Analysis of structure of the population, kinship coefficients and inbreeding trend depending on sex, type of breeding of Tatra Sheepherd dogs

Sweklej Edyta[1][¶], Horoszewicz Elżbieta[1][¶], Niedziółka Roman[1][¶][*]

[1]Institute of Zootechnics and Fisheries, Siedlce University of Natural Sciences and Humanities, Siedlce, Poland

[¶]These authors contributed equally to this work.
[*] roman.niedziolka@uph.edu.pl
Elżbieta Horoszewicz ORCID – http://orcid.org/0000-0001-8877-6185
Roman Niedziółka ORCID – http://orcid.org/0000-0002-5531-3704

Abstract

The aim of the study was to analyse the structure of the population, kinship coefficients and inbreeding trend taking into account the sex, breeding system: champions (CH) and non-champions (nCH), breeding country: Poland (PL) and foreign country (Z) and the inbreeding degree of Tatra Shepherd dogs. Out of the currently registered 587 Tatra Shepherd dogs, 41.9% have been qualified for breeding. In the past decade, 1961 puppies were born, which corresponds to an average litter of 5.8 puppies. The breed's inbreeding rate amounted to 6.34%, and for a 4-generation population was 6.68%. The highest inbreeding rate was found in nCH and PL groups consisting of both male and female dogs. The inbreeding rate was significantly higher in 2005-2014 compared to the years 1994-2004. The limit value F_X was exceeded for 25.65% of Shepherd dogs, and the critical value was exceeded for 11.52%. An increasing ancestor loss coefficient (AVK) was found, which may result in an increased number of inbred animals. In particular, it referred to female dogs in the nCH, PL, and F group, whereas a significant increase of AVK was observed in the group of male dogs from

27   foreign kennels. The resulting COR values, respectively 55.58% for males and 55.44% for

28   females, testify to insignificant inbreeding and suggest that breeders look for male inbreds.

29   Studies have shown that there is no risk of inbred depression yet; however, the gene pool of

30   the Tatra Shepherd dog breed has become noticeably restricted. In addition, leaving the stud

31   book for the breed open must be considered due to an increase in the popularity of the breed,

32   and thus an increase in mating.

Introduction

34   There are about 500 million dogs around the world, including more than 63 million

35   living in the EU. The highest number of dogs in Europe live in Russia – more than 15 million,

36   in the Germany – 9,4 million, in the United Kingdom – 9 million and in the Poland 7,6

37   million. It is estimated that 25% of households in the European Union and 24% in the Europe

38   keep at least one dog. In Poland and Romania, it is estimated that 42% of households have at

39   least one dog, which puts Poland first in Europe. On the other hand, according to the

40   American Veterinary Medical Association (AVMA), more than 70 million dogs live in the

41   United States of America, while the American Pet Products Association (APPA) estimates

42   their count as about 77.8 million. Both sources recount that smaller breeds are predominant in

43   the USA. The World Canine Organization (Fédération Cynologique Internationale, FCI)

44   classified 367 breeds, and Poland has currently 340 registered breeds split into hunting,

45   guardian and shepherd dogs [1-5].

46   The oldest canine organization in Poland is the Polish Kennel Club (ZKwP – founded in

47   1938) which keeps Stud Books (KW) for Polish breeds and maintains the longest pedigree

48   lines for all world recognized breeds, verifies pairs of parents and registered litter, conducts

49   mental health tests and organizes renowned shows of purebred dogs. ZKwP is a patron of 5

50   national breeds including: Polish Grey Hound (FCI standard no. 333), Polish Hunting Dog

51 (FCI standard no. 354), Polish Hound (FCI standard no. 52), Polish Lowland Sheepdog (FCI

52 standard no. 251) and Tatra Shepherd Dog (FCI stanadard no. 252). In 1973 Fédération

53 Cynologique Internationale (FCI), at the request of ZKwP, approved the Tatra Shepherd dog

54 standard number 252 as a shepherd and guardian dog. In order to protect the exterior of dogs

55 in Poland every year more than 120 purebred dog shows are organized, including 15

56 international ones with the participation of Tatra Shepherd dogs [6, 7]. Recently, dog shows

57 have become increasingly popular, and the selection has been more oriented at the phenotype

58 and grooming of dogs [8]. Studies show that such breeding leads to a loss of genetic

59 variability in some breeds in Europe [9-14].

60   The Tatra Shepherd Dog breed has a number of relatives classified as separate breeds

61 living along the Carpathians, Alps and Pyrenees. The territorial proximity between Tatra

62 Shepherd dog and Slovak Cuvac suggest a close relationship of these two breeds. However,

63 based on the cross-population studies, on the grounds of DNA polymorphism a genetic

64 distance dendrogram was designed for six breeds of white shepherd dogs: Pyrenean Mountain

65 Dog (France), Maremma Sheepdog (Italy), Akbash Dog (Turkey), Tatra Shepherd Dog

66 (Poland), Slovak Cuvac (Slovakia), and the Kuvasz (Hungary). Studies have shown that Tatra

67 Shepherd dogs are the closest relatives of Akbash dogs [7, 15, 16]. Despite their unique

68 guarding efficiency, Tatra Shepherd Dogs indirectly contribute to green grazing of sheep and

69 are a tourist amenity to the numerous visitors in the region of Podhale [1, 3, 17, 18]. The main

70 features that predispose them to this type of work are endurance, strength, courage, distrust of

71 strangers, resistance to various weather conditions, good hearing and sight, and a well-

72 developed defensive instinct [19, 20].

73   Despite many genetically valuable Tatra Shepherd dogs having been taken abroad from

74 Poland by their owners, the population seems to be reconstructed and quite even. However, it

75   is still not sufficiently numerous, which prompts the monitoring of relationship in order to

76   avoid inbreeding [21, 22].

77   Inbreeding increases the level of homozygotism of an animal, which has positive and

78   less positive effects. Creating homozygous animals can reveal latent defects in recessive

79   genes. Many authors claim that the loss of genetic variability and inbreeding contributes to the

80   development of physical diseases, defects and disorders such as reduced fertility and

81   prolificacy, the occurrence of lethal alleles in a litter, and lower offspring survival rate. In

82   addition, anomalies may occur in the hip joint anatomy leading to dysplasia among house

83   dogs, especially of large breeds [23-26]. The critical inbreeding rate is 12.5%. The inbreeding

84   coefficients for a breed range from about 0.82% for Golden Retrievers, 2% for German

85   Shepherd Dogs, 4,5% for Bullmastiff Dogs, through 9% for Great Danes to 26% for Nova

86   Scotia Duck Tolling Retrievers and as much as 37% for Polish Hounds [27-33]. The F_x

87   coefficient is supplemented by information about the content of a unique pool of genes

88   revealed by the Ancestor Loss Coefficient (AVK). AVK makes it possible to assess

89   inbreeding in previous generations and indicates a percentage ratio of unique ancestor to the

90   total number of ancestors for a specific number of generations [9, 34-36].

91   The variations in the population of Tatra Shepherd Dogs have been shown by Radko et

92   al. [37]. The DNA polymorphism analysis demonstrated a considerable genetic differentiation

93   of microsatellite markers and the lack of inbreeding in the analysed population of Tatra

94   Shepherd dogs. Other studies carried out in Poland [21, 38, 39] confirm the differentiated

95   level of inbreeding with an upward trend, depending on the sex and age as well as the region

96   of occurrence of the Tatra Shepherd Dog breed. It should be accepted that genetic equilibrium

97   rarely occurs even in natural populations where natural choice and selection take place [40,

98   41].

4

99   The studies aimed at analyzing the structure of the population, estimating the

100 relationship and inbreeding trend based on pedigrees taking into account features such as: sex,

101 breeding type (champions, non-champions) and origin (domestic and foreign) of Tatra

102 Shepherd dogs.

Material and methods

The origin of the Tatra Shepherd breed

105 The first pedigree Tatra Shepherds in Poland were born in 1957 in Łeba, in the kennel

106 run by Danuta Hryniewicz. They were the descendants of dogs she had owned since 1935,

107 registered with the Polish Association of Pedigree Dog Breeders. During the first International

108 Pedigree Dog Show in Poland held in Poznań in 1962, only two Tatra Shepherds were shown,

109 but in the following years the number of those dogs increased continuously. In 1973, the

110 Fédération Cynologique Internationale (FCI), at the request of ZKwP (Polish Kennel Club)

111 approved a breed standard of Tatra Shepherd dog under number 252. In 1979–1980 Tatra

112 Shepherds were the most numerous Polish breed of dogs registerd with ZKwP (in total 329

113 dogs) [6,7]. After 1981 Clubs or sections associating Tatra Shepherd breeders were

114 established abroad. The kennels comprised from several hundred (Netherlands, Belgium,

115 Germany) to several dozen dogs (USA, France, Austria, Norway, Finland) [6, 42].

Genetic analysis

117 Analysis of the indicators of genetic variation of the population covered dogs entered

118 into the Stud Book (non-pedigree parents) and dogs with 1 to 18-generation pedigrees within

119 the same breed. A pedigree database containing data of 505 Tatra Shepherds (202 male dogs

120 and 303 female dogs) born in 1964-2014 was developed and used to identify a standardized

121 population with full 4-generation pedigrees totalling 194 dogs, including 82 males and 112

5

122   females born in 1994-2014. The Wright coefficients of inbreeding (F_x) and the ancestor loss

123   coefficient (AVK) were estimated for all animals split according to: sex, having a champion

124   title (CH) or not having a champion title (nCH), origin: from Polish kennels (POL) and from

125   foreign kennels (Z). In addition, the coefficient of kinship between the proband and its direct

126   primary ancestors (R_{XA}) and secondary ancestors (R_{XY}) was estimated.

Statistical analysis

128   The inbreeding coefficient, the kinship coefficient of the proband and its direct primary

129   ancestors (R_{XA}) and secondary ancestors (R_{XY}) is calculated according to the formulas [40,

130   43-45]:

131   Inbreeding coefficient:

132
$$F_X = \Sigma\left(\frac{1}{2}\right)^{n_1 + n_2}(1 + F_A)$$

133   Secondary kinship:

134
$$R_{XY} = \frac{\Sigma\left(\frac{1}{2}\right)^{n_1 + n_2}(1 + F_A)}{\sqrt{(1 + F_X)(1 + F_Y)}}$$

135   Primary kinship:

136
$$R_{XA} = \Sigma\left(\frac{1}{2}\right)^{n}\sqrt{\frac{(1 + F_A)}{(1 + F_X)}}$$

137   Key to formulas:

138   F_X – inbreeding coefficient of specimen X,

139   F_Y – inbreeding coefficient of specimen Y,

140   F_A – inbreeding coefficient of a common ancestor A

141   R_{XA} – coefficient of kinship between specimen X and its ancestor A,

142   R_{XY} – coefficient of kinship between specimens X and Y,

143   n_1, n_2 – number of paths from the parents of specimen X to an ancestor A shared by the

144   parents.

145   The calculations were made using the Pedigree Explorer software (Wild Systems P/L,

146   Australia). Secondary kinship was calculated with the support of the CFC programme [46].

147   The results of the study were subjected to an analysis of variance taking the following features

148   into account: sex, champion (CH), non-champion nCH), domestic kennel (PL), and foreign

149   kennel (Z). The data are presented as means (SE) with their standard deviations (SD). The

150   significance of differences between the mean values for respective groups was verified by

151   means of Tukey's test (p≤0,001) using Statistica 12 software [47].

Results

Population of Tatra Shepherd dogs

154   The population of Tatra Shepherd dogs has been growing both in domestic and foreign kennels.

155   Since 2003 a year-on-year increase has been observed in the number of Tatra Shepherd dogs

156   newly registered with the divisions of the Polish Kennel Club. Every year, more females than

157   male dogs are registered. At the end of 2011, the number of registered Tatra Shepherds was 473

158   (184 males and 289 females), and 112 Shepherds, including 46 male dogs and 66 female dogs,

159   were qualified for breeding (Table 1). As at 31 December 2016, out of 587 registered dogs (221

160   males and 366 females) as many as 246 (83 males and 163 females) were qualified for breeding,

161   which corresponded to 41.9% of all the registered animals of this breed. Over five years only

162   (2011-2016), 1961 puppies were born from 337 litters, which accounts for an average of about 5.8

163   puppies per litter. The analysis of the trend until 2021 shows a constant growth in the breed

164   population both among male dogs (+8.30%) and female dogs (+17.93%). The largest growth is

165   observed among breeding dogs. This is a positive symptom of recognizing the Tatra Shepherd

166   dog in the population. Among other things, it is due to its suitability as a shepherd and guard dog

167   but also due to the decision of the authorities to open a stud book for the breed in order to extend

168   the gene pool. In 2016 there were 121 registered Tatra Shepherd dog breeders in Poland. The

169 highest number, that is, 40 are registered in the Lesser Poland voivodeship – in the region of

170 Podhale, which corresponds to 33.06%.

Pedigree analysis and occurrence of inbreeding

172 The studies have shown a considerable degree of inbreeding within the breed (Table 2). The

173 average inbreeding rate F_X throughout the analysed population from the stud book (KW) and

174 with 1 to 18-generation pedigrees was 2.93%. Only for inbred animals (F_X) it amounted to

175 6.4%. For a standardized 4-generation population, the inbreeding rate was 6.68%, and 6.85%

176 for inbred animals.

177   For the purposes of further calculations, the dogs with 4-generation pedigrees were

178 divided into: champions (CH), non-champions (nCH) and dogs bred in Poland (PL) and

179 abroad (Z) (Table 3). The average inbreeding value for Tatra shepherd dogs with full, 4-

180 generation pedigrees, born in 1994-2014 amounted to 6.52% for males and 6.79% for

181 females. The highest inbreeding rate was observed among males (7.08%) and females

182 (7.12%) in the group of non-champions (nCH) and among males (6.75%) and females

183 (6.91%) born in Polish kennels (PL). To get a full picture of changes in the inbreeding rate of

184 this breed, two periods of about ten years each were selected: 1994-2004 and 2005-2014. The

185 level of inbreeding among Tatra Shepherd dogs born in 1994-2004 was 5.87% for males and

186 4.88% for females, whereas in 2005-2014 it was 6.94% and 8.22%, respectively. Statistically

187 significant differences were identified only for female dogs born in Poland, while they were

188 highly significant for females born abroad and non-champion females, as well as all female

189 dogs together. The significantly lowest ($p \leq 0.001$) inbreeding rate (388%) was recorded for

190 female dogs born in 1994-2004 outside Poland in comparison to the group of female dogs

191 born in 2005-2014. The highest inbreeding rate was found in the group of nCH females in

192 2005-2014 and was significantly ($p \leq 0.001$) higher in comparison to the nCH group in the

193 years 1994-2004. A decreased rate of inbreeding among male dogs born in 2005-2014 in

194   comparison to dogs born in 1994-2004 was observed only in the group of champion dogs.

195   Other groups showed an upward but statistically insignificant trend.

196   The intensity of inbred classes (F_X) among Tatra Shepherd dogs shows the lowest

197   number of specimens in the class of non-related animals and in particular male dogs (Table

198   4). The limit value is 6.5% and the critical value 12.5%. The analysis shows that 25.65% of

199   Tatra Shepherd dogs, including 23.75% males and 27.03% females exceeded the limit

200   inbreeding value. On the other hand, 11.52% (respectively 12.50% males and 10.81%

201   females) exceeded the critical inbreeding value.

202   The average ancestor loss coefficient (AVK) within the entire analysed population

203   (Table 5) entered in the stud book (KW) and with 1 to 18-generation pedigrees amounted to

204   92.30%, including 84.81% for inbred animals. However, for a standardized 4-generation

205   population it is 82.61%, including 82.31% for inbred animals.

206   The values of the ancestor loss coefficient for Tatra Shepherd dogs with full, 4-

207   generation pedigrees split into groups: CH, nCH, PL and Z are presented in Table 6. The

208   highest AVK was noted for male dogs (84.30%) and female dogs (85.83%) from the CH

209   group, and the lowest for male dogs from the Z group (81.39%) and female dogs from the

210   nCH group (81.23%). A higher AVK means less inbreeding. The AVK coefficient increased

211   significantly (p≤0.05) in the group of dogs from foreign kennels to 93.30% in 2005-2014.

212   AVK values were significantly decreased over the analysed years in the groups: nCH, PL, Z

213   for female dogs to the following level, respectively: 77.17% (p≤0.001), 78.96% (p≤0.05),

214   77.25% (p≤0.001). It can be concluded that the ancestor loss coefficient and the inbreeding

215   rate were growing in the group of female dogs.

216   The estimated kinship in the breed is presented by Table 7. It turned out that the average

217   kinship between probands and their parents in the direct male line was 55.58%, and in the

218   female line 55.44%. Values above 50% indicate that each line, both paternal and maternal,

219 was characterised by a certain degree of inbreeding. A higher kinship coefficient for the

220 paternal line may suggest that breeders look for male line inbreds.

221   In the population of Tatra Shepherd dogs with 1 to 18-generation pedigrees (Table 8),

222 an average secondary kinship between the proband and its parents was stated at the level of

223 7.9% for all mixed pairs and 12.15% for inbred pairs. Considering the secondary kinship for

224 mixed pairs (male and female) of dogs with full, four-generation pedigrees, the following

225 results were obtained: 12.72% for all the analysed pairs and 13.05% for inbred pairs.

226

Discussion

228   In 1999-2002 an average annual upward trend was noted among Tatra Shepherd dogs

229 registered in Poland amounting to 7.4%, and in 2003 there was a downward trend of 36% in

230 comparison to the previous year. In 2007, 21% of breeding female dogs were used for

231 reproduction [48]. As a result of studies, it was established that in 2004-2014 the average

232 annual trend among the registered Tatra Shepherds was upward in relation to the previous

233 year by 11.9%, whereas in the discussed period both increases and decreases were observed.

234 The largest increase was observed in 2004 in comparison to the previous year (69.2%), and

235 the largest decrease (14.9%) in 2007. In 2011-2016, the kennels used on average 45% of

236 breeding female dogs, and the highest percentage, i.e. 49%, was recorded in 2016.

237   The number of dogs shown at dog shows could be a measure of the breed's popularity.

238 The groups of breeds that are popular in Poland such as Retrievers (Golden or Labrador) or

239 Yorkshire Terriers during the shows often include more than 100 animals [49]. Thus, the

240 Tatra Shepherd dog cannot be classified as a popular breed, but it can be stated that the

241 population of Tatra Shepherd dogs remained at a comparable level in 2005-2014, and the

242 average number of dogs shown at dog shows was 21, with an average annual upward trend of

243 7.1%. Attendance at the most prestigious club dog shows was on average 56 dogs in 2005-

244   2017, assuming the highest number, that is, 77 dogs in 2007 [6]. The number of Tatra

245   Shepherd dogs abroad is relatively high (about 700 in the Netherlands, about 500 in Germany,

246   and several dozen dogs in Belgium and Finland). The profit motive contributed to a high degree

247   to the export of the best specimens, as puppies are often sold abroad at higher prices than in

248   Poland [50-51].

249   Kalinowska et al. [21] demonstrated that half of the active population registered with

250   the Krakow Division of ZKwP was inbred, whereas in a 4-generation population more than

251   23% of dogs were inbred (about 27% males and 20% females). The average inbreeding rate

252   was 1.37%, and the rate estimated only among inbred animals is 5.85%. The highest

253   inbreeding rate was 14.06%. The latest studies on the population consisting of 491 dogs

254   showed that 46% of Tatra Shepherds (20% males and 26% females) were inbred, and in the

255   standardized 4-generation population 40%, including 16% males and 22% females is of an

256   origin connected with inbreeding. The average inbreeding rate was at the level of 2.93% for

257   the entire population and among inbred animals it was 6.34%. The highest inbreeding rate

258   was 20.31%. The studies by Kania-Gierdziewicz and Gierdziewicz [38] conducted for the

259   Tatra Shepherd dog breed in Silesian voivodeship showed that 77.42% of the population is

260   inbred (including 81.82% of males and 75% of females), and the average inbreeding rates

261   (F_X) are respectively 4.8% for all and 5.8% for inbred animals, whereas the average kinship

262   coefficient is 11.5%. In another experiment carried out in 2015 on the population of Tatra

263   Shepherd dogs living in the region of Podhale, Kania-Gierdziewicz et al. [22] found that the

264   average inbreeding rate for the breed is 7.17%, and the average kinship coefficient is 18.2%.

265   In addition, the inbreeding rate showed an upward trend. Similar F_X results at the level of

266   8.8% were obtained by Leroy et al. [12] for Pyrenean Shepherd and by Cecchi et al. [33] for

267   the Bracco Italiano breed – F_x = 6,7%. A slightly higher inbreeding levels of the Boxer breed

268   were above 10% and the inbreeding rate amounted to 0.14% per year [52]. In contrast

11

269   Bullmastiff Dogs inbreeding coefficients ranged from 0 in 1980 to 0.054 in 1997, an overall

270   increase in mean inbreeding coefficient is seen until the mid 1990's, reaching 0.043 in 1995

271   and remain relatively stable to 0.044 in 2013 [13]. The current Norwegian Lundehund

272   population is highly inbred and has lost 38.8% of the genetic diversity in the base

273   population. The ancestor with the highest contribution in the pedigree is a female with 18

274   offspring born in the 1960s. Her contribution to the last cohort is 41%. Immediate actions are

275   needed to increase the genetic diversity in the current Lundehund population. The only option

276   to secure the conservation of this rare breed is to introduce individuals from foreign breeds as

277   breeding candidates [11]. For Swedish protected dog breeds there is no correlation between

278   average F and population size measured either as the size of the full pedigree or as the number

279   of living dogs (coefficients of correlation, r, range from 0.00 to 0.53 and 0.15–0.60,

280   respectively, with $0.07 < P < 1.00$). Breeds like the Swedish lapphund and the Swedish vallhund,

281   however, reach almost as high average F-0.09 - in spite of pedigree sizes of several thousand

282   individuals, census sizes of well over 1000, and over 50 founders. Similarly, the Swedish

283   elkhound and the Drever have pedigrees comprising over 50,000 dogs, with over 10,000

284   defined as alive in 2012 but average F is over 0.07 [10]. A study of genealogical parameters

285   for a number of breeds in Australia found that the mean inbreeding coefficient ranged from 0

286   to 0.101 across 32 analysed breeds [53].

287   The AVK of the analysed Tatra Shepherds was satisfactory and it was above 91% for

288   the general population of dogs and 84% for the inbred population. The period of analysis

289   significantly contributed to a reduction in AVK, mostly for female dogs from groups nCH,

290   PL, Z born in 2005-2014. Similar results for AVK were obtained for Newfoundland dogs –

291   above 85% [35].

292   Secondary kinship R_{XY} within the entire population was lower than for inbred pairs by

293   4.25%. On the other hand, similar results were obtained for pairs with 4-generation pedigrees.

294 Kalinowska et al. [21] obtained similar R_{XY} values for inbred pairs within the range 14.51-

295 14.92% and lower for the entire population, 4.53-6.12%. Slightly lower R_{XY} results, around

296 3.91%, were estimated for the entire population of German Shepherd dogs from the region of

297 Krakow [54].

298   With regard to quite a high level of inbreeding in the breed, new blood is recommended

299 in breeding Tatra Shepherd dogs. The source of enriching the gene pool can be dogs entered

300 in the stud book. Insofar as excessive inbreeding can contribute to inbreeding depression, the

301 dogs entered in the stud book, despite their phenotype complying with the breed standard, are

302 a mystery in terms of origin, genotype, possible inbreeding or why their ancestors were

303 excluded from breeding. Thus, dogs to be entered into the stud book should be thoroughly

304 selected and these should only be dogs having unquestionable typical physical and mental

305 traits of the breed. Among all stud dogs in Poland mentioned in the Newsletter of the Tatra

306 Shepherd Dogs Club, 61.11% did not leave a male line continuer [6, 21]. A way of enriching

307 the line can be reaching the descendants of such dogs that are not shown at dog shows and

308 obtaining genetic material by entering them into the stud book and then using them for

309 breeding. Therefore, the import of Tatra Shepherd dogs bred in the Netherlands or France that

310 show a low degree of kinship with dogs in Poland can be an excellent choice to abandon

311 extensive inbreeding, and aim at improving the breed [22, 36, 37, 49].

312   This way of reducing the inbreeding is confirmed by studies concerning dog breeding

313 and endangered breeds with small populations [13, 16, 33, 55].These observations are

314 alarming since reduced genetic variation and inbreeding are generally associated with the loss

315 of the adaptive potential and reduced options of effective selection [10, 52, 56]. We note that

316 this rapid genetic diversity loss is parallel to an increasing requirement of dogs for a number

317 of different purposes in the modern society [8, 57-59].

318

Conclusion

319

320   In Poland, there are about 121 registered breeders of Tatra Shepeherd dogs, most of

321 them in Lesser Poland voivodeship, i.e. 33.06% on a national scale. In 2016 a record-breaking

322 number of puppies of this breed were born (467), while for the first time in the second decade

323 of the 21st century the number of male dogs born was 20% higher than the number of females.

324   Taking into account the inbreeding rate in the breed, it was concluded that no risk of

325 inbreeding depression occurs yet but there is a trend to reduce the pool of genes. Therefore, it

326 is suggested that the stud book for the Tatra Shepherd dog is left open because the breed has

327 gained popularity year on year, so the number of matings will increase. Based on the results, it

328 must be assumed that the maximum inbreeding rate (F_X) in the analysed breed should not

329 exceed 6.85%, whereas the ancestor loss coefficient (AVK) should not be lower than 76%.

330

Author Contributions

331

332 **Conceptualization:** Edyta Sweklej, Elżbieta Horoszewicz, Roman Niedziółka.

333 **Data curation:** Edyta Sweklej, Elżbieta Horoszewicz.

334 **Formal analysis:** Edyta Sweklej, Elzbieta Horoszewicz, Roman Niedziółka.

335 **Funding acquisition**: Elżbieta Horoszewicz, Roman Niedziółka.

336 **Investigation**: Edyta Sweklej.

337 **Methodology**: Edyta Sweklej, Elżbieta Horoszewicz.

338 **Software**: Edyta Sweklej, Roman Niedziółka.

339 **Supervision**: Roman Niedziółka.

340 **Validation**: Edyta Sweklej, Elżbieta Horoszewicz.

341 **Visualization**: Elżbieta Horoszewicz, Roman Niedziółka.

342 **Writing – original draft**: Edyta Sweklej, Elżbieta Horoszewicz, Roman Niedziółka.

343 **Writing – review & editing**: Elżbieta Horoszewicz, Roman Niedziółka.

References

344

345   1.   FCI Breeds. Breeds Nomenclature. Federation Cynologique Internationale. 2017. Available from:
346   http://www.fci.be/en/nomenclature/provisoire.aspx

347   2.   FEDIAF. European Pet Food Industry Federation. Facts & Figures. 2018.
348   http://www.fediaf.org/images/FEDIAF_Facts__and_Figures_2018_ONLINE_final.pdf

349   3.   Horoszewicz E, Sweklej E, Niedziółka R, Tereszkiewicz K. Dogs as a form of enrichment agrotouristic
350   farms offer. Human Social Sci. 2017; 24(2): 111-1222. http://dx.doi.org/10.7862/rz.2017.hss.24

351   4.   The Humane Society of the United States (2016). Pets by the Numbers. Available from:
352   http://www.humanesociety.org/issues/pet_overpopulation/facts/pet_ownership_statistiscs.html?Referrer=
353   http://www.petsecure.com.au/pet-care/a-guide-to-worldwide-pet-ownership/

354   5.   Young JK, Olson KA, Reading RP, Amgalanbaatar S, Berger J. Is Wildlife Going to the Dogs? Impacts
355   of Feral and Free-roaming Dogs on Wildlife Populations. BioScience. 2011; 61(2): 125-132.
356   https://doi.org/10.1525/bio.2011.61.2.7

357   6.   The Polish Kennel Club – Main Board (ZKwP). Tatra Sheepherd dog – Commentary to the FCI Standard
358   252. 2009; Warsaw. [In Polish]. Available from: https://www.zkwp.pl/images/ sampledata/komentarze/
359   Owczarek_Podhalanski_komentarz.pdf

360   7.   Redlicka A, Redlicki M. Tatra Shepherd dog. MAKO RESS, Warszawa. 2003.

361   8.   Lindblad-Toh K, Wade CM, Mikkelsen TS, Karlsson EK, Jaffe DB, Kamal M, "et al.". Genome
362   sequence, comparative analysis and haplotype structure of the domestic dog. Nature. 2005; 438(7069):
363   803–819. https://doi.org/10.1038/nature04338

364   9.   Calboli FCF, Sampson J, Fretwell N, Balding DJ. Population Structure and Inbreeding From Pedigree
365   Analysis of Purebred Dogs. Genetics. 2008;179:593–601. PMID: 18493074. https://doi.org/
366   10.1534/genetics.107.084954

367   10. Jansson M, Laikre L. Pedigree data indicate rapid inbreeding and loss of genetic diversity within
368   populations of native, traditional dog breeds of conservation concern. PloS ONE. 2018; 13(9): e0202849.
369   https://doi.org/10.1371/journal.pone.0202849.

370   11. Kettunen A, Daverdin M, Helfjord T, Berg P. Cross-Breeding Is Inevitable to Conserve the Highly Inbred
371   Population of Puffin Hunter: The Norwegian Lundehund. PLoS ONE. 2017; 12(1): e0170039.
372   https://doi.org/10.1371/journal.pone.0170039

373   12. Leroy G, Rognon X, Varlet A, Joffrin C, Verrier E. Genetic variability in French dog breeds assessed by
374   pedigree data. J Anim Breed Genet. 2006;123:1–9. https://doi.org./10.1111/j.1439-0388.2006.00565.x

375   13. Mortlock S-A, Khatkar MS, Williamson P. Comparative Analysis of Genome Diversity in Bullmastiff
376   Dogs. PLoS ONE. 2016; 11(1): e0147941. https://doi.org/10.1371/journal.pone.0147941

377   14. Voges S, Distl O. Inbreeding trends and pedigree analysis of Bavarian mountain hounds, Hanoverian
378   hounds and Tyrolean hounds. J. Anim. Breed. Genet. 2009;126:357–365. https://doi.org/10.1111/j.1439-
379   0388.2009.00800.x

380   15. Ściesiński K. Characteristics of contemporary Tatra Shepherd dog population. Part I. Prz Hod. 2002; 6:
381   25–28. [in Polish]. Available from: http://ph.ptz.icm.edu.pl/index.php/2002/06/01/ph-6-2002-czerwiec/

382   16. Yilmaz O., Ertuğrul M. Determination of Akbash Shepherd Dog raised in Turkey. Bitlis Eren University,
383   J Sci Techn. 2012; 2146-7706, 2: 6-9. https://doi.org/10.17678/beuscitech.47144

384   17. Chodzeń J. Polish Championship in Sheep Grazing in Traditional Style according to the regulations IHT-
385   TS FCI (Internationale Herding Trial – Traditional Style). Dog. 2014; 3 (355): 43-45. [In Polish]
386   Available from: https://www.zkwp.pl/index.php/ct-menu-item-16/2-uncategorised/197-kwartalnik-
387   archiwum

388   18. Radzik-Rant A, Wojnarska M. Natural and cultural aspects in pastoral husbandry of the Hutsulshchyna
389   and Podhale regions. Wiad Zoot. 2008; XLVI(2): 29-37. [In Polish]. Available from:
390   https://wz.izoo.krakow.pl/files/WZ_2008_2_art05.pdf

391   19. Arhant Ch., Bubna-Littiz H., Bartels A., Futschik A., Troxler J. Behaviour of smaller and larger dogs:
392   Effects of training methods, inconsistency of owner behaviour and level of engagement in activites with
393   the dog. App Anim Beh Sci. 2010; 123: 131–142. https://doi.org/10.1016/j.applanim.2010.01.003.

20. Haverbeke A., Messaoudi E., Stevens M., Giffroy J.-M. Diederich C. (2010). Efficiency of working dogs undergoing a new Human Familiarization and Training Program. J Vet Beh. 2010; 5(2): 112–119. https://doi.org/10.1016/j.jveb.2009.08.008.

21. Kalinowska B, Gierdziewicz M, Kania-Gierdziewicz J. Genetic structure analysis of Tatra Shepherd dog population in area of Krakow Branch of Polish Kennel Club. I. Inbreeding and relationships coefficients. EJPAU. 2010; 13(3), #2. Available from: http://www.ejpau.media.pl/volume13/issue3/art-02.html

22. Kania-Gierdziewicz J, Gierdziewicz M, Budzyński B. Genetic structure analysis of Tatra Shepherd dog population from Tatra Mountain region. Ann Anim Sci. 2015; 15(2): 323–335. https://doi.org/10.2478/aoas-2014-0090.

23. Hall SJ, Wallace ME. Canine epilepsy: A genetic counselling programme for Keeshonds. Vet. Rec. 1996;138:358–360. http://dx.doi.org/10.1136/vr.138.15.358 PMID: 8737262

24. Krzemińska P, Gogulski M, Aleksiewicz R, Świtoński M. Genetic markers of canine hip dysplasia. Med Wet. 2018; 74(2): 83-87. https://dx.doi.org/10.21521/mw.6069

25. Ólafsdóttir G, Kristjánsson T. Correlated pedigree and molecular estimates of inbreeding and their ability to detect inbreeding depression in the Icelandic sheep dog, a recently bottlenecked population of domestic dogs. Conserv Genet. 2008; 9: 1639–1641. https://doi.org/10.1007/s10592-008-9526-0

26. Ubbink GJ, van de Broek HAW, Hazewinkel K, Rothuizen J. Risk estimates for dichotomous genetic disease traits based on a cohort study of relatedness in purebred dog populations. Vet. Rec. 1998; 142(13): 328-331. https://doi.org/ 10.1136/vr.142.13.328

27. Beuchat C. Inbreeding of purebred dogs determined from DNA. 2016. Available from: http://www.instituteofcaninebiology.org/blog/inbreeding-of-purebred-dogs-determined-from-dna.

28. Drozd L, Karpiński M. Inbreeding of some dog breeds recorded in Polish Kennel Club. Ann UMCS. 1997; sec.EE, XV(42): 293–297. [in Polish] Available from: bwmeta1.element.agro-article-c7f64ab1-5168-43b9-8658-614bd222dcee

29. Falconer D. Einführung in die Quantitative Genetics. Stuttgart. 1984. Eugen Ulmer Verlag.

30. Głażewska I. Genetic diversity in Polish hounds estimated by pedigree analysis. Livest Sci. 2008; 113: 296–301. http://doi.org/10.1016/j.livsci.2007.06.012

31. Mäki K. Population structure and genetic diversity of worldwide Nova Scotia Duck Tolling Retriever and Lancashire Heeler dog populations. Genetic diversity of two dog breeds. J Anim Breed Genet. 2010; 127(4): 318-326. https://doi.org/ 10.1111/j.1439-0388.2010.00851.x. PMID: 20646119

32. Kania-Gierdziewicz J, Gierdziewicz M, Kalinowska B. Inbreeding and relationship analysis of the Golden and Labrador Retriever populations in the Cracow Branch of the Polish Kennel Club. Rocz Nauk PTZ. 2014; 10(1): 9-19. Available from: http://rn.ptz.icm.edu.pl/index.php/pl/archiwum/

33. Cecchi F., Paci G., Spaterna A., Ciampolini R. Morphological Traits and Inbreeding Depression in Bracco Italiano Dog Breed. I J Anim Sci. 2013; 14(3): 3721. https://doi.org/10.4081/ijas.2015.3721

34. Schleger W, Stur I. Hundezüchtung in Theorie und Praxis. Wien. Jugend Und Volk. 1990.

35. Kruzińska B, Święcicka N, Nowak-Życzyńska Z, Boruta A, Kalińska A, Głowacka J. Analysis of genetic relatedness and inbreeding in Polish population of the Newfoundland dog breed. Ann of Warsaw Univ of Life Sci – Anim Sci. 2019; 58 (1): 47–54. https://doi.org/ 10.22630/AAS.2019.58.1.6

36. Jansson M, Laikre L. Recent breeding history of dog breeds in Sweden: modest rates of inbreeding, extensive loss of genetic diversity, and lack of correlation between inbreeding and health. J Anim Breed Genet. 2014; 131: 153–162. PMID:24289536. https://doi.org/10.1111/jbg.12060.

37. Radko A, Rubiś D, Szumiec A. Analysis of microsatellite DNA polymorphism in the Tatra Shepherd Dog. J App Anim Res. 2018; 46 (1): 254-256. http://dx.doi.org/10.1080/09712119.2017.1292912

38. Kania-Gierdziewicz, J., Gierdziewicz, M. Genetic structure analysis of Tatra Shepherd dog population from Silesian Voivodeship. Rocz Nauk PTZ. 2013; 9 (3): 9-19. (In Polish, English Abstract) Available from: http://ptz.icm.edu.pl/download/2013/tom_9_3/I_Kania-Gierdziewicz.pdf

39. Świderek P, Fiszdon K, Kacprzak N. Inbreeding in Pembroke Welsh Corgi population in Poland. Ann Anim Sci. 2015; 15(4): 861-866. https://doi.org/10.1515/aoas-2015-0027

443 40. Boichard D, Maignel L, Verrier E. The value of using probabilities of gene origin to measure genetic
444   variability in a population. Genet Sel Evol. 1997; 29(1):5-23. https://doi.org/10.1186/1297-9686-29-1-5

445 41. Charon I, Świtoński M. Animal genetic and genomics. PWN Warsaw, Poland. 2016.

446 42. Bukład E. Memories of Henry Derezinski (1913-2008). Dog. 2012; 1 (345): 19-23. [In Polish]. Available
447   from: https://www.zkwp.pl/index.php/ct-menu-item-16/2-uncategorised/197-kwartalnik-archiwum

448 43. Tier B. Computing inbreeding coefficients quickly. Genet Sel Evol. 1990; 22: 419–430.
449   https://doi.org/10.1186/1297-9686-22-4-419

450 44. Kania-Gierdziewicz J. Methods of estimating relationship and inbreeding coefficients used in analysis of
451   population genetic structure. Wiad Zoot. 2008; XLVI, 3: 29–41. Available from:
452   https://wz.izoo.krakow.pl/files/WZ_2008_3_art05.pdf

453 45. Wright S. Coefficients of inbreeding and relationship. Am Nat.1992; 56(645): 330-338. Available from:
454   https://aipl.arsusda.gov/publish/other/wright1922.pdf

455 46. Sargolzaei M, Iwaisaki H, Colleau J. CFC: A tool for monitoring genetic diversity. Proc. 8th World
456   Congr. Genet. Appl. Livest. Prod., CD-ROM Communication 27-28. Belo Horizonte, Brazil, Aug, 13-18
457   2006. Available from: http://www.wcgalp8.org.br

458 47. StatSoft Inc. Statistica (data analysis software system), 2016;version 12,5. www.stat-soft.com.

459 48. Krzysztoszek E. Polish Dog Breeds – Part. II. Prz Hod. 2009; 2: 26-29. Available from:
460   http://ph.ptz.icm.edu.pl/wp-content/uploads/2016/11/Luty-2009.pdf#page=28

461 49. Sell B. Podhalan exhibition geography. 2009. Available from:
462   http://owczarekpodhalanski.pl/czytelnia/artykuy/122-geografia-wystawowa-podhalana-rok-2009

463 50. Fiszdon K, Redlicki M. Tatra Shepherd Dog, Chuvach, Kuvasz, Maremma and the Abruzzes Shepherd
464   Dog – similarities and differences in terms of potential crossbreeding. World Congress for Polish Breeds,
465   Opole, Poland 16.01. 2016; 82. Available from: http://zkwp.pl/index.php/ct-menu-item-20/2-
466   uncategorised/172-komunikaty-zarzadu-glownego-zkwp

467 51. Kozyra I, Sell B, Sell B. Male lines of Tatra Shepherd Dog – the genealogical data. World Congress for
468   Polish Breeds, Opole, Poland 16.01. 2016; 89. Available from: http://zkwp.pl/index.php/ct-menu-item-
469   20/2-uncategorised/172-komunikaty-zarzadu-glownego-zkwp

470 52. Mostert B.E., van Marle-Köster E., Visser C., Oosthuizen M. Genetic analysis of pre-weaning survival
471   and inbreeding in the Boxer dog breed of South Africa. SAJ Anim Sci. 2015; 45: 476-484.
472   https://dx.doi.org/10.414314/sajas.v45i5.4.

473 53. Shariflou M.R., James J.W., Nicholas F.W., Wade C.M. A genealogical survey of Australian registered
474   dog breeds. Vet J.2011; 189(2):203–10. https://doi.org/10.1016/ j.tvjl.2011.06.020.

475 54. Kania-Gierdziewicz J, Kalinowska B, Gierdziewicz M. Inbreeding and relationship in the German
476   Shepherd dog population in area of Cracow Branch of Polish Kennel Club. Sc Ann Pol So Anim Prod.
477   2011; 7(3): 21-29. Available from: http://rn.ptz.icm.edu.pl/wp-content/uploads/2014/01/Kania-labradory-
478   ang.pdf.

479 55. Shinkarenko L.N., Guliakova O.G., Malienko V.A., Melnichuk S.D., Spiridonov V.G. Analysisis of
480   genetic variation in dogs (American Pit Bull Terirer breed) with high inbreeding level using microsatellite
481   markers. Tsitol Gen. 2010; 44(4): 16-22. PMID: 20722281

482 56. Allendorf F.W., Luikart G.H., Aitken S.N. Conservation and the Genetics of Populations, 2nd Edition.
483   Wiley-Blackwell, 2012.

484 57. Browne C., Stafford K., Fordham R. The use of scent-detection dogs. I Vet J. 2006; 59: 97–104.
485 58. Horvath G., af Klinteberg Järverud G., Järverud S., Horváth, I. Human ovarian carcinomas detected by
486   specific odor. Int Can Therap. 2008; 7: 76–80. PMID:18505901.
487   https://doi.org/10.1177/1534735408319058.

488 59. Wells D.L. (2007). Domestic dogs and human health: An overview. B J Health Psych. 2007; 12: 145–
489   156. PMID:17288671. https://doi.org/10.1348/135910706X103284.

Table 1. The population of registered Tatra Shepherd dogs within the time interval 2011-2016 (number of dogs) and the forecasted growth in 2017-2021.

Year	Adult dogs				Puppies	
	Dogs in total	Breeding Dogs	Bitches in total	Breeding Bitches	Dogs	Bitches
2011	184	46	289	66	136	150
2012[1]	-	-	-	-	-	-
2013	218	81	309	152	190	201
2014	222	85	308	150	193	195
2015	220	89	337	152	205	224
2016	221	83	366	163	259	208
Trend until 2021[2]	+8.30	+47.80	+17.93	+56.18	+29.81	+19.23

Data collected from all branches of the Cennel Club fot the Tatra Sheepherd dog [6], [1] No confirmed data, [2] Trend values expressed in %

Table. 2. The average inbreeding rate of the Tatra Shepherds population.

Specification	Group	The wole population		4 generational pedigree	
		N	mean± SD	N	mean± SD
F_x Total	Dogs	198	3,14 ± 0.46	82	6,52 ± 0.48
	Bitches	293	2,79 ± 0.42	112	6,79 ± 0.44
	Total	491	2,93 ± 0.44	194	6,68 ± 0.45
F_x Inbred animals	Dogs	99	6,29 ± 0.47	81	6,60 ± 0.47
	Bitches	128	6,38 ± 0.42	108	7,04 ± 0.42
	Total	227	6,34 ± 0.44	189	6,85 ± 0.45

N – Number, SE – group averange, SD - Standard deviation, Fx – Inbreeding rate expressed in %

Table 3. Values of the inbreeding rate of the standardized population of Tatra Shepherd dogs, taking into account their sex, group and years of study.

Analyzed years	Dogs					Bitches				
	Total	CH	nCH	PL	Z	Total	CH	nCH	PL	Z
	N=82	N=31	N=51	N=71	N=11	N=112	N=28	N=84	N=96	N=16
F_x (1994-2004)	5.87	6.04	6.62	6.22	4.33	4.88[A]	5.38	4.60[A]	5.08[a]	3.88[A]
±SD	0.50	0.41	0.51	0,48	0.61	0.46	0.40	0.46	0.46	0.38
F_x (2005-2014)	6.94	4.90	7.58	7.06	5.86	8.22[B]	6.46	8.58[B]	8.19[b]	8.40[B]
±SD	0.47	0.41	0.50	0.45	0.49	0.42	0.38	0.42	0.43	0.37
F_x (1994-2014)	6.52	5.60	7.08	6.75	5.02	6.79	5.80	7.12	6.91	6.14
±SD	0.48	0.41	0.50	0.46	0.58	0.44	0.39	0.45	0.44	0.37

N – Number, SE – group averange, ±SD - Standard deviation, F_x – Inbreeding rate expressed in %, CH - Champion, nCH- Untitled champion, PL – Bred in Poland, Z –Bred abroad

[a,b] – Sex averages marked with different letters in columns differ significantly at p≤0,05

[A, B] – Sex averages marked with different letters in columns differ significantly at p≤0,001

Table 4. Intensity of inbred classes for Tatra Shepherd dogs

Inbreeding clasess	Total	Dogs	Bitches
$F_x = 0\%$	2.62	1.25	3.60
$0 < F_x < 1,5\%$	5.24	11.25	0.90
$1,5 < F_x < 6,5\%$	54.97	51.25	57.66
$6,5\% < F_x < 12,5\%$	25.65	23.75	27.03
$12,5 < F_x$	11.52	12.50	10.81

Data F_x represent the percentage share in the group

Table 5. The average ancestor loss coefficient in the population of Tatra Shepherds dogs.

Specyfication	Group	The wole population		4 generational pedigree	
		N	mean± SD	N	mean± SD
AVK	Dogs	198	91.13 ± 9.88	82	82.93 ± 9.46
	Bitches	293	92.42 ± 9.85	112	82.38 ± 9.95
	Total		92.30 ± 9.85	194	82.61 ± 9.75
AVK Inbred animals	Dogs	99	85,12 ± 9.44	81	82.76 ± 9.40
	Bitches	128	84.57 ± 9.64	108	81.98 ± 9.52
	Total	227	84.81 ± 9.53	189	82.31 ± 9.65

Data area mean in % ±SD, AVK – Ancestor loss coefficient

Table 6. Values of the ancestor loss coefficient of the standardized population of Tatra Shepherd dogs, taking into account their sex, group and years of study.

Analyzed years	Dogs					Bitches				
	Total	CH	nCH	PL	Z	Total	CH	nCH	PL	Z
	N=82	N=31	N=51	N=71	N=11	N=112	N=28	N=84	N=96	N=16
AVK (1994-2004)	83.33	83.33	83.33	83.87	81.43[a]	87.57[A]	86.47	88.17[A]	87.08[a]	90.00[A]
±SD	9.54	9.12	9.76	9.45	9.70	9.89	8.81	11.02	10.21	11.34
AVK (2005-2014)	82.67	85.63	81.67	82.81	93.30[b]	78.49[B]	84.85	77.17[B]	78.96[b]	77.25[B]
±SD	8.97	8.89	9.32	9.31	9.56	9.98	8.70	9.23	8.94	10.80
AVK (1994-2014)	*82.93*	84.30	82.09	83.19	81.39	*82.38*	85.83	81.23	82.18	84.24
±SD	*9.46*	9.09	9.59	9.40	9.67	*9.95*	8.71	10.08	9.81	11.02

Designations as in Table 3, AVK – Ancestor loss coefficient

Table 7. Primary kinship in the population of Tatra Shepherd dogs.

Sex	Primary kinship	
	Men's line	Female line
	COR (R_{XA}) ± SD	COR (R_{XB}) ± SD
Dogs	55.53 ± 3.47	55.34 ± 3.49
Bitches	55.68 ± 3.30	55.56 ± 3.23
Total	55.58 ± 3.42	55.44 ± 3.39

COR (R_{XA}) - Primary kinship in men's line
COR (R_{XB}) - Primary kinship in female line

Table 8. Secondary kinship of Tatra Shepherd dogs.

Specyfication	Index	The wole population[1]	4 generational pedigree
All pairs animals	**N**	**349**	**196**
	R_{XY}	7.9	12.72
	±SD	0.89	0.86
Inbreeding pairs animals	**N**	228	191
	R_{XY}	12.15	13.05
	±SD	0.84	0.85

R_{XY} - Secondary kinship,
[1]The wole population – 1-18 generational pedigree