
1980	437	0.0000	0.2500	0.0046	0.0281
1981	534	0.0000	0.2500	0.0069	0.0293
1982	461	0.0000	0.2500	0.0109	0.0425
1983	469	0.0000	0.2500	0.0030	0.0191
1984	404	0.0000	0.2500	0.0069	0.0333
1985	411	0.0000	0.2500	0.0085	0.0334
1986	349	0.0000	0.2500	0.0078	0.0327
1987	417	0.0000	0.3125	0.0123	0.0388
1988	368	0.0000	0.2500	0.0130	0.0455
1989	418	0.0000	0.2500	0.0147	0.0434
1990	415	0.0000	0.2500	0.0129	0.0409
1991	456	0.0000	0.2500	0.0109	0.0333
1992	437	0.0000	0.3125	0.0159	0.0433
1993	450	0.0000	0.2524	0.0117	0.0352
1994	371	0.0000	0.2813	0.0148	0.0426

Continue...

Year	No of Animals	<i>F</i>			
		Min	Max	Avg	Std
1995	514	0.0000	0.3125	0.0200	0.0503
1996	524	0.0000	0.2656	0.0181	0.0443
1997	405	0.0000	0.3125	0.0220	0.0516
1998	464	0.0000	0.3750	0.0263	0.0561
1999	565	0.0000	0.2656	0.0267	0.0488
2000	597	0.0000	0.2500	0.0331	0.0533
2001	557	0.0000	0.2578	0.0248	0.0474
2002	864	0.0000	0.3750	0.0261	0.0526
2003	768	0.0000	0.3750	0.0308	0.0620
2004	757	0.0000	0.3296	0.0315	0.0607
2005	860	0.0000	0.3301	0.0246	0.0505
2006	749	0.0000	0.3809	0.0227	0.0514
2007	834	0.0000	0.2896	0.0160	0.0377
2008	744	0.0000	0.3751	0.0188	0.0433
2009	704	0.0000	0.2806	0.0248	0.0513
2010	671	0.0000	0.3857	0.0225	0.0514
2011	831	0.0000	0.2998	0.0296	0.0575
2012	617	0.0000	0.3254	0.0245	0.0469
2013	640	0.0000	0.4035	0.0300	0.0523
2014	717	0.0000	0.3786	0.0253	0.0438
2015	637	0.0000	0.3269	0.0245	0.0443
2016	388	0.0000	0.4009	0.0285	0.0468
2017	176	0.0000	0.4009	0.0325	0.0551
2018	13	0.0000	0.0910	0.0257	0.0267

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.

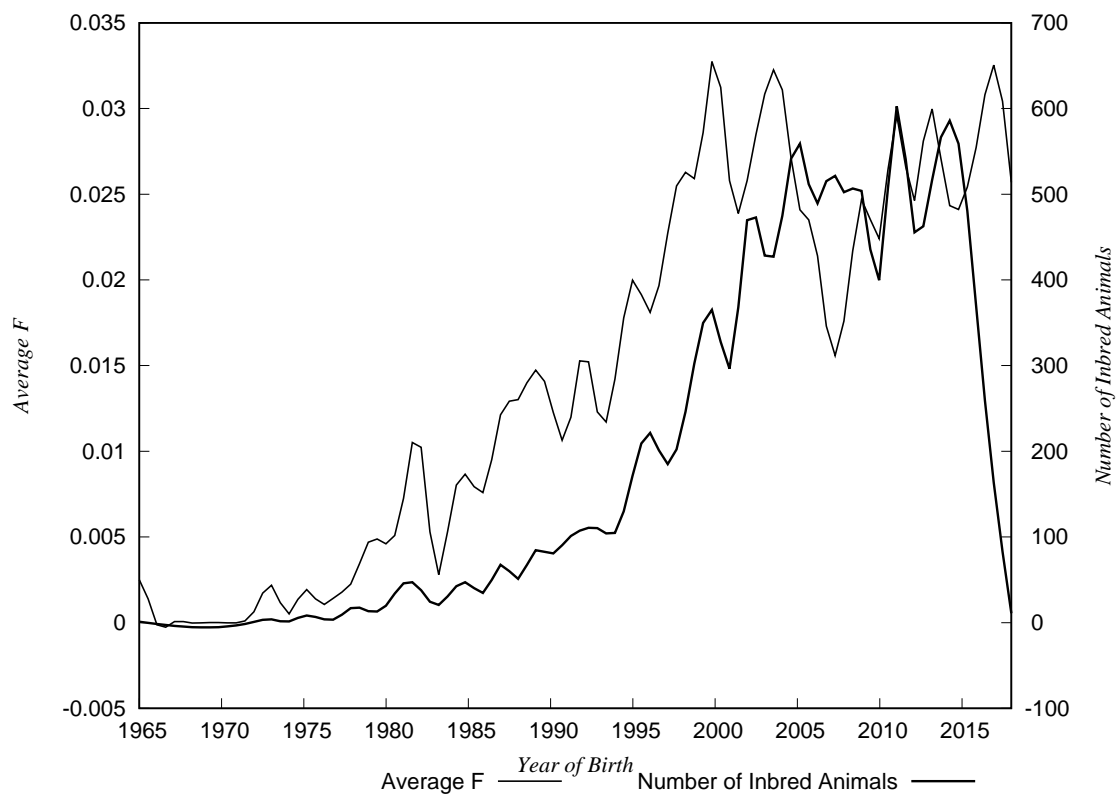
Table 5: Inbreeding coefficients (F) of INBRED animals by year

Year	No of Animals	F			
		Min	Max	Avg	Std
1965	1	0.2500	0.2500	0.2500	-
1972	1	0.2500	0.2500	0.2500	-
1973	4	0.1250	0.2500	0.2188	0.0625
1974	1	0.2500	0.2500	0.2500	-
1975	8	0.0625	0.1250	0.1094	0.0289
1976	5	0.0625	0.1250	0.1000	0.0342
1977	5	0.0625	0.2500	0.1375	0.1027
1978	18	0.0078	0.2500	0.0673	0.0519
1979	13	0.0313	0.2500	0.1394	0.0977
1980	20	0.0078	0.2500	0.1012	0.0889
1981	45	0.0078	0.2500	0.0823	0.0634
1982	41	0.0078	0.2500	0.1223	0.0827
1983	20	0.0078	0.2500	0.0715	0.0616
1984	37	0.0078	0.2500	0.0753	0.0844
1985	46	0.0039	0.2500	0.0761	0.0700
1986	36	0.0027	0.2500	0.0755	0.0731
1987	68	0.0078	0.3125	0.0757	0.0669
1988	51	0.0039	0.2500	0.0941	0.0862
1989	83	0.0029	0.2500	0.0740	0.0716
1990	80	0.0005	0.2500	0.0671	0.0714
1991	97	0.0012	0.2500	0.0512	0.0562
1992	109	0.0029	0.3125	0.0636	0.0672
1993	109	0.0010	0.2524	0.0484	0.0579
1994	107	0.0020	0.2813	0.0513	0.0666
1995	173	0.0001	0.3125	0.0595	0.0721
1996	222	0.0010	0.2656	0.0428	0.0599
1997	186	0.0005	0.3125	0.0479	0.0676
1998	228	0.0002	0.3750	0.0536	0.0704
1999	329	0.0002	0.2656	0.0459	0.0567
2000	357	0.0002	0.2500	0.0553	0.0593
2001	303	0.0001	0.2578	0.0455	0.0564
2002	476	0.0002	0.3750	0.0474	0.0634
2003	429	0.0001	0.3750	0.0551	0.0744
2004	465	0.0000	0.3296	0.0514	0.0706
2005	563	0.0000	0.3301	0.0375	0.0584
2006	490	0.0000	0.3809	0.0346	0.0602
2007	524	0.0000	0.2896	0.0254	0.0449
2008	500	0.0000	0.3751	0.0280	0.0503

Continue...

Year	No of Animals	<i>F</i>			
		Min	Max	Avg	Std
2009	496	0.0000	0.2806	0.0353	0.0580
2010	402	0.0000	0.3857	0.0375	0.0620
2011	601	0.0002	0.2998	0.0409	0.0641
2012	466	0.0001	0.3254	0.0325	0.0516
2013	497	0.0001	0.4035	0.0386	0.0565
2014	582	0.0002	0.3786	0.0312	0.0468
2015	534	0.0001	0.3269	0.0292	0.0469
2016	339	0.0011	0.4009	0.0326	0.0487
2017	152	0.0012	0.4009	0.0376	0.0576
2018	11	0.0047	0.0910	0.0304	0.0264

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 (ΔF), 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 (ΔF) 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.

ΔF : 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				ΔF	N_e
	Animals	Sires	Dams	Parents		
1951	-	-	-	-	-	-
1952	-	-	-	-	-	-
1954	-	-	-	-	-	-
1959	-	-	-	-	-	-
1960	0.0000	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	0.0011	0.0000	0.0000	0.0000	0.0011	468
1966	0.0007	0.0000	0.0000	0.0000	0.0007	712
1967	0.0005	0.0000	0.0017	0.0008	-0.0003	-1752
1968	0.0004	0.0000	0.0012	0.0006	-0.0002	-2626
1969	0.0003	0.0000	0.0009	0.0004	-0.0001	-3893
1970	0.0003	0.0000	0.0007	0.0003	-0.0001	-7427
1971	0.0002	0.0000	0.0005	0.0003	0.0000	-14238
1972	0.0002	0.0000	0.0005	0.0002	0.0000	-12867
1973	0.0007	0.0000	0.0004	0.0002	0.0005	976
1974	0.0007	0.0000	0.0000	0.0000	0.0007	715
1975	0.0010	0.0000	0.0002	0.0001	0.0009	573
1976	0.0011	0.0000	0.0002	0.0001	0.0010	511
1977	0.0012	0.0000	0.0002	0.0001	0.0011	438
1978	0.0015	0.0000	0.0001	0.0001	0.0014	345
1979	0.0020	0.0000	0.0002	0.0001	0.0019	260
1980	0.0024	0.0000	0.0002	0.0001	0.0022	223

Continue...

Year	Avg F		Dams	Parents	ΔF	N_e
	Animals	Sires				
1981	0.0034	0.0004	0.0007	0.0005	0.0029	174
1982	0.0047	0.0004	0.0011	0.0007	0.0040	126
1983	0.0050	0.0006	0.0014	0.0010	0.0040	125
1984	0.0057	0.0006	0.0019	0.0013	0.0044	113
1985	0.0066	0.0007	0.0027	0.0017	0.0049	102
1986	0.0069	0.0008	0.0031	0.0019	0.0050	100
1987	0.0080	0.0010	0.0034	0.0022	0.0058	86
1988	0.0088	0.0018	0.0035	0.0026	0.0062	80
1989	0.0094	0.0025	0.0035	0.0030	0.0063	79
1990	0.0110	0.0039	0.0040	0.0040	0.0070	71
1991	0.0115	0.0052	0.0041	0.0047	0.0069	73
1992	0.0126	0.0073	0.0044	0.0059	0.0068	74
1993	0.0130	0.0082	0.0048	0.0065	0.0066	76
1994	0.0134	0.0115	0.0057	0.0085	0.0049	101
1995	0.0145	0.0130	0.0071	0.0099	0.0047	107
1996	0.0151	0.0139	0.0079	0.0108	0.0043	115
1997	0.0163	0.0140	0.0088	0.0113	0.0050	100
1998	0.0185	0.0137	0.0099	0.0117	0.0069	73
1999	0.0203	0.0120	0.0111	0.0116	0.0088	57
2000	0.0236	0.0121	0.0124	0.0122	0.0116	43
2001	0.0247	0.0112	0.0130	0.0122	0.0127	39
2002	0.0256	0.0113	0.0136	0.0125	0.0133	38
2003	0.0275	0.0129	0.0148	0.0139	0.0138	36
2004	0.0286	0.0144	0.0161	0.0153	0.0136	37
2005	0.0282	0.0167	0.0169	0.0168	0.0115	43
2006	0.0275	0.0194	0.0182	0.0187	0.0089	56
2007	0.0251	0.0220	0.0194	0.0206	0.0046	108
2008	0.0243	0.0230	0.0206	0.0217	0.0026	189
2009	0.0241	0.0249	0.0223	0.0235	0.0006	805
2010	0.0229	0.0263	0.0232	0.0246	-0.0018	-285
2011	0.0227	0.0261	0.0240	0.0250	-0.0023	-216
2012	0.0226	0.0257	0.0248	0.0252	-0.0026	-191
2013	0.0236	0.0252	0.0258	0.0255	-0.0020	-247
2014	0.0251	0.0244	0.0261	0.0253	-0.0002	-2270
2015	0.0260	0.0237	0.0257	0.0248	0.0012	405
2016	0.0264	0.0232	0.0257	0.0245	0.0020	254
2017	0.0273	0.0224	0.0256	0.0240	0.0034	148
2018	0.0267	0.0227	0.0254	0.0241	0.0027	186

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	
1951	1	1	1	2	1
1952	2	1	1	2	1
1954	3	1	1	2	1
1959	2	1	1	2	1
1960	6	2	2	4	3
1961	12	2	2	4	3
1962	18	4	3	7	5
1963	73	8	6	14	10
1964	135	11	9	20	14
1965	234	32	45	77	52
1966	356	44	94	138	84
1967	482	58	146	204	116
1968	626	73	198	271	149
1969	790	90	257	347	187
1970	907	104	336	440	222
1971	1075	125	430	555	271
1972	1337	134	498	632	296
1973	1605	143	593	736	323
1974	1965	167	734	901	381
1975	2263	170	884	1054	399
1976	2553	182	1088	1270	437
1977	2810	181	1242	1423	442

Continue...

Year	Number of				<i>N_e</i>
	Animals	Sires	Dams	Parents	
1978	3057	202	1402	1604	494
1979	3071	206	1480	1686	506
1980	3117	209	1588	1797	517
1981	3161	206	1731	1937	515
1982	3173	206	1779	1985	517
1983	3182	206	1825	2031	518
1984	3157	203	1862	2065	513
1985	3091	203	1899	2102	514
1986	3065	207	1927	2134	523
1987	3045	208	1951	2159	526
1988	2879	207	1881	2088	522
1989	2836	211	1896	2107	532
1990	2782	200	1817	2017	504
1991	2834	197	1776	1973	497
1992	2860	175	1763	1938	446
1993	2961	178	1775	1953	453
1994	2915	172	1711	1883	438
1995	3061	170	1784	1954	435
1996	3167	162	1826	1988	417
1997	3157	164	1809	1973	421
1998	3165	164	1807	1971	421
1999	3293	172	1887	2059	441
2000	3440	177	1934	2111	454
2001	3626	187	2059	2246	480
2002	3976	201	2352	2553	518
2003	4220	211	2548	2759	546
2004	4572	207	2793	3000	540
2005	4968	213	3106	3319	558
2006	5152	240	3307	3547	627
2007	5389	254	3551	3805	664
2008	5576	267	3771	4038	698
2009	5416	273	3719	3992	712
2010	5319	279	3714	3993	727
2011	5393	310	3800	4110	803
2012	5150	308	3660	3968	795
2013	5041	318	3611	3929	818
2014	4924	326	3527	3853	836
2015	4817	328	3443	3771	839
2016	4501	319	3273	3592	814
2017	4006	312	2946	3258	790
2018	3188	269	2444	2713	679

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 (ΔF) is equal to the rate of additive genetic relationships (Δf). 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 (Δf) 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	Δf	Avg	ΔF	() = True GI
1951	1	0.00000	-	0.00000	-	-
1952	2	0.00000	-	0.00000	-	-
1953	-	-	-	-	-	-
1954	3	0.00000	-	0.00000	-	-
1955	-	-	-	-	-	-
1956	-	-	-	-	-	-
1957	-	-	-	-	-	-
1958	-	-	-	-	-	-
1959	2	0.00000	0.00000	0.00000	0.00000	7 (-)
1960	6	0.00000	-	0.00000	-	-

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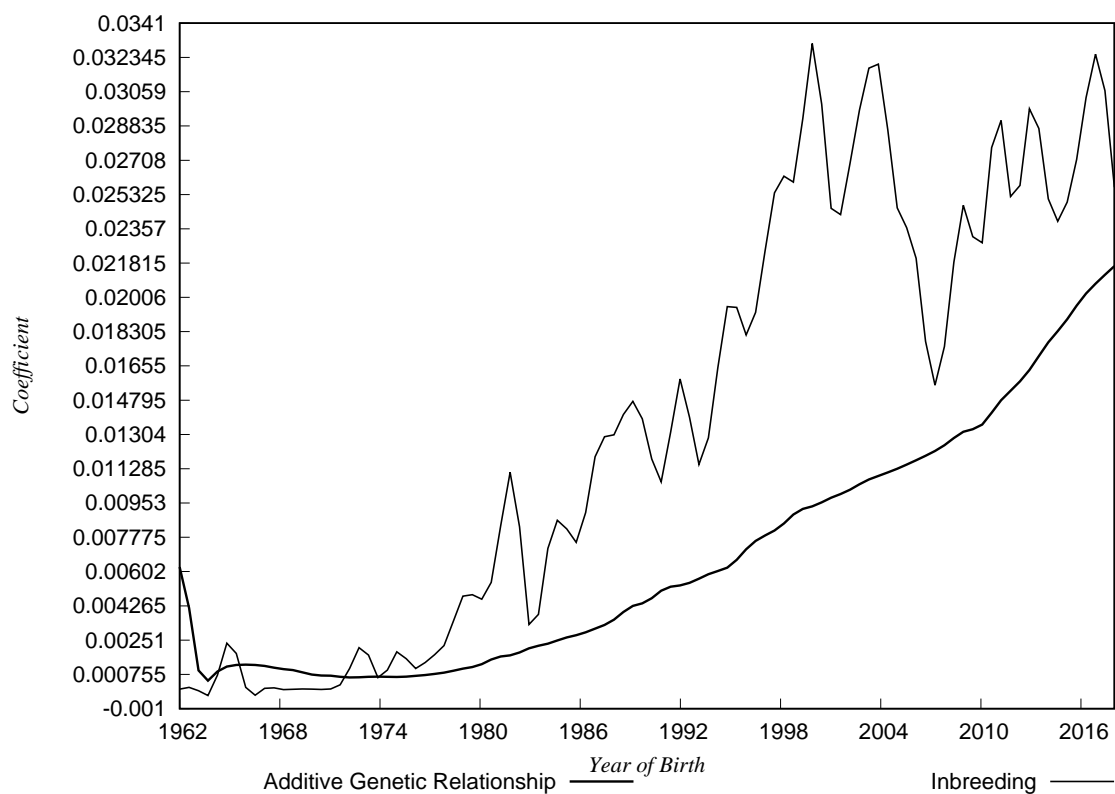
Year	No Animals	AGR		F		Generation Interval
		Avg	Δf	Avg	ΔF	() = True GI
1961	12	0.00000	0.00000	0.00000	0.00000	7 (-)
1962	18	0.00625	-	0.00000	-	-
1963	73	0.00147	-	0.00000	-	2 (2.1)
1964	135	0.00070	-	0.00000	-	2 (2.0)
1965	234	0.00119	-	0.00250	-	2 (2.3)
1966	356	0.00125	0.00125	0.00000	0.00000	7 (-)
1967	482	0.00120	0.00120	0.00000	0.00000	7 (-)
1968	626	0.00105	0.00105	0.00000	0.00000	3 (2.6)
1969	790	0.00094	-0.00534	0.00000	0.00000	3 (3.3)
1970	907	0.00073	-0.00074	0.00000	0.00000	4 (3.6)
1971	1075	0.00069	-0.00002	0.00000	0.00000	4 (3.5)
1972	1337	0.00060	-0.00060	0.00070	-0.00180	4 (4.2)
1973	1605	0.00062	-0.00063	0.00220	0.00220	4 (4.0)
1974	1965	0.00064	-0.00057	0.00050	0.00050	4 (3.9)
1975	2263	0.00062	-0.00043	0.00190	0.00190	5 (4.6)
1976	2553	0.00067	-0.00027	0.00110	0.00110	5 (4.8)
1977	2810	0.00075	0.00002	0.00160	0.00160	5 (5.2)
1978	3057	0.00087	0.00019	0.00250	0.00250	6 (5.8)
1979	3071	0.00105	0.00045	0.00480	0.00410	6 (5.9)
1980	3117	0.00124	0.00062	0.00460	0.00241	5 (5.4)
1981	3161	0.00163	0.00100	0.00690	0.00640	6 (5.7)
1982	3173	0.00176	0.00114	0.01090	0.00902	6 (5.5)
1983	3182	0.00211	0.00144	0.00300	0.00190	6 (6.1)
1984	3157	0.00231	0.00155	0.00690	0.00531	6 (6.0)
1985	3091	0.00260	0.00173	0.00850	0.00602	6 (6.2)
1986	3065	0.00282	0.00178	0.00780	0.00301	7 (6.5)
1987	3045	0.00313	0.00189	0.01230	0.00774	7 (6.6)
1988	2879	0.00354	0.00191	0.01300	0.00614	7 (6.7)
1989	2836	0.00420	0.00244	0.01470	0.00384	7 (6.7)
1990	2782	0.00449	0.00238	0.01290	0.00993	7 (6.8)
1991	2834	0.00512	0.00282	0.01090	0.00403	7 (6.9)
1992	2860	0.00531	0.00272	0.01590	0.00746	7 (7.0)
1993	2961	0.00561	0.00279	0.01170	0.00393	7 (7.1)
1994	2915	0.00599	0.00287	0.01480	0.00253	7 (6.9)
1995	3061	0.00632	0.00279	0.02000	0.00709	7 (6.7)
1996	3167	0.00722	0.00303	0.01810	0.00345	7 (6.9)
1997	3157	0.00784	0.00336	0.02200	0.00922	7 (7.0)
1998	3165	0.00833	0.00322	0.02630	0.01557	7 (6.6)
1999	3293	0.00909	0.00380	0.02670	0.01097	6 (6.3)
2000	3440	0.00939	0.00381	0.03310	0.02165	7 (6.7)
2001	3626	0.00979	0.00383	0.02480	0.01015	6 (6.2)
2002	3976	0.01014	0.00384	0.02610	0.00622	7 (7.2)
2003	4220	0.01062	0.00343	0.03080	0.01293	7 (6.8)
2004	4572	0.01096	0.00315	0.03150	0.00971	7 (6.8)
2005	4968	0.01129	0.00299	0.02460	-0.00175	7 (6.9)
2006	5152	0.01167	0.00261	0.02270	-0.00411	7 (6.8)
2007	5389	0.01208	0.00271	0.01600	-0.01769	7 (7.0)
2008	5576	0.01260	0.00283	0.01880	-0.00615	7 (6.6)

Continue...

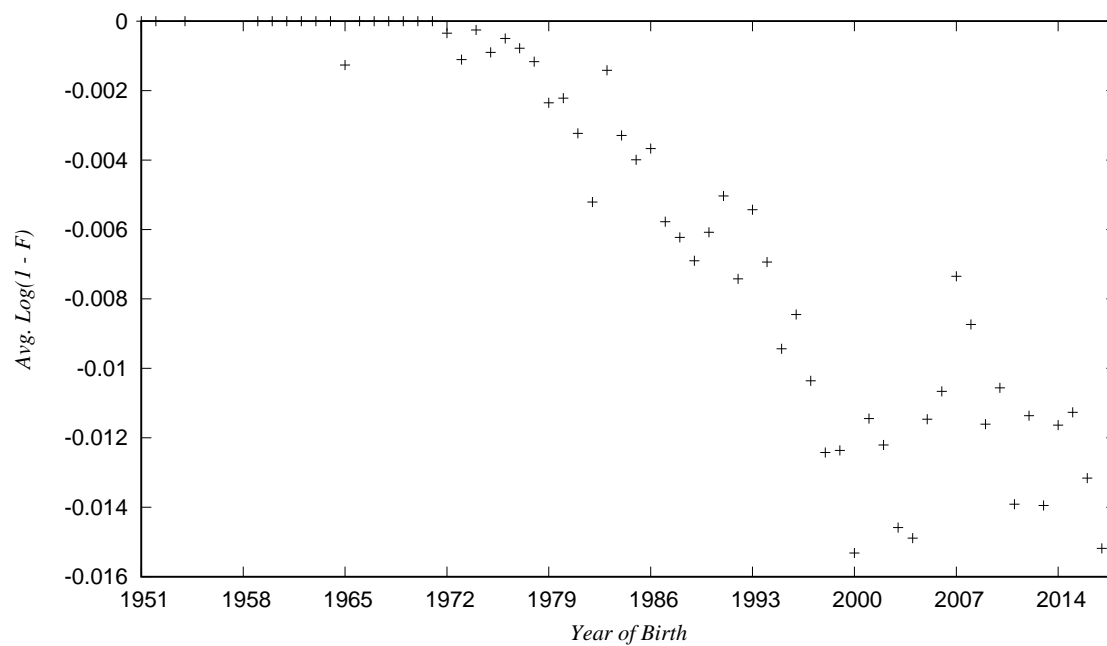
Year	No Animals	AGR		<i>F</i>		Generation Interval
		Avg	Δf	Avg	ΔF	() = True GI
2009	5416	0.01320	0.00309	0.02480	-0.00133	7 (6.9)
2010	5319	0.01349	0.00289	0.02250	-0.00856	7 (7.0)
2011	5393	0.01457	0.00364	0.02960	-0.00196	7 (6.7)
2012	5150	0.01546	0.00422	0.02450	-0.00010	6 (6.3)
2013	5041	0.01645	0.00483	0.03000	0.00747	7 (6.7)
2014	4924	0.01771	0.00569	0.02530	0.00945	7 (7.0)
2015	4817	0.01874	0.00622	0.02450	0.00581	8 (8.0)
2016	4501	0.01994	0.00683	0.02850	0.00379	7 (-)
2017	4006	0.02087	0.00748	0.03250	0.01023	7 (-)
2018	3188	0.02166	0.00720	0.02570	-0.00402	7 (-)

Fixed Time interval used to calculate Delta AGR: 7

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

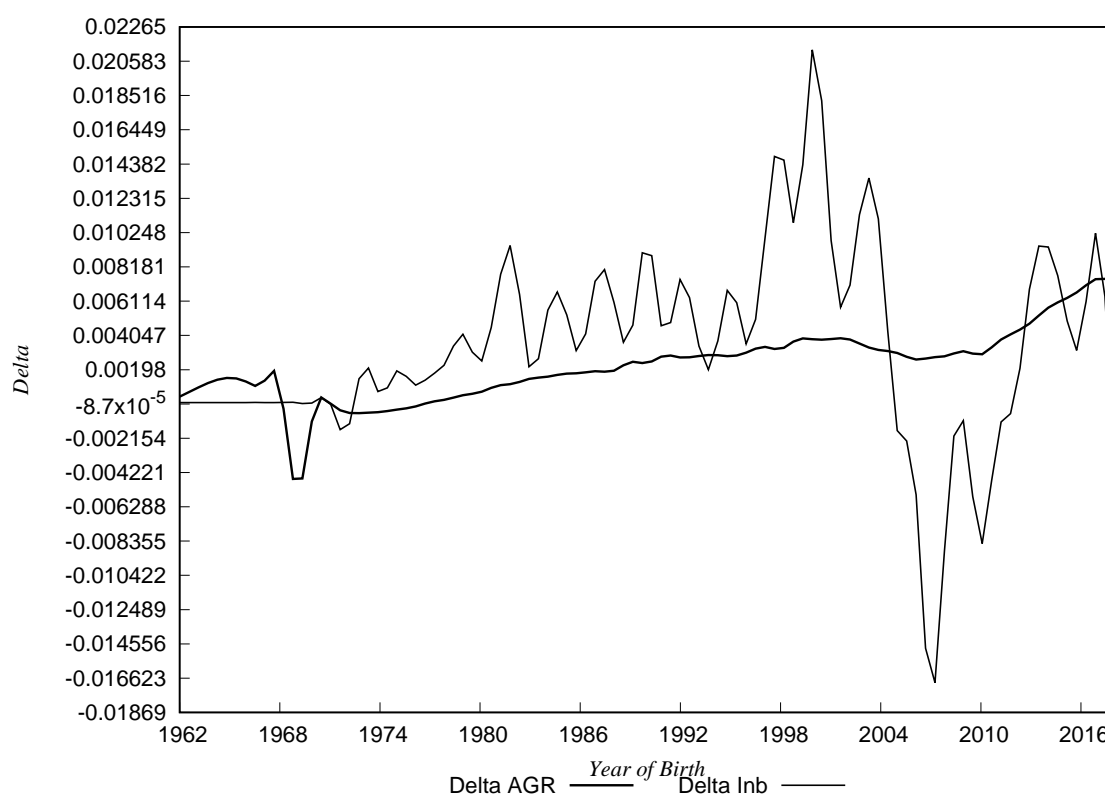


The average rate of change of the additive genetic relationships between 1962 and 2018 for the 55 breed was 0.00034 per year based on the slope of the regression fitted. This result in a Δf per generation of 0.00243. The rate of change of the average inbreeding coefficients based on the slope of the regression between 1962 and 2018 was 0.00063, which represents a ΔF per generation of 0.00452. The effective population sizes for the 55 breed, based on Δf and ΔF were 206 and 111, respectively.

Figure 4: Average $\text{Log}(1-F)$ by year of birth for animals born between 1951 and 2018.

*(The rate of inbreeding per generation for the 55 breed,
based on the Log(1-Inbreeding) is 0.005 which presents an Ne of 100.
Calculations were performed on 25638 animals born between 1951 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: 55
Inputfile: POPREP.TXT
Initiated by: quaglia@anabic.it
Submitted at: 2020-08-26 12:12:36
Started at: 2020-08-26 12:13:01
Finished at: 2020-08-26 12:33:10

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'.
25638 input lines processed.
25638 animals accepted.
- INFO: (concerning Inbreeding Report)
No shortening of infiles for the AGR computations done.

Monitoring the Population 55

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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 - ΔF_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 - ΔF_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)	$\Delta F_i = 1 - \text{ecg}_i \sqrt{1 - F_i}$	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

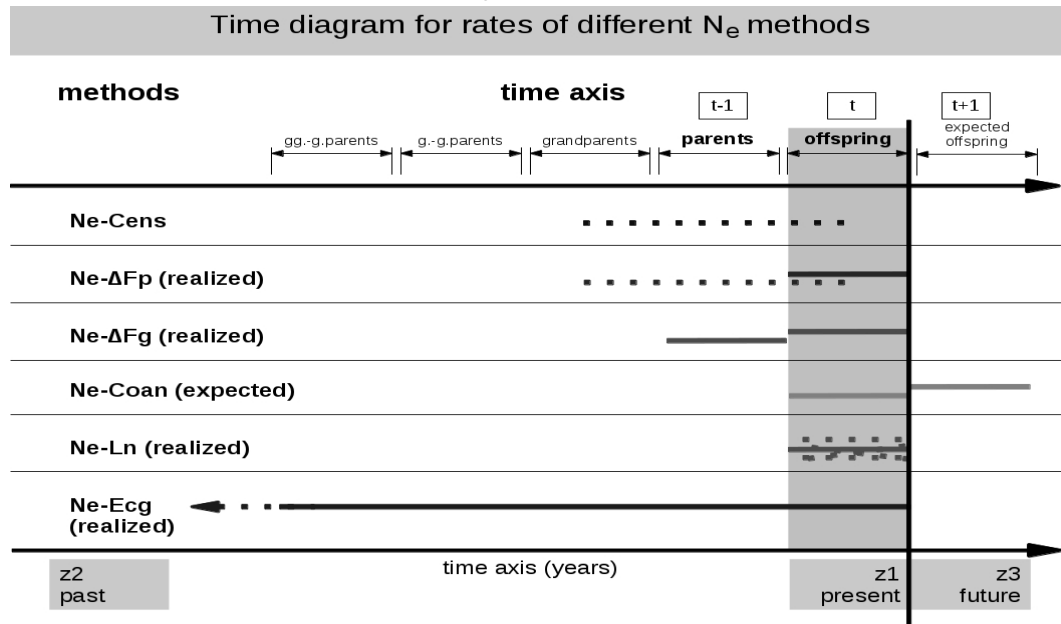


Table 2: Order of methods in cascade

Method	Based on data from
N_e -Ln	animals born in generation t
N_e - ΔF_p	animals and their parents born in generation t
N_e - ΔF_g	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 - ΔF_p 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 - ΔFg . 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 - ΔFg 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 - ΔFg) 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 - ΔFg . 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 - ΔFg 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 σ 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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- [Wright, 1923] Wright, S. (1923). Mendelian analysis of the pure breeds of livestock. *J. Hered.*, (14):339–348.

Breed: 55 • 25638 pedigree records • generation interval: 7 • August 26, 2020

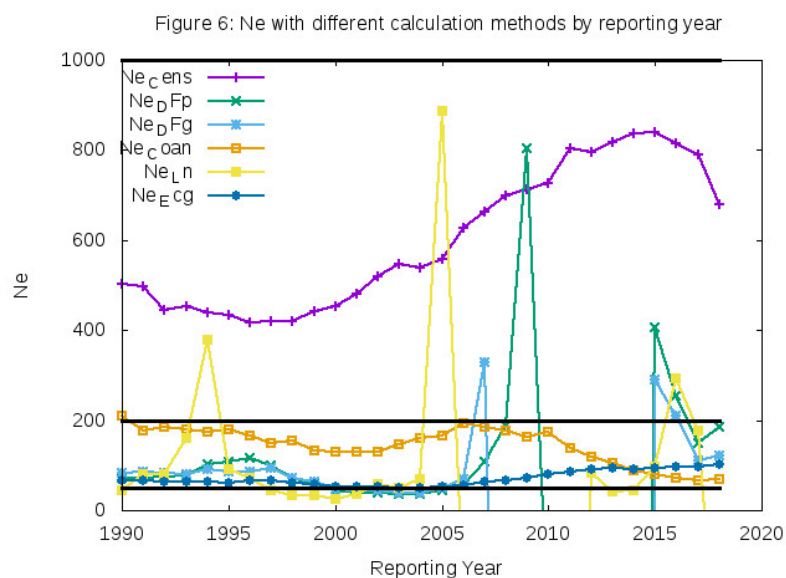
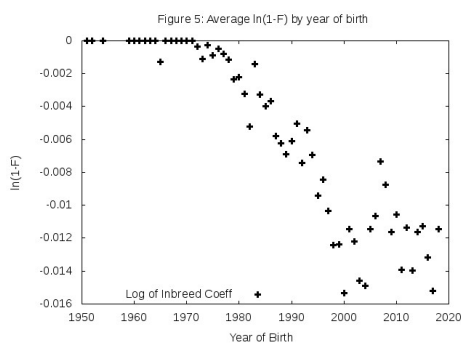
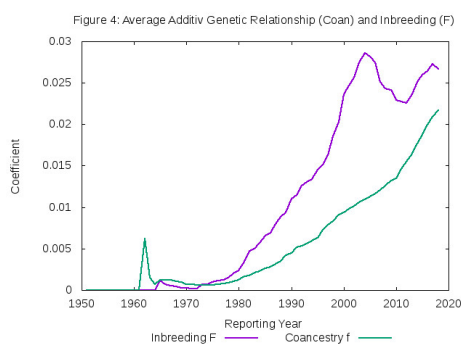
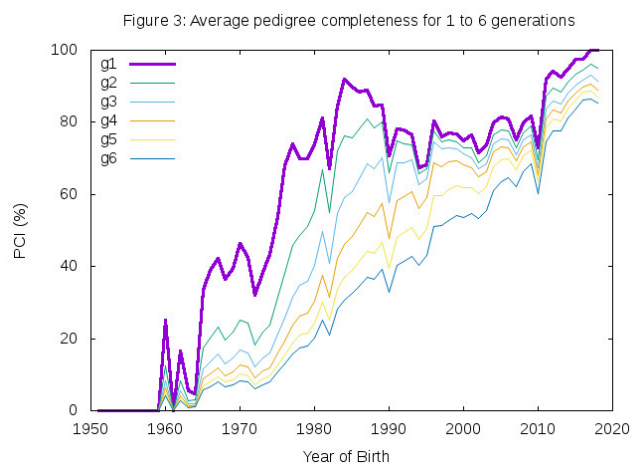
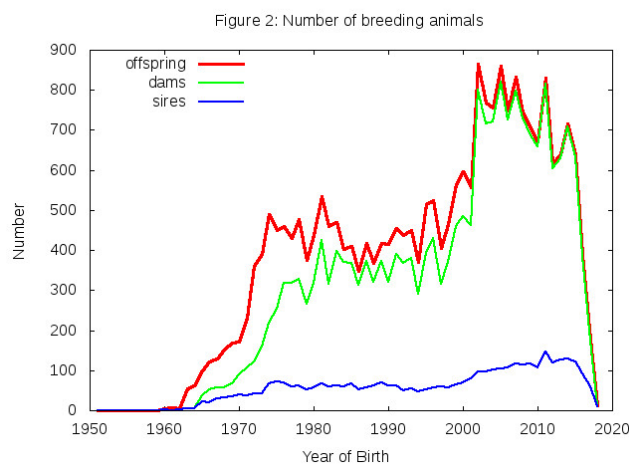


Table 3: Effective Population Size N_e

N_e -Method	2018	2017	2016	2015	2014	2013	data history
N_e -Cens	679	790	814	839	836	818	2011 – 2005
N_e - ΔF_p	186	148	254	405	-2270	-247	2018 – 2005
N_e - ΔF_g	122	111	211	289	-80710	-123	2018 – 2005
N_e -Coan	69	67	73	80	88	104	2025 – 2012
N_e -Ln	-339	176	293	97	43	42	2018 – 2012
N_e -Ecg	101	97	96	93	92	93	2018 – 1951

Proposed N_e : N_e -Coan = 69

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

Table 4: Decision tree for N_e calculation

Year	N_e -Cens	N_e - ΔF_p	N_e - ΔF_g	N_e -Coan	N_e -Ln	N_e -Ecg
2018	679	186	122	69	-339	101
2017	790	148	111	67	176	97
2016	814	254	211	73	293	96
2015	839	405	289	80	97	93
2014	836	-2270	-80710	88	43	92
2013	818	-247	-123	104	42	93
2012	795	-191	-88	118	84	91
σ	48.0	939.1	32727.5	6.6	204.6	1.4

Table 5: Decision cascade – side conditions

Method	Completeness [Years]	Stability [σ]	Diff	OK
N_e -Coan ^a	11/14	6.6 32727.5/20	11541.00	no
N_e -Ln	6/7	204.6/20	-	no
N_e - ΔF_p	4/7	939.1/20	-	no
N_e - ΔF_g	4/7	32727.5/20	-	no
N_e -Coan	7/7	6.6/20	-	yes
N_e -Ecg	7/7	1.4/20	-	yes
N_e -Cens	7/7	48.0/20	-	no

^aAvg N_e -Coan – Avg N_e - ΔF_g : $85.57 - (-11455.43) = 11541.00$

PopReport

A Population Structure Report

Population: 55
Inputfile: POPREP.TXT
Initiated by: quaglia@anabic.it
Submitted at: 2020-08-26 12:12:36
Started at: 2020-08-26 12:13:01
Finished at: 2020-08-26 12:33:10

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'.
25638 input lines processed.
25638 animals accepted.
- INFO: (concerning Inbreeding Report)
No shortening of infiles for the AGR computations done.

Population Structure Report for Population: 55

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August 26, 2020

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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 55 breed in 1965, 22 sires and 36 dams produced the 99 offspring during this year.

In the batch of future parents (select) born in this year 1965 19 sires and 24 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	
1960	-	1	1	-	1	1	4
1962	-	2	2	-	1	1	6
1963	-	5	5	-	3	3	55
1964	-	3	3	-	3	3	62
1965	-	22	19	-	36	24	99
1966	-	19	18	-	50	40	123
1967	-	30	26	-	56	39	130
1968	-	31	27	-	56	45	151
1969	-	33	27	-	65	46	170
1970	-	38	31	-	88	64	172
1971	-	36	34	-	106	55	230
1972	-	42	38	-	122	79	361
1973	-	42	37	-	159	100	391

Continue...

Year	sires			dams			Number of animals
	services	births	select	services	births	select	born
1974	-	66	50	-	219	142	490
1975	-	71	62	-	253	149	449
1976	-	69	55	-	317	202	460
1977	-	58	49	-	317	193	429
1978	-	62	56	-	328	188	477
1979	-	51	44	-	265	153	375
1980	-	57	42	-	318	165	437
1981	-	66	53	-	423	190	534
1982	-	58	50	-	314	140	461
1983	-	61	50	-	396	192	469
1984	-	58	49	-	370	180	404
1985	-	67	55	-	366	189	411
1986	-	52	48	-	313	192	349
1987	-	57	48	-	371	228	417
1988	-	62	53	-	320	188	368
1989	-	68	63	-	373	231	418
1990	-	60	49	-	320	174	415
1991	-	60	56	-	390	254	456
1992	-	48	42	-	367	253	437
1993	-	54	45	-	379	265	450
1994	-	47	43	-	289	188	371
1995	-	50	50	-	392	245	514
1996	-	57	52	-	430	294	524
1997	-	58	51	-	315	223	405
1998	-	55	52	-	370	275	464
1999	-	63	59	-	458	297	565
2000	-	68	64	-	485	318	597
2001	-	79	70	-	462	316	557
2002	-	95	84	-	799	469	864
2003	-	96	82	-	715	369	768
2004	-	100	90	-	720	389	757
2005	-	103	86	-	819	383	860
2006	-	107	84	-	724	329	749
2007	-	116	86	-	796	312	834
2008	-	113	83	-	729	256	744
2009	-	117	85	-	685	237	704
2010	-	107	72	-	659	194	671
2011	-	145	82	-	815	206	831
2012	-	118	50	-	603	106	617
2013	-	126	33	-	628	49	640
2014	-	128	20	-	708	33	717
2015	-	122	13	-	633	16	637
2016	-	91	-	-	385	-	388
2017	-	60	-	-	174	-	176
2018	-	10	-	-	13	-	13
Total	-	1194	935	-	12705	6868	25638

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 ≥ 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 55 breed in 1966, 4 two year-old males were used in reproduction while 2 three year-old males were used. The average age of males that produced offspring during 1966 was 1.6 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	≥ 16	
1960	-	-	-	-	-	-	-	1	-	-	-	-	-	-	-	-	8.0
1962	2	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	1.0
1963	4	-	1	-	-	-	-	-	-	-	-	-	-	-	-	-	1.4
1964	3	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	1.0
1965	16	4	1	-	-	1	-	-	-	-	-	-	-	-	-	-	1.5
1966	12	4	2	-	1	-	-	-	-	-	-	-	-	-	-	-	1.6
1967	11	6	5	5	1	1	-	-	-	-	-	-	-	-	1	-	2.8
1968	12	5	5	6	1	-	2	-	-	-	-	-	-	-	-	-	2.6
1969	10	5	7	4	5	-	1	1	-	-	-	-	-	-	-	-	2.9
1970	9	6	4	3	5	4	4	1	2	-	-	-	-	-	-	-	3.9
1971	13	6	3	5	2	3	2	1	1	-	-	-	-	-	-	-	3.1
1972	10	5	4	6	3	4	3	2	3	-	2	-	-	-	-	-	4.3
1973	7	6	9	6	4	3	4	-	1	1	1	-	-	-	-	-	4.0
1974	8	23	10	4	4	3	3	1	2	3	4	1	-	-	-	-	4.1
1975	4	11	16	6	5	6	5	1	4	2	5	5	1	-	-	-	5.4
1976	6	4	12	11	4	2	5	3	3	2	3	6	7	1	-	-	6.4
1977	2	3	10	10	7	5	1	2	2	2	2	3	5	3	1	-	6.6
1978	3	13	11	5	5	4	4	2	-	2	2	5	1	2	2	1	5.9
1979	-	10	7	11	3	5	1	4	2	-	-	2	3	1	-	2	5.8
1980	4	5	10	15	11	1	3	-	2	1	-	1	1	1	1	1	5.0
1981	2	6	14	10	14	14	1	1	-	-	2	-	1	-	1	-	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	
1982	2	10	11	7	13	6	6	2	-	-	-	-	-	-	-	1	4.4
1983	1	9	14	9	4	13	4	4	1	-	-	-	-	-	-	2	4.9
1984	-	9	13	15	8	2	5	3	2	-	-	-	-	-	-	1	4.6
1985	2	3	10	20	12	7	3	5	-	2	-	-	1	-	-	2	5.2
1986	1	6	5	10	8	9	6	2	5	-	-	-	-	-	-	-	5.1
1987	1	7	5	9	13	7	6	2	2	5	-	-	-	-	-	-	5.2
1988	1	6	9	13	8	9	6	5	1	1	3	-	-	-	-	-	5.2
1989	1	6	12	11	11	7	6	6	4	2	-	1	-	1	-	-	5.3
1990	1	3	14	11	8	5	3	6	4	4	1	-	-	-	-	-	5.3
1991	1	3	9	12	8	9	7	1	4	1	4	1	-	-	-	-	5.6
1992	1	2	9	6	10	8	4	2	-	2	3	1	-	-	-	-	5.5
1993	-	3	8	11	7	7	5	5	2	1	2	1	2	-	-	-	5.8
1994	-	3	10	8	12	1	6	3	2	1	-	1	-	-	-	-	5.1
1995	-	4	9	10	8	8	6	1	2	1	-	-	1	-	-	-	5.1
1996	-	6	6	9	12	9	7	4	2	1	1	-	-	-	-	-	5.3
1997	-	6	12	7	6	11	7	3	4	2	-	-	-	-	-	-	5.2
1998	1	3	20	7	6	2	7	5	-	2	1	1	-	-	-	-	4.9
1999	1	6	18	16	7	7	2	5	1	-	-	-	-	-	-	-	4.3
2000	2	8	10	17	15	5	5	1	5	-	-	-	-	-	-	-	4.5
2001	2	16	12	12	18	6	6	4	1	2	-	-	-	-	-	-	4.4
2002	-	11	23	10	14	13	10	8	3	-	3	-	-	-	-	-	5.0
2003	1	4	22	24	13	10	8	5	5	3	-	1	-	-	-	-	5.0
2004	-	2	18	23	20	12	11	6	2	2	4	-	-	-	-	-	5.3
2005	1	2	21	13	24	18	7	5	4	2	4	2	-	-	-	-	5.4
2006	1	11	18	19	10	21	11	6	4	2	2	2	-	-	-	-	5.2
2007	1	10	21	21	20	8	19	10	3	-	1	1	1	-	-	-	5.1
2008	-	11	18	23	19	13	8	9	7	-	2	1	1	1	-	-	5.2
2009	-	6	21	18	23	14	13	4	10	4	2	1	1	-	-	-	5.5
2010	-	3	17	23	20	18	6	6	4	5	2	1	1	1	-	-	5.6
2011	3	7	23	24	30	19	17	7	5	4	3	-	1	-	1	1	5.4
2012	-	8	17	22	17	14	17	10	5	3	1	2	-	1	-	1	5.6
2013	2	10	14	20	27	16	11	8	5	6	2	-	3	-	1	1	5.7
2014	1	10	25	21	16	24	9	5	5	2	5	3	-	1	-	1	5.4

Continue...

Year	age of males in year																
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	≥ 16	Avg
2015	–	6	18	30	13	13	15	12	4	2	3	2	2	–	1	1	5.8
2016	–	9	6	20	18	10	6	14	2	4	–	2	–	–	–	–	5.5
2017	–	15	7	4	9	11	3	4	3	1	2	–	–	–	–	1	5.2
2018	–	1	3	1	–	1	1	–	1	1	1	–	–	–	–	–	5.8
Total	166	367	639	643	562	429	318	208	136	81	73	47	33	13	9	16	5.6

For example: For the 55 breed in 1971, 3 two year-old females were used in reproduction while 8 three year-old females were used. The average age of females that produced offspring during 1971 was 2.0 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
1960	–	–	–	–	–	–	–	–	1	–	–	–	–	–	–	–	9.0
1962	1	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	1.0
1963	3	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	1.0
1964	3	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	1.0
1965	35	–	–	–	–	–	–	–	–	–	1	–	–	–	–	–	1.3
1966	49	1	–	–	–	–	–	–	–	–	–	–	–	–	–	–	1.0
1967	53	3	–	–	–	–	–	–	–	–	–	–	–	–	–	–	1.1
1968	52	–	1	3	–	–	–	–	–	–	–	–	–	–	–	–	1.2
1969	54	1	8	–	1	–	–	–	1	–	–	–	–	–	–	–	1.4
1970	74	–	5	4	1	3	–	1	–	–	–	–	–	–	–	–	1.5
1971	76	3	8	6	6	3	3	1	–	–	–	–	–	–	–	–	2.0
1972	73	8	16	9	5	7	–	3	1	–	–	–	–	–	–	–	2.2
1973	90	8	13	18	11	10	3	5	1	–	–	–	–	–	–	–	2.5
1974	152	9	15	7	4	5	11	8	6	1	1	–	–	–	–	–	2.3
1975	133	22	27	17	14	10	11	10	7	2	–	–	–	–	–	–	2.8
1976	166	13	39	29	15	18	10	8	9	7	1	1	1	–	–	–	2.9
1977	123	29	63	28	22	16	11	4	4	5	7	3	1	1	–	–	3.2
1978	89	19	68	48	34	22	7	8	9	8	8	4	2	1	1	–	3.9
1979	59	5	38	38	33	25	16	16	14	3	9	4	2	1	2	–	4.8
1980	81	10	34	45	37	32	28	11	14	5	4	7	2	5	1	2	4.7
1981	57	18	49	56	49	40	47	32	27	14	10	5	4	11	2	2	5.6
1982	45	8	22	36	34	45	43	25	18	10	10	6	4	2	3	3	5.8
1983	45	5	26	38	50	42	49	45	42	15	15	5	4	5	6	4	6.4
1984	37	6	29	25	40	47	53	33	28	24	20	13	4	8	–	3	6.6
1985	21	5	48	51	31	35	42	31	20	30	15	19	7	2	4	5	6.7
1986	9	10	20	46	48	21	39	36	23	17	12	8	12	3	5	4	6.9
1987	4	15	40	45	47	46	28	34	28	26	13	24	6	6	7	2	6.9
1988	3	21	33	33	42	40	41	15	21	19	14	13	8	2	6	9	6.9
1989	3	16	52	31	31	48	41	35	27	18	29	19	13	4	1	5	7.0

Continue...

Year	age of females in year																
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	≥ 16	Avg
1990	1	13	31	41	41	24	34	30	29	17	24	16	9	6	1	3	7.1
1991	2	12	34	45	40	37	39	47	32	29	23	19	16	8	1	6	7.4
1992	1	8	22	46	47	39	42	23	36	22	31	21	9	11	2	7	7.6
1993	1	9	47	38	29	55	35	37	28	27	23	24	15	8	2	1	7.2
1994	4	13	18	25	30	35	34	32	34	23	16	12	6	6	1	-	7.2
1995	-	22	53	44	46	45	40	38	32	15	15	20	13	8	1	-	6.6
1996	2	24	41	47	43	36	49	46	36	26	22	27	10	13	5	3	7.2
1997	-	5	22	43	29	39	29	32	27	32	16	12	7	13	4	5	7.6
1998	-	17	39	50	50	33	43	28	23	17	25	13	8	13	4	7	7.0
1999	-	16	60	50	49	50	32	45	39	31	20	29	18	7	4	8	7.2
2000	-	8	43	69	48	49	41	52	41	37	25	23	26	12	4	7	7.5
2001	2	13	44	54	53	45	48	46	39	37	26	20	14	14	3	4	7.3
2002	3	20	80	77	74	94	69	76	81	56	43	46	29	22	19	10	7.6
2003	2	18	76	79	61	61	69	55	60	66	48	49	30	16	15	10	7.7
2004	1	18	66	89	81	71	56	70	53	46	40	45	29	18	19	18	7.7
2005	-	28	71	79	93	79	72	73	60	56	49	50	42	28	17	22	7.8
2006	-	19	64	94	89	69	66	54	53	56	51	26	35	22	10	16	7.5
2007	1	30	70	85	106	97	83	61	54	37	45	42	24	27	10	24	7.4
2008	2	18	87	86	80	84	59	66	58	39	38	49	19	12	9	23	7.3
2009	2	19	54	84	78	72	78	64	65	52	31	24	15	14	10	23	7.4
2010	-	20	55	70	75	66	81	63	49	35	37	31	14	22	16	25	7.7
2011	5	28	68	104	72	102	70	81	70	60	38	39	16	26	17	19	7.4
2012	3	16	60	67	65	61	69	55	55	51	35	29	13	7	6	11	7.3
2013	-	22	58	68	59	70	70	65	52	53	51	26	15	5	4	10	7.3
2014	3	24	64	72	78	63	73	68	53	54	47	43	27	16	10	13	7.6
2015	1	20	41	76	55	46	76	60	50	43	46	26	31	21	14	27	8.1
2016	1	16	22	42	47	36	25	45	48	26	18	24	14	7	6	8	7.6
2017	1	14	13	15	23	17	12	4	13	11	14	12	3	4	4	14	7.9
2018	-	2	1	-	1	1	2	-	1	1	-	-	2	-	1	1	8.5
Total	1628	727	2058	2352	2197	2091	1979	1777	1572	1259	1066	928	579	437	257	364	8.1

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 ≥ 16 are often few in the population and they are conveniently placed together in one group i.e. ≥ 16 group. In this instance, the *cohort is defined as the total number of animals born in a given year.*

For example: For breed 55 in 1967, 3 females were in their second parity while in 1973, 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
1960	1	–	–	–	–	–	–	–	–	–
1962	1	–	–	–	–	–	–	–	–	–
1963	3	–	–	–	–	–	–	–	–	–
1964	3	–	–	–	–	–	–	–	–	–
1965	36	–	–	–	–	–	–	–	–	–
1966	49	1	–	–	–	–	–	–	–	–
1967	53	3	–	–	–	–	–	–	–	–
1968	52	4	1	–	–	–	–	–	–	–
1969	60	5	1	–	–	–	–	–	–	–
1970	81	6	–	1	–	–	–	–	–	–
1971	97	8	–	1	–	–	–	–	–	–
1972	99	22	1	–	1	–	–	–	–	–
1973	136	22	2	–	–	–	–	–	–	–
1974	181	36	3	–	–	–	–	–	–	–
1975	192	52	10	–	–	–	–	–	–	–
1976	251	55	12	2	–	–	–	–	–	–
1977	222	86	12	4	–	–	–	–	–	–
1978	232	77	18	3	2	1	–	–	–	–
1979	163	61	32	11	–	–	–	–	–	–
1980	219	69	27	8	1	–	–	–	–	–
1981	284	104	31	6	4	1	–	–	–	–
1982	204	65	31	11	2	–	1	–	–	–
1983	234	111	34	13	3	–	1	1	–	–
1984	241	74	35	15	4	1	–	–	1	–
1985	233	82	33	11	8	–	–	–	–	–
1986	189	84	29	10	1	–	–	–	–	–
1987	230	92	36	7	4	2	1	–	–	–
1988	203	68	32	10	4	3	1	–	–	–
1989	210	117	34	10	–	2	–	–	–	–
1990	186	87	30	16	3	–	–	–	–	–
1991	217	109	43	15	4	1	1	–	–	–
1992	197	107	39	12	6	3	1	2	–	–
1993	189	118	55	13	2	2	–	–	–	–
1994	149	81	33	21	4	2	1	–	–	–
1995	244	84	41	21	1	1	–	–	–	–

Continue...

Year	parity number									
	1	2	3	4	5	6	7	8	9	10
1996	235	104	58	21	11	1	–	–	–	–
1997	166	82	37	18	7	4	1	–	–	–
1998	221	84	42	8	10	4	–	1	–	–
1999	263	117	49	13	10	4	2	–	–	–
2000	268	136	54	19	6	–	1	1	–	–
2001	273	120	50	16	2	1	–	–	–	–
2002	510	163	86	33	6	2	–	–	–	–
2003	427	169	68	33	15	3	–	–	–	–
2004	388	212	77	27	13	4	–	–	–	–
2005	458	216	83	42	12	6	2	–	–	–
2006	410	179	80	40	12	2	3	1	–	–
2007	461	195	78	33	21	5	1	2	–	–
2008	422	177	80	34	12	3	1	–	1	–
2009	365	194	75	34	12	4	–	–	–	1
2010	369	175	69	28	12	4	2	–	–	–
2011	450	216	100	34	12	1	2	–	–	–
2012	316	178	67	25	10	7	–	–	–	–
2013	342	165	79	27	14	–	1	–	–	–
2014	407	184	71	34	9	3	–	–	–	–
2015	325	166	97	29	12	3	1	–	–	–
2016	199	104	47	28	4	2	1	–	–	–
2017	80	52	22	12	5	1	2	–	–	–
2018	9	2	–	1	–	1	–	–	–	–
Total	12705	5280	2124	810	281	84	27	8	2	1

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 55 breed the Generation interval (average age of parents when their selected offspring were born) for the selection path between sire to son (ss) was 3.5 year in 1972. This values was calculated based on the avarage ages of 9 selected sons, born during 1972. 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 5.2, 2.0 and 3.1 year, respectively. During 1972, the generation interval for the males was 5.0 year and 3.0 year for the female born during this year. The generation interval in 1972 for all four selection paths together, or for the population in total (pop), was 4.2 year, based on the average age of parents of 86 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
1963	3.1	1	2.0	4	2.0	1	2.0	2	2.2	5	2.0	3	2.1	5
1964	2.0	1	2.0	2	2.0	1	2.0	2	2.0	3	2.0	3	2.0	3
1965	2.8	4	2.1	19	4.3	4	2.0	20	2.2	23	2.4	24	2.3	26
1968	3.5	2	3.1	44	2.0	2	2.0	44	3.2	46	2.0	46	2.6	47
1969	4.0	2	4.1	48	5.5	2	2.2	45	4.1	50	2.4	47	3.3	50
1970	7.2	4	4.4	60	2.0	3	2.5	61	4.6	64	2.5	64	3.6	70
1971	2.0	4	4.3	51	2.4	6	2.7	49	4.2	55	2.7	55	3.5	60
1972	3.5	9	5.2	71	2.0	8	3.1	72	5.0	80	3.0	80	4.2	86
1973	3.6	7	4.6	89	3.2	8	3.5	92	4.5	96	3.4	100	4.0	104
1974	4.9	6	4.5	134	2.1	6	3.3	136	4.6	140	3.2	142	3.9	147
1975	6.5	19	5.6	123	3.5	19	3.6	130	5.7	142	3.6	149	4.6	150
1976	6.5	17	5.9	183	3.8	16	3.6	189	6.0	200	3.7	205	4.8	208

Continue...

Year	Generation interval and number of animal													
	ss	Nss	sd	Nsd	ms	Nms	md	Nmd	male	Nmale	female	Nfemale	pop	Npop
1977	5.2	18	6.6	174	4.8	18	3.9	178	6.5	192	3.9	196	5.2	196
1978	7.1	17	6.7	172	4.8	17	4.8	176	6.7	189	4.8	193	5.8	195
1979	7.8	20	6.2	131	5.6	20	5.4	133	6.4	151	5.5	153	5.9	155
1980	6.1	25	5.3	142	6.6	25	5.0	144	5.4	167	5.2	169	5.4	171
1981	7.2	14	5.0	177	6.4	14	6.3	178	5.2	191	6.3	192	5.7	192
1982	5.7	19	4.8	125	8.0	18	6.0	123	4.9	144	6.2	141	5.5	147
1983	4.8	16	5.3	179	6.7	16	7.1	176	5.2	195	7.1	192	6.1	195
1984	5.0	20	5.1	164	7.1	20	6.9	162	5.0	184	6.9	182	6.0	184
1985	5.3	17	5.3	174	7.4	17	7.2	174	5.3	191	7.2	191	6.2	191
1986	6.3	15	5.7	178	6.7	15	7.3	177	5.8	193	7.2	192	6.5	195
1987	6.0	21	5.9	209	7.6	21	7.3	208	5.9	230	7.3	229	6.6	231
1988	5.7	15	5.9	169	8.0	15	7.5	173	5.9	184	7.6	188	6.7	191
1989	6.4	22	5.9	200	6.6	23	7.6	208	6.0	222	7.5	231	6.7	231
1990	5.5	11	6.2	161	7.3	11	7.4	165	6.1	172	7.4	176	6.8	184
1991	6.6	17	5.5	221	8.8	18	8.1	237	5.6	238	8.1	255	6.9	261
1992	5.6	12	5.8	221	8.4	12	8.2	241	5.8	233	8.2	253	7.0	254
1993	4.9	12	6.5	242	7.5	12	7.8	256	6.5	254	7.8	268	7.1	271
1994	6.4	22	5.6	142	8.1	22	7.8	168	5.7	164	7.8	190	6.9	191
1995	5.4	23	6.0	208	7.9	23	7.4	226	6.0	231	7.4	249	6.7	250
1996	6.2	26	5.8	261	7.8	26	7.9	270	5.9	287	7.9	296	6.9	296
1997	6.0	19	5.8	198	8.5	19	8.0	205	5.8	217	8.1	224	7.0	224
1998	4.3	25	5.8	246	7.3	25	7.4	253	5.6	271	7.4	278	6.6	279
1999	4.7	30	4.8	257	7.3	30	7.6	269	4.8	287	7.6	299	6.3	301
2000	5.2	29	5.0	275	8.0	29	8.1	290	5.0	304	8.1	319	6.7	321
2001	4.6	20	4.7	275	7.2	20	7.6	297	4.7	295	7.6	317	6.2	317
2002	5.1	29	5.7	348	8.2	29	8.1	441	5.6	377	8.1	470	7.2	473
2003	5.0	29	5.3	283	7.7	29	7.9	341	5.3	312	7.9	370	6.8	372
2004	5.8	32	5.4	317	8.5	32	7.9	357	5.4	349	8.0	389	6.8	391
2005	5.5	36	5.5	308	7.8	36	8.0	350	5.5	344	8.0	386	6.9	389
2006	5.1	36	5.2	256	7.9	36	8.0	293	5.2	292	8.0	329	6.8	330
2007	5.7	31	5.6	243	8.8	31	7.9	283	5.6	274	8.0	314	7.0	315
2008	4.7	31	5.3	191	6.9	31	7.7	226	5.2	222	7.6	257	6.6	259
2009	5.4	32	5.7	188	7.8	32	7.7	207	5.7	220	7.7	239	6.9	239
2010	5.5	23	5.8	150	7.9	23	7.8	171	5.8	173	7.8	194	7.0	194
2011	6.1	33	5.7	169	7.3	33	7.6	173	5.8	202	7.6	206	6.7	207
2012	5.4	23	5.1	82	7.6	23	7.5	83	5.2	105	7.5	106	6.3	106
2013	5.4	14	6.5	32	7.6	14	7.1	35	6.2	46	7.3	49	6.7	49
2014	6.0	13	6.5	20	7.4	13	7.9	20	6.3	33	7.7	33	7.0	33
2015	5.5	9	5.5	7	7.2	9	14.6	7	5.5	16	10.4	16	8.0	16
Total	5.6	-	5.5	-	7.1	-	7.0	-	5.5	-	7.1	-	6.4	-

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 ΔF 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
1952	2	2.0	-	-	2	2.0	-	-	1	1.0	-	-	1	1.0	-	-
1959	1	1.0	-	-	1	1.0	-	-	1	1.0	-	-	-	-	-	-
1960	17	10.0	1	1.0	14	8.5	1	1.0	1	1.0	1	1.0	13	7.5	-	-
1961	10	5.8	2	1.3	9	5.0	2	1.3	-	-	1	1.0	9	5.0	1	1.0
1962	11	10.0	3	1.7	11	8.0	3	1.7	2	2.0	2	2.0	9	6.7	1	1.0
1963	39	15.0	3	1.4	21	10.5	3	1.3	4	1.6	1	1.0	21	9.8	3	1.3
1964	37	11.1	9	1.8	26	7.8	8	1.5	6	2.2	1	1.0	24	7.0	7	1.5
1965	55	8.6	5	1.4	43	6.9	4	1.3	11	3.5	1	1.0	32	6.4	4	1.3
1966	33	10.1	4	1.5	14	6.5	3	1.3	2	1.5	1	1.0	14	6.8	3	1.3
1967	36	7.8	4	1.5	26	6.2	3	1.3	5	3.5	2	1.3	21	5.6	3	1.3
1968	37	12.6	8	1.5	16	6.0	4	1.2	2	1.5	1	1.0	16	6.0	4	1.2
1969	33	10.4	5	1.5	17	5.8	3	1.2	4	1.6	1	1.0	13	5.9	3	1.2
1970	25	5.6	6	1.7	10	3.5	4	1.4	2	1.5	2	1.1	10	3.5	3	1.3
1971	33	10.1	6	1.6	26	8.7	6	1.5	3	1.8	2	1.1	26	8.6	4	1.4
1972	24	8.0	6	1.5	22	6.3	5	1.3	6	1.9	2	1.1	21	5.8	5	1.3
1973	41	14.3	7	1.6	24	8.1	6	1.4	2	1.4	2	1.0	22	8.9	5	1.4
1974	46	10.7	6	1.6	22	7.3	4	1.4	4	4.0	2	1.0	18	6.6	4	1.4
1975	46	18.3	6	1.5	28	9.8	4	1.3	6	2.0	2	1.1	24	9.9	4	1.3
1976	56	18.0	7	1.6	34	10.1	7	1.5	5	2.0	4	1.4	34	9.2	7	1.4
1977	105	18.5	8	1.5	46	10.2	7	1.4	10	2.8	3	1.2	43	9.6	4	1.3
1978	53	13.9	4	1.5	22	7.2	4	1.2	6	2.4	1	1.0	22	6.3	4	1.2
1979	55	20.1	5	1.5	26	11.2	3	1.4	5	2.1	1	1.0	22	10.0	3	1.4
1980	64	16.8	8	1.7	33	10.3	5	1.5	5	1.7	2	1.2	33	9.8	5	1.4
1981	53	12.9	7	1.8	26	8.3	5	1.5	4	2.0	2	1.1	26	7.5	5	1.5
1982	89	17.4	6	1.7	53	11.0	5	1.5	6	1.9	2	1.1	52	10.3	5	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
1983	81	15.3	6	1.9	50	10.8	5	1.6	3	1.8	2	1.1	48	10.3	5	1.5
1984	39	11.5	6	1.8	34	10.1	5	1.5	6	2.4	2	1.2	28	9.6	4	1.4
1985	64	21.4	5	1.9	38	13.9	4	1.7	10	2.4	1	1.0	30	12.1	4	1.6
1986	74	14.7	7	1.9	59	10.9	5	1.6	3	1.6	2	1.1	59	11.1	5	1.5
1987	75	19.0	7	1.9	55	14.9	5	1.5	5	2.7	2	1.1	54	14.1	4	1.5
1988	77	20.5	8	1.9	60	14.1	6	1.7	3	1.6	2	1.1	58	13.4	5	1.6
1989	63	16.7	6	1.8	49	12.5	4	1.5	9	2.7	1	1.0	40	11.6	4	1.4
1990	71	18.8	6	1.7	47	14.0	5	1.4	5	2.8	2	1.2	42	12.7	5	1.3
1991	106	23.3	6	1.9	51	16.0	6	1.6	3	1.6	2	1.0	50	14.9	5	1.5
1992	54	16.1	8	1.9	38	10.6	6	1.6	12	3.3	4	1.3	26	10.8	6	1.5
1993	71	20.7	8	2.0	31	12.9	7	1.7	6	4.0	4	1.3	31	11.9	7	1.6
1994	105	29.9	7	1.9	54	16.8	6	1.5	4	2.0	3	1.3	51	15.9	5	1.5
1995	59	21.4	10	1.8	29	14.5	9	1.6	5	2.8	4	1.3	28	12.5	6	1.4
1996	71	24.3	6	2.0	54	16.3	5	1.7	12	3.6	4	1.2	54	15.0	5	1.6
1997	62	20.1	7	1.9	26	11.9	5	1.6	4	2.0	3	1.2	26	11.8	5	1.5
1998	81	24.0	7	1.9	57	15.2	5	1.4	11	3.7	2	1.1	46	13.2	4	1.4
1999	68	25.3	6	1.8	40	15.1	5	1.4	10	3.0	3	1.1	39	14.1	3	1.4
2000	101	26.5	7	1.9	47	14.4	5	1.4	8	3.1	3	1.3	45	12.7	4	1.3
2001	76	16.9	7	1.8	23	8.2	7	1.4	6	2.7	2	1.2	17	7.2	5	1.3
2002	66	23.4	6	1.6	44	11.8	5	1.3	15	3.0	2	1.1	32	10.3	3	1.2
2003	76	23.6	7	1.8	28	11.1	4	1.3	6	2.8	2	1.2	28	10.0	4	1.3
2004	87	22.8	6	1.7	34	9.3	3	1.2	12	3.2	3	1.1	22	7.8	3	1.1
2005	48	14.8	7	1.6	20	6.3	3	1.2	10	3.1	3	1.2	17	5.0	2	1.1
2006	55	16.3	7	1.7	14	5.4	3	1.1	3	1.5	3	1.1	14	5.1	2	1.1
2007	57	15.9	5	1.5	19	4.7	3	1.1	4	2.0	2	1.1	19	4.4	2	1.1
2008	58	22.5	5	1.4	25	3.6	2	1.1	11	2.2	1	1.0	14	3.4	1	1.0
2009	39	14.0	4	1.3	5	1.9	1	1.0	2	1.3	1	1.0	5	1.8	1	1.0
2010	31	15.0	4	1.3	3	2.4	1	1.0	3	1.8	1	1.0	3	2.5	1	1.0
2011	48	11.9	3	1.2	4	1.8	1	1.0	1	1.0	-	-	4	2.2	1	1.0
2012	56	10.0	3	1.2	2	2.0	1	1.0	-	-	1	1.0	2	2.0	-	-
2013	11	3.4	3	1.1	-	-	-	-	-	-	-	-	-	-	-	-
2014	10	3.0	2	1.1	-	-	-	-	-	-	-	-	-	-	-	-
2015	9	3.6	1	1.0	-	-	-	-	-	-	-	-	-	-	-	-
Total	106	16.6	10	1.7	60	10.0	9	1.4	15	2.3	4	1.1	59	9.4	7	1.4

Figure 1: Dams with the most Progeny in the Population

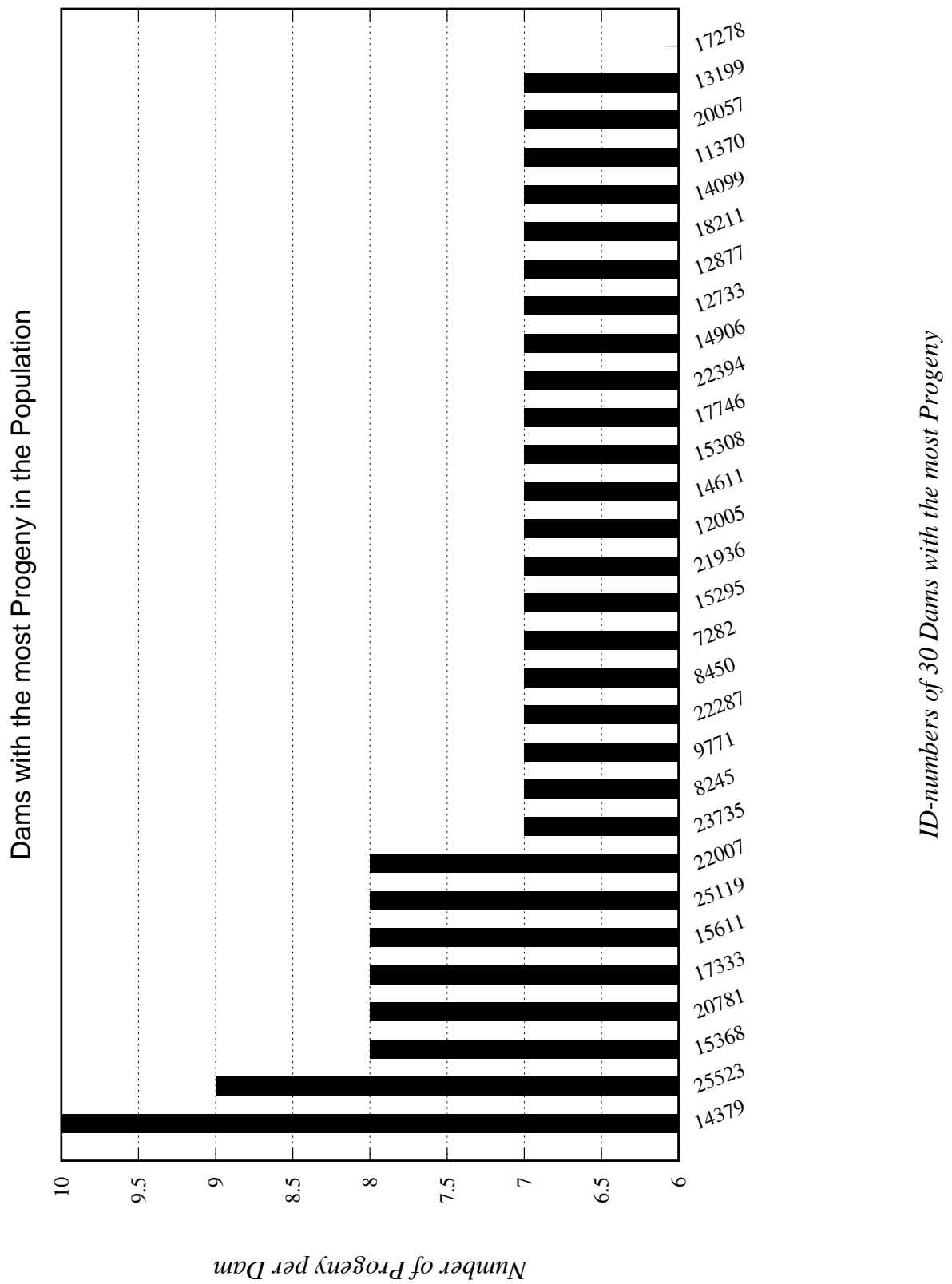


Figure 2: Number of Progeny per Dam

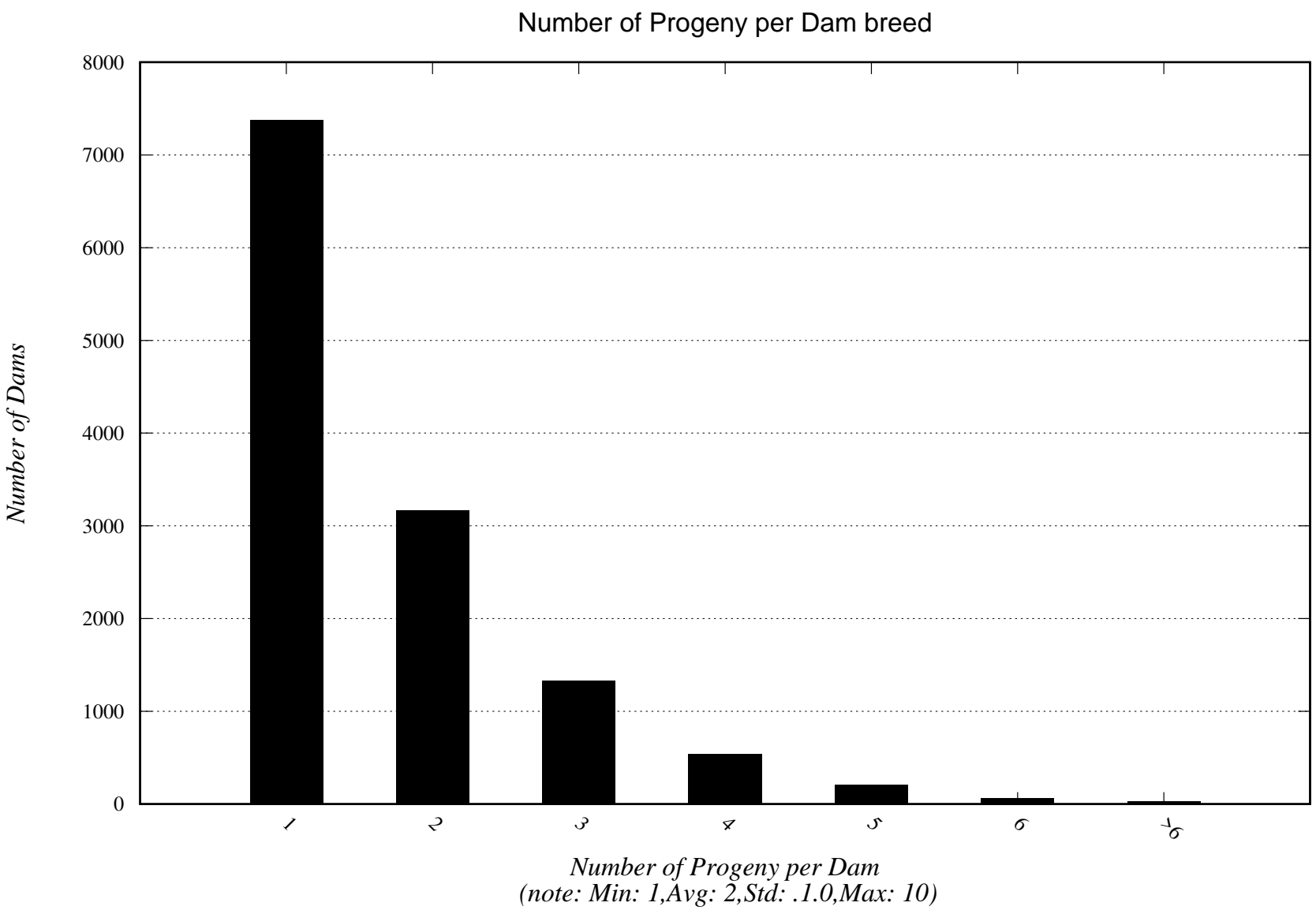


Figure 3: Sires with the most Progeny in the Population

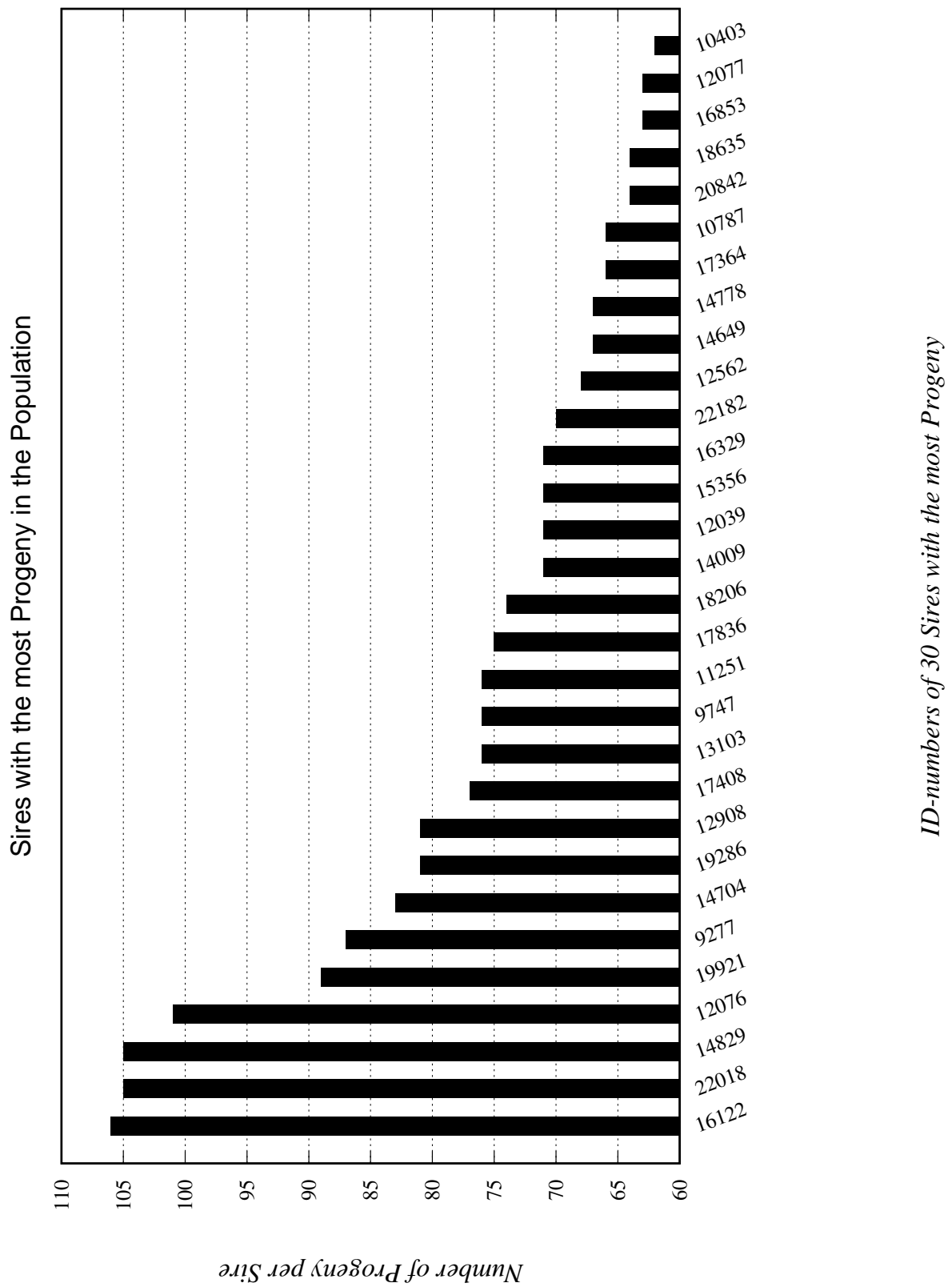


Figure 4: Number of Progeny per Sire

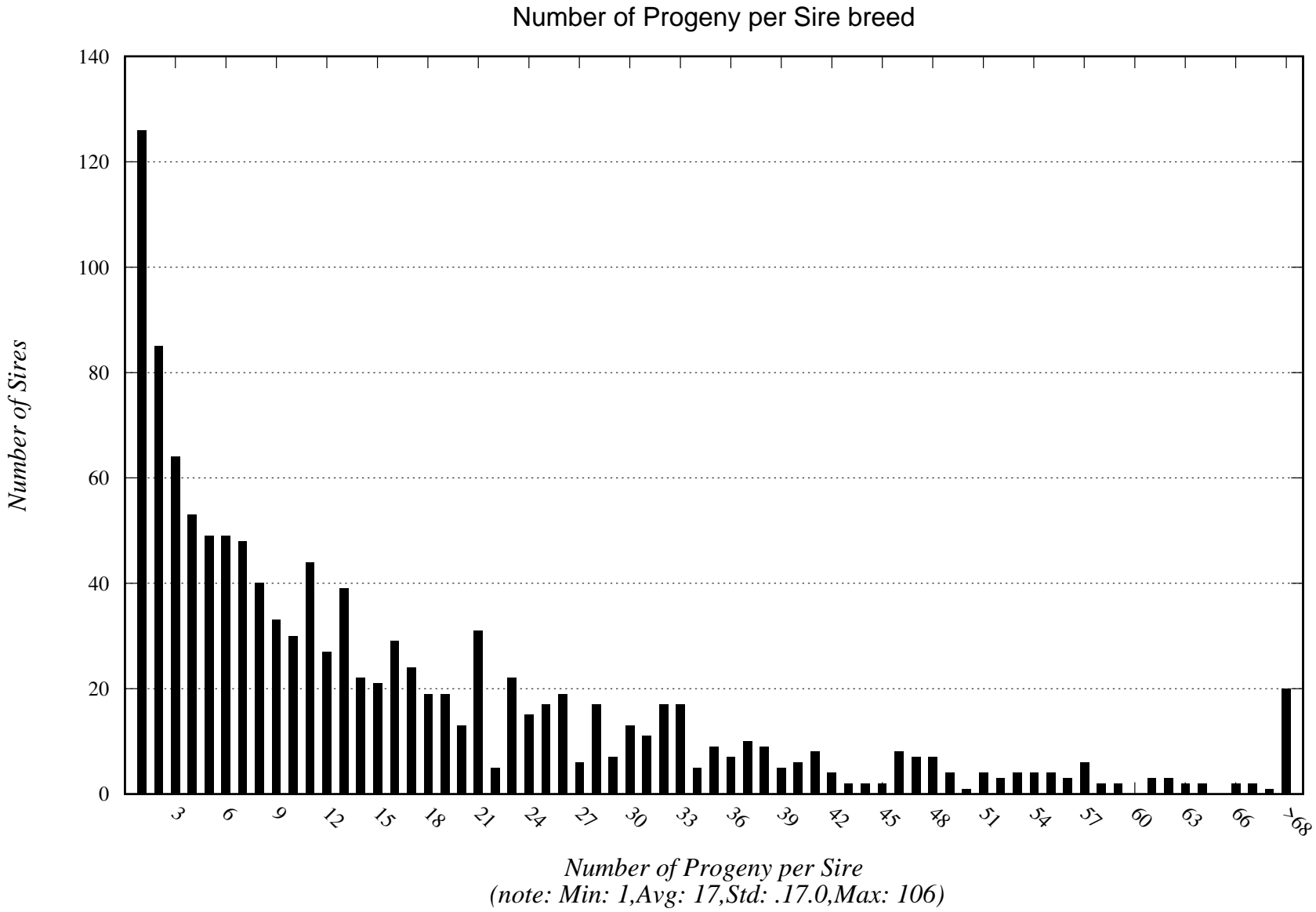


Figure 5: Dams with the most Selected Progeny in the Population

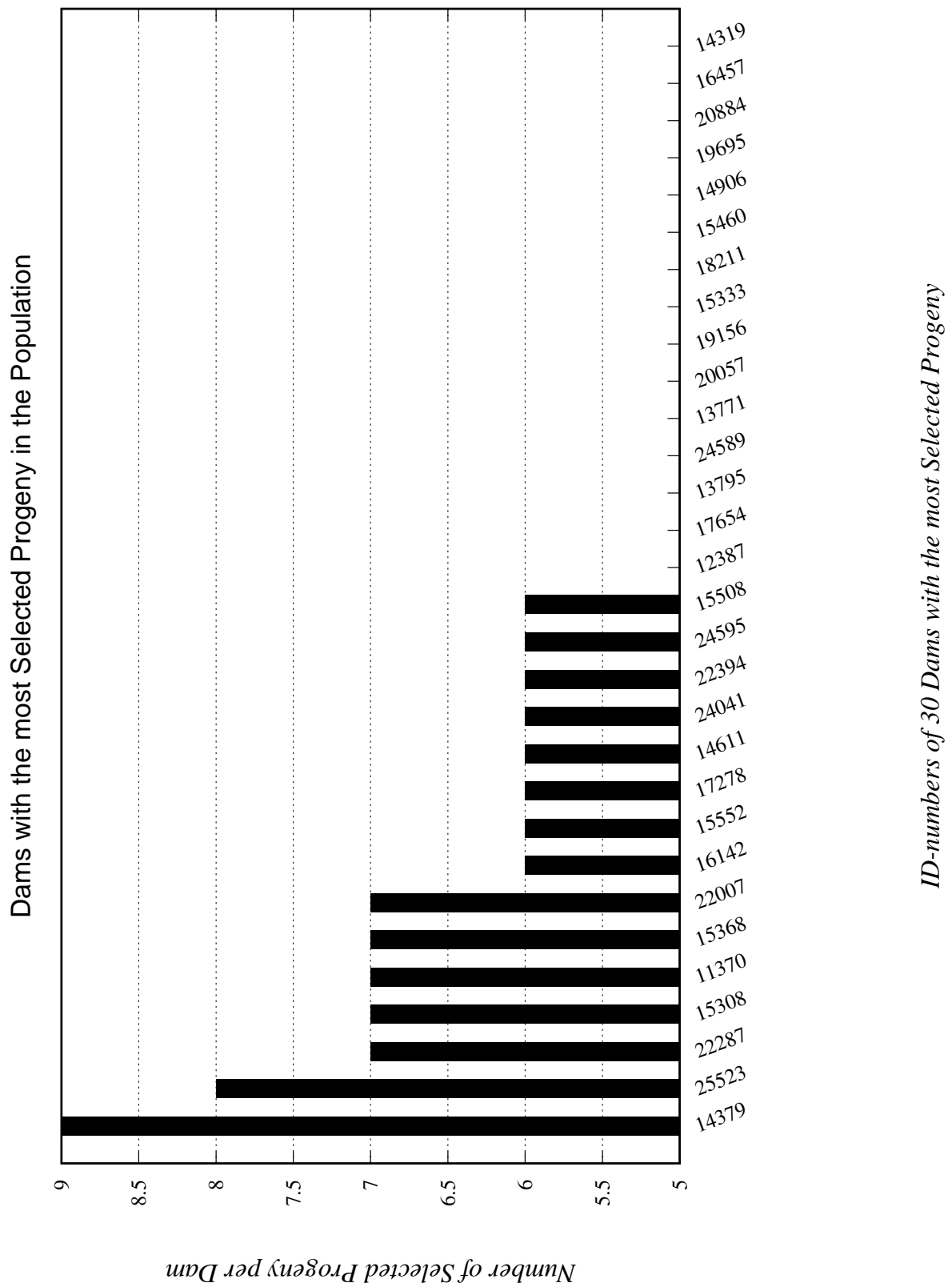


Figure 6: Number of Selected Progeny per Dam

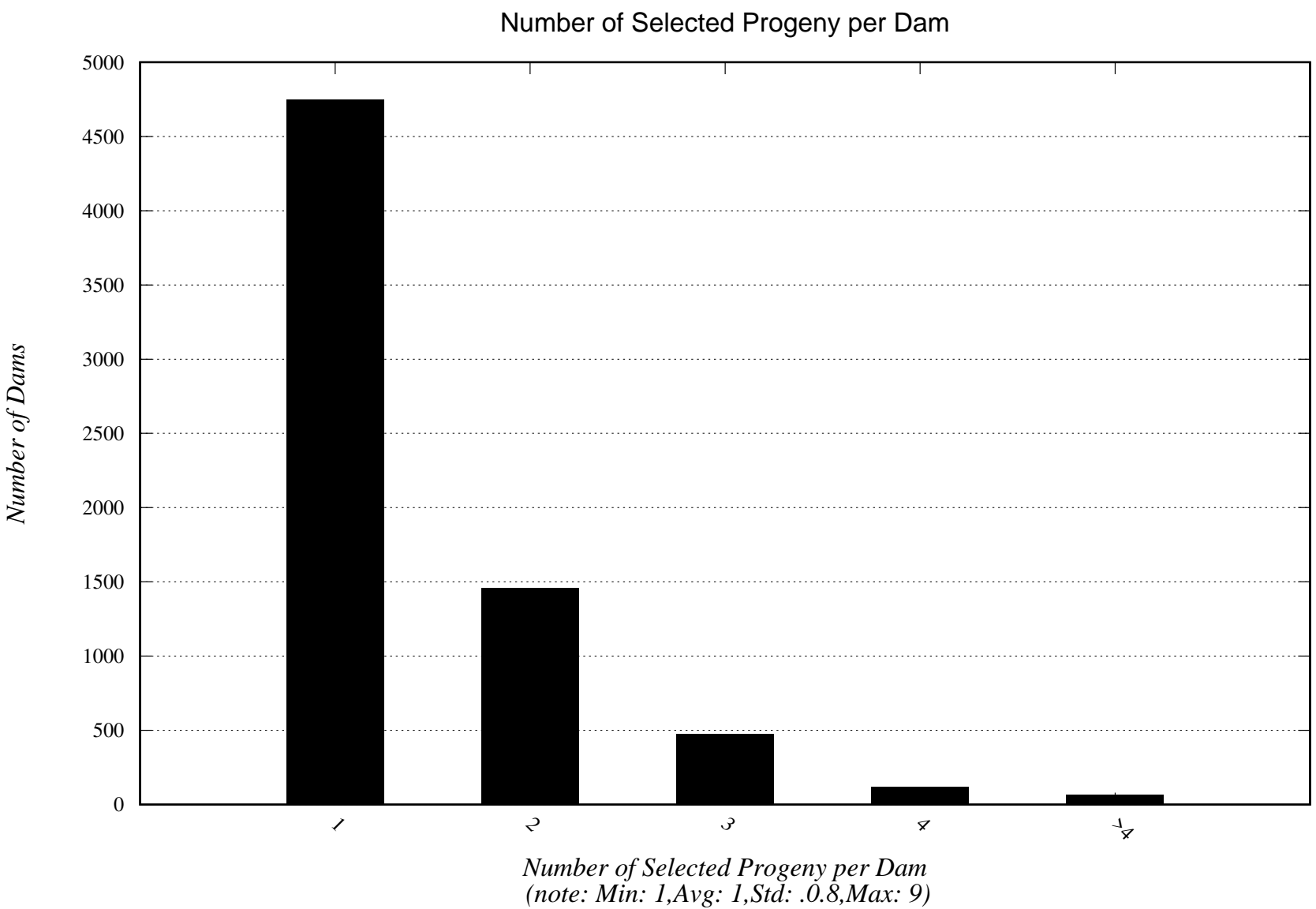


Figure 7: Sires with the most Selected Progeny in the Population

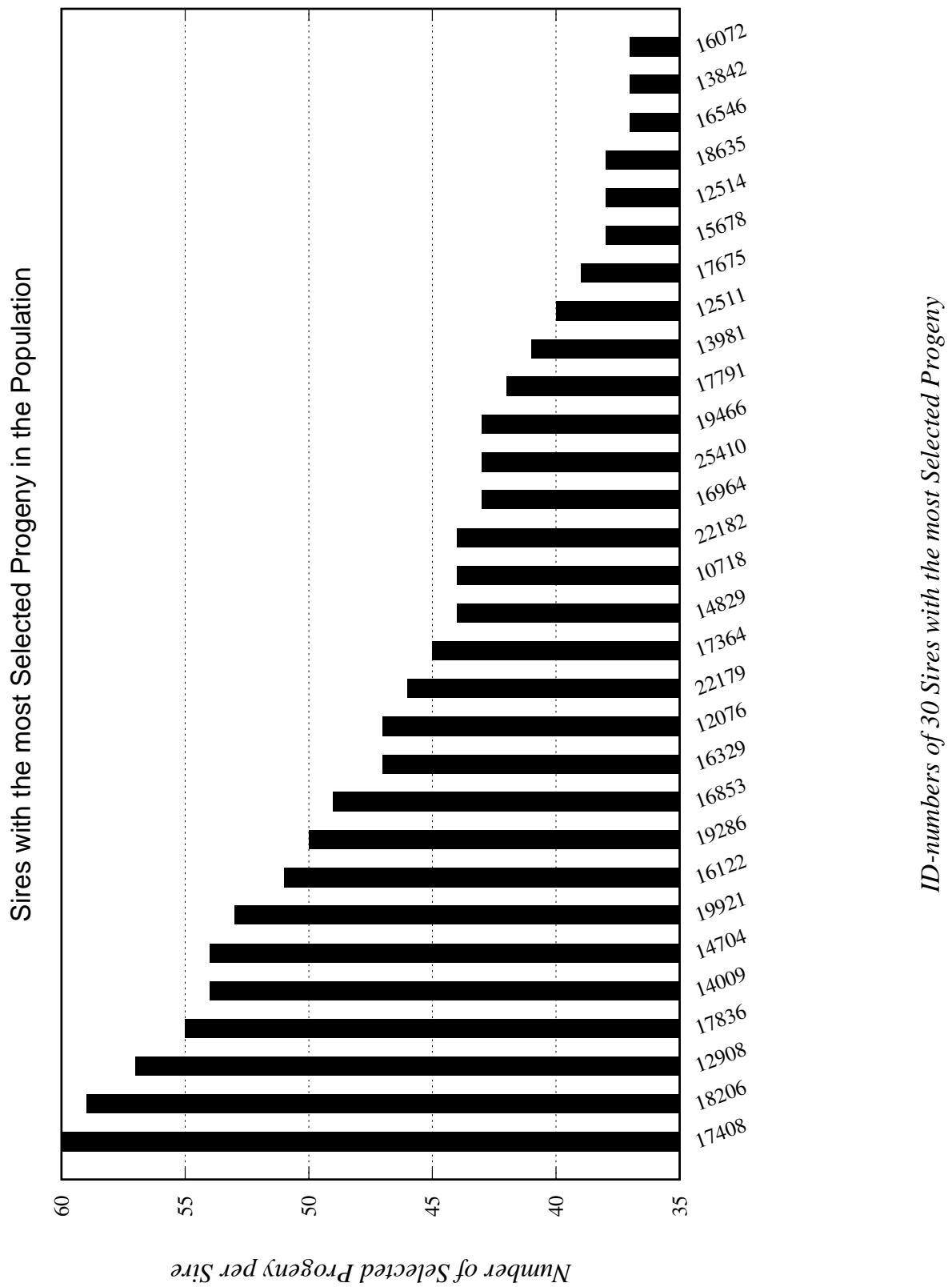


Figure 8: Number of Selected Progeny per Sire

