Oikos

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Appendix A1

Selection of populations for demographic analysis

To select populations for demographic modelling, we only used data from study populations for which all the required demographic data were available. This meant eliminating some populations where the age-specific data (e.g. litter size or probability of breeding) were incomplete. We only used data from populations for which age or stage- (i.e. juvenile, adult) specific values were provided for all vital rates. Stage-specific vital rates were deemed acceptable because, typically, the most significant differences exist between juveniles and adults (Fig. 1). Survival rates were based on standing age distributions; most studies only reported an overall mean number of individuals in each age class, which were used to infer survival estimates. This approach was necessary because most studies were of less than 5 years duration and estimating inter-annual variation from short time periods is unreliable.

Appendix 2

Estimating process error using Kendall’s (1998) method: an example using a Swedish population

To assess the relative contributions of process and sampling error to observed uncertainty in demographic rates we followed Kendall’s (1998) method. The only population that had sufficient data to apply this technique was the Sweden (South) population. Age distribution data for this population were available for six consecutive years, and the probability of breeding was available for four of those six years (Englund 1970, 1980). Kendall’s method was applied to the survival and breeding probabilities. The contributions of sampling and process error to these vital rates can be estimated by assuming that a beta distribution describes between-year variation in the survival or breeding probability, with the number of survivors and breeders for a given year drawn randomly from the binomial distribution (Kendall 1998). For example, if the probability parameter of interest is π, then the likelihood that the long-term probability is $\bar{\pi}$ and variation in π among years is $\sigma^2(\pi)$, given the data in year *t*, is

$$L_t(\bar{\pi}, \sigma^2(\pi)) = \binom{N_t}{m_t} \frac{B(m_t + a, N_t - m_t \quad b)}{B(a,b)} \qquad \text{(A1)}$$

where N_t is the total number of trials (individuals) in year *t*, m_t is the number of successes (survivors or breeders), *B* is the beta function, and *a* and *b* are the parameters of the beta distribution derived from the mean and variance:

$$a = \bar{\pi}\left[\frac{\bar{\pi}(1-\bar{\pi})}{\sigma^2(\pi)} - 1\right] \qquad \text{and} \qquad b = (1-\bar{\pi})\left[\frac{\bar{\pi}(1-\bar{\pi})}{\sigma^2(\pi)} - 1\right]$$

The total log-likelihood is the natural logarithm of Eq. A1 summed across all years of data. Maximum likelihood was then used to find the best parameter estimates for $\bar{\pi}$ and $\sigma^2(\pi)$, with the latter quantifying the variance due to process error.

The relative contributions to uncertainty in λ caused by process and sampling error were estimated as follows. First, to determine the contribution of process error alone, we sampled the survival and breeding probabilities for the matrix element replicates from beta distributions. For both survival or breeding probability, the parameters of the relevant beta distribution were denoted as the mean $\bar{\pi}$ and variance σ^2, both estimated as described above (i.e. with the sampling error removed). The LSA method was then used to determine λ from the matrix replicates (see 'Process error' in Fig. A1). Next, to determine the combined contributions of process and sampling error, we used the LSA method as in the original model. Importantly, however, for each replicate matrix elements were drawn from the beta distributions of the sampling error associated with data from a randomly chosen year (see 'Sampling and process error' in Fig. A1).

There is good agreement between the mean λ estimates for the Sweden (South) population for all of the three methods used to account for uncertainty in vital rates. As expected, the uncertainty in λ is largest when both sources of variance are included (Fig. A1). Process error and sampling error contributed similar uncertainty to our estimates of λ.

References

Doak, D. F. et al. 2005. Understanding and predicting the effects of sparse data on demographic analyses. – Ecology 86: 1154–1163.

Kendall, B. E. 1998. Estimating the magnitude of environmental stochasticity in survivorship data. – Ecol. Appl. 8: 184–193.

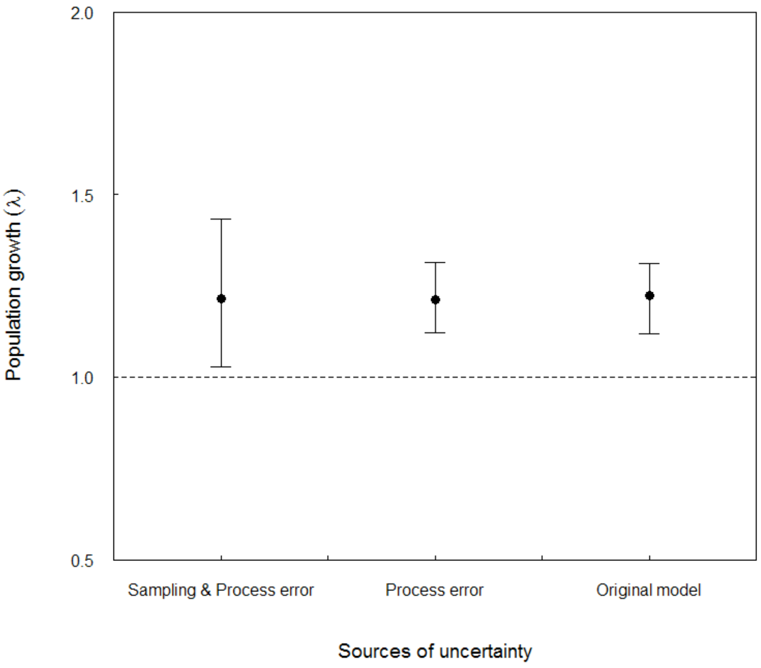

Figure A1. Population growth rates for the Sweden (South) population with both process and sampling variance included, sampling error removed, and the estimate from our original model. Error bars are 95% confidence intervals determined from the matrix replicates (Methods).

So, how representative of other fox populations is the Sweden (South) population? The Sweden (South) population most likely falls towards the higher end of the process error spectrum, coming from an area that is prone to environmental fluctuations, although not as extreme as experienced farther north in Sweden but there were less data available for this population. However, it is known to be subject to high inter-annual variation owing to regulation by prey cycles (Lindström 1989). As many fox populations are likely to experience less environmental variation, we expect the process variation in these populations to be less pronounced. However, our results should be interpreted with caution, given that Doak et al. (2005) suggest that studies of less than five years duration are inadequate to quantify sources of variation, and that sample sizes for the Sweden (South) population were small in some years.

Table A1. Summary of a review of global fox population dynamics (± standard deviations, where provided). Underlined populations were selected for demographic analysis.

Study no.	Study population	References	Data type[1]	Total study duration (years)	Max study area (km^2)	Max sample size (from one study)	Habitat[2]	Sex ratio: all ages*; adults**; juveniles^; embryos^^	Density km^{-2} (individual, litter* or group**)	Home range (km^{-2})
1	UK: London	1, 2, 3	MD	6	1618	1141	4	1 : 0.96*		
2	UK: London	4	CMR, SS	6	7.6	209	4		2.33 ± 0.39 1.03*	1.65
3	UK: Bristol	5, 3, 6, 7, 8, 9, 10, 11, 12	MD, RT, BE, SS, CMR, G	30+	116	1701	4	1 : 0.81* 1.2:1.0**	14.00± 8.34 1.82*	0.51 ± 0.48
4	UK: Oxford	13, 14, 15, 16	RT	10	9.17	>120	3,4		2.15 2.5**	0.92 ± 0.66
5	UK: Wales	17, 18	CMR,	6	580	476	1,2	1:82**	1.85 ± 1.27 0.90 ± 0.57*	2.35 ± 2.33
6	UK: Hampshire	19	BE	1	53	124	2		0.57*	
7	UK: Dorset	20	RT, SS	2	11	14	2			2.43 ± 0.97
8	UK	21, 22	MD	3	2322	656	1,2	1 : 1**	0.94 ± 0.85	
9	UK: Scotland	23, 24	MD	23	48760	4765	1,2		1.09 ± 0.67	
10	Ireland	25, 26	CMR	2	-	292				
11	Belarus	27	SS	3	300	-	2		0.92 ± 0.93	
12	Belgium	28	MD	2	589	314	3,4	0.95:1*		
13	France: North-eastern	29, 30, 31, 32	RT, SS, MD, G	7	250	1259	1,3			1.18 ± 0.75
14	France	33		-	-	-				
15	Germany	34	MD, BE	15	130	955	2	1.5: 1**	0.73 ± 0.25 0.55 ± 0.17*	7.00
16	Germany	35, 36	MD, CMR	5	1012	1371	1,2		0.74 0.31*	
17	Italy	37, 38	RT, MD	2	2448	317	1,2,4	1 : 0.96^^		1.98 ± 1.28
18	Netherlands	39	RT	5	-	150	2		0.55*	3.48 ± 3.77
19	Netherlands	40, 41	RT	6	300	311	2			
20	Norway	42	SS	3	18	2	2			5.47 ± 0.46

Table A1 contd.

Study no.	Study population	References	Data type[1]	Total study duration (years)	Max study area (km^2)	Max sample size (from one study)	Habitat[2]	Sex ratio: all ages*; adults**; juveniles^; embryos^^	Density - individual/ litter*/ group**/ km	Home range (km)
21	**Poland**	43, 44	SS, MD, BE	9	89	113	1,2	1.17 : 1**	0.71 ± 0.18 0.0.94-0.171*	
22	**Poland**	45	SS	3	66	-	1,2		1.30 ± 0.31 0.31 ± 0.02*	
23	**Russia**	46	MD	5	-	759				
24	**Spain: Doñana**	47, 48	MD, SS	4	500	116	-	0.9:1^^	1.70	
25	**Spain: Ebro**	49	MD	7	-	413	1,2	1:0.76*		
26	**Sweden: South**	50, 51	MD, CMR	6	-	799	1,2			
27	**Sweden: North**	50, 51	MD, CMR	4	-	870	1,2			
28	**Sweden**	52	BE	6	3	13	1,2			4.00 ± 1.84
29	**Sweden**	53, 54, 55, 56, 57	MD, RT, SS	17	130	874	2			
30	**Switzerland**	58, 59, 60	MD, SS	8	30	88	1,2		0.4 - 3.2 0.37 ± 0.04*	5.66 ± 11.68
31	**Japan**	61	MD	4	6800	690	1,2			
32	**Japan**	62	RT	1	24	4		1 : 0.65** 1 : 0.74^		3.95 ± 1.98
33	**Japan**	63		1	-	6				4.94 (3.57-6.31)
34	**USA: New York State**	64		2	-	175		0.95 : 1^^		
35	**USA: Indiana**		MD	1	-	104				
36	**USA: Midwest USA**	65, 66	MD, SS, CMR, RT	9	84	2049	1,2	1 : 0.79** 1 : 0.82^ 1 : 0.96^^		9.71
37	**USA: Minnesota**	67	SS, RT	2	41.44	32				6.993 ± 1.372
38	**USA (Midwest): Wisconsin**	68, 69		4	83.73	-		1 : 1.04^	0.09 ± 0.03**	
39	**USA: Illinois**	70	RT, MD	5	3000	611	1,4			

Table A1 contd.

Study no.	Study population	References	Data type[1]	Total study duration (years)	Max study area (km^2)	Max sample size (from one study)	Habitat[2]	Sex ratio: all ages*; adults**; juveniles^; embryos^^	Density - individual/ litter*/ group**/ km	Home range (km)
40	USA: New York State	71, 72, 73	CMR, MD	5	26	2848	1,2	1.06:1** 1.35:1^	0.74 0.97 ± 0.09**	
41	USA (East): Maryland	74	MD	3	-	210	1,2	1:1*		
42	USA: North Dakota	75, 76	MD, RT	5	-	363	1,2	1.33:1** 1: 0.93^^	0.10 ± 0.04**	
43	USA: Alaska	77	CMR, BE	4	3	30	2		9.53 ± 0.45	
44	Canada: Alberta	78	SS, BE	9	21	-	1,2			
45	Canada: Ontario	15, 79	RT	8	-	120	1		0.54 ± 0.65	9 (5.00-20.00)
46	Canada: Ontario	80	RT	1	4	7	3		0.57**	0.77 ± 0.39
47	Australia: Canberra	81		2	-	437	-	1:0.87*		
48	Australia: NSW	82		5	-	838				
49	Australia: Victoria	83, 84	MD	4	24	317		1: 0.79**	2.7 ± 1.38	2.56 ± 2.30
50	Australia: Melbourne	85, 86, 87	RT, MD, SS	5	21	50	4		5.99 ± 4.93 1.18 ± 0.96*	0.28 ± 0.12
51	Australia (Hunted): NSW	88, 89	RT, MD, SS	3	-	534	1,2	1 : 0.72* 1:0.72^		
52	Australia: NSW	90		2	77	21	2,4			1.35 ± 0.042
53	Australia: NSW	91	SS,MD	2	108	276	1			
54	Australia (Non-hunted): Western	92	MD, SS,	1	200	204	1	1:1*	0.46–0.52	
55	Australia: south	93	SS	10	20 km transect	-	2,4		0.60	
56	Australia: Melbourne	94	RT	2	26	9	2,3			0.45 ± 0.13

[1] Data type: MD: mortality data; CMR: capture–mark–recapture; RT: radiotelemetry; SS: sign surveys; BE: behavioural observations; G: genetic. – Data not provided

[2] Habitat: 1 – rural agricultural; 2 – rural non-agricultural 3: low population density; 4 – high population density

References

1. Harris, S. 1977. Distribution, habitat utilization and age structure of a suburban fox (*Vulpes vulpes*) population. – Mamm. Rev. 7: 25–39.

2. Harris, S. 1979. Age-related fertility and productivity in red foxes, *Vulpes vulpes*, in suburban London. – J. Zool. 187: 195–199.

3. Harris, S. and Smith, G. C. 1987. Demography of two urban fox (*Vulpes vulpes*) populations. – J. Appl. Ecol. 24: 75–86.

4. Page, R. J. C. 1981. Dispersal and population density of the fox (*Vulpes vulpes*) in an area of London. – J. Zool. 194: 485–491.

5. Harris, S. 1981. An estimation of the number of foxes (*Vulpes vulpes*) in the city of Bristol, and some possible factors affecting their distribution. – J. Appl. Ecol. 18: 455–465.

6. Harris, S. and Trewhella, W. J. 1988. An analysis of some of the factors affecting dispersal in an urban fox (*Vulpes vulpes*) population. – J. Appl. Ecol. 25: 409–422.

7. Trewhella, W. J. et al. 1988. Dispersal distance, home-range size and population density in the red fox (*Vulpes vulpes*) - a quantitative analysis. – J. Appl. Ecol. 25: 423–434.

8. Baker, P. J. et al. 1998. Potential fitness benefits of group living in the red fox, *Vulpes vulpes*. – Anim. Behav. 56: 1411–1424.

9. Baker, P. J. et al. 2000. Flexible spatial organization of urban foxes, *Vulpes vulpes*, before and during an outbreak of sarcoptic mange. – Anim. Behav. 59: 127–146.

10. Baker, P. J. et al. 2001. Bristol's foxes - 40 years of change. – Brit. Wildlife 12: 411–417.

11. Iossa, G. et al. 2008. Body mass, territory size and life-history tactics in a socially monogamous canid, the red fox *Vulpes vulpes*. – J. Mamm. 89: 1481–1490.

12. Soulsbury, C. D. et al. 2008. Fitness costs of dispersal in red foxes (*Vulpes vulpes*). – Behav. Ecol. Sociobiol. 62: 1289–1298.

13. Macdonald, D. W. 1981. Resource dispersion and the social organization of the red fox (*Vulpes vulpes*). – Proc. Worldwide Furbearer Conf. 1: 918–949.

14. Newdick, M. T. 1984. The behavioural ecology or urban foxes, *Vulpes vulpes*, in Oxford.

15. Voigt, D. R. and Macdonald, D. W. 1984. Variation in the spatial and social behaviour of the red fox, *Vulpes vulpes*. – Acta Zool. Fenn. 171: 261-265.

16. Doncaster, C. P. and Macdonald, D. W. 1991. Drifting territoriality in the red fox *Vulpes vulpes*. – J. Anim. Ecol. 60: 423–439.

17. Lloyd, H. G. 1975. The red fox in Britain. – In: Fox, M. W. (ed.), The wild canids: their systematics, behavoral ecology and evolution. van Nostrand Reinhold, pp. 207–215.

18. Lloyd, H. G. 1980. The red fox. – Batsford.

19. Insley, H. 1977. Estimate of population density of red fox (*Vulpes vulpes*) in New Forest, Hampshire. – J. Zool. 183: 549–553.

20. Reynolds, J. C. and Tapper, S. C. 1995. The ecology of the red fox *Vulpes vulpes* in relation to small game in rural southern England. – Wildlife Biol. 1: 105–119.

21. Heydon, M. J. and Reynolds, J. C. 2000. Demography of rural foxes (*Vulpes vulpes*) in relation to cull intensity in three contrasting regions of Britain. – J. Zool. 251: 265–276.

22. Heydon, M. J. et al. 2000. Variation in abundance of foxes (*Vulpes vulpes*) between three regions of rural Britain, in relation to landscape and other variables. – J. Zool. 251: 253–264.

23. Hewson, R. and Kolb, H. H. 1973. Changes in numbers and distribution of foxes (*Vulpes vulpes*) killed in Scotland from 1948-1970. – J. Zool. 171: 345–365.

24. Kolb, H. H. and Hewson, R. 1980. A study of fox populations in Scotland from 1971 to 1976. – J. Appl. Ecol. 17: 7–19.

25. Fairley, J. S. 1969. Tagging studies of red fox *Vulpes vulpes* in north-east Ireland. – J. Zool. 159: 527–532.

26. Fairley, J. S. 1969. Survival of fox (*Vulpes vulpes*) cubs in northern Ireland. – J. Zool. 159: 532–534.

27. Sidorovich, V. E. et al. 2006. Variations in the diet and population density of the red fox *Vulpes vulpes* in the mixed woodlands of northern Belarus. – Mamm. Biol. 71: 74–89.

28. Chalon, P. X. et al. 1998. Age structure and sex ratio of a Red Fox (*Vulpes vulpes*) population in Belgium. – Cah. Ethol. 18: 17–38.

29. Artois, M. and Aubert, M. F. A. 1991. Foxes and rabies in Lorraine: a behavioural ecology approach. – Hystrix 3: 149–158.

30. Poulle, M. L. et al. 1994. Dynamics of spatial relationships among members of a fox group (*Vulpes vulpes*, Mammalia, Carnivora). – J. Zool. 233: 93–106.

31. Henry, C. et al. 2005. Effect of sex and female reproductive status on seasonal home range size and stability in rural red foxes (*Vulpes vulpes)*. – Ecoscience 12: 202–209.

32. Gachot-Neveu, H. et al. 2009. Genetic detection of sex-biased and age-biased dispersal in a population of wild carnivore, the red fox,*Vulpes vulpes*. – Zool. Sci. 26: 145–152.

33. Artois, M. and Aubert, M. F. A. 1982. Structure des populations (age et sexe) de renards en zones indemnes ou atteintes de rage. – Compar. Immunol. Microbiol. Infectious Dis. 5: 327–245.

34. Stubbe, M. 1980. Population ecology of the red fox (*Vulpes vulpes* L., 1758) in the G.D.R. – Biogeographica 18: 71–96.

35. Vos, A. 1994. Population dynamics of the red fox (*Vulpes vulpes*) after the disappearance of rabies in county Garmisch-Partenkirchen, Germany, 1987-1992. II. North European symposium on the ecology of small and medium-sized carnivores. – Finn. Zool. Bot. Publ. Board, pp. 93–97.

36. Vos, A. C. 1994. Reproductive performance of the red fox, *Vulpes vulpes*, in Garmisch-Partenkirchen, Germany, 1987-1992. – Z. Säugetier. 59: 326–331.

37. Cavallini, P. and Santini, S. 1995. Age-determination in the red fox in a mediterranean habitat. – Z. Säugetier. 60: 136–142.

38. Cavallini, P. 1996. Variation in the social system of the red fox. – Ethol. Ecol. Evol. 8: 323–342.

39. Niewold, F. J. J. 1980. Aspects of the social structure of red fox populations: a summary. – Biogeographica 18: 185–193.

40. Mulder, J. L. 1985. Spatial organization, movements and dispersal in a Dutch red fox (*Vulpes vulpes*) population - some preliminary results. – Rev. Ecol. Terr. Vie 40: 133–138.

41. Mulder, J. L. 2004. Longevity records in the red fox. – Lutra 47: 51–52.

42. Frafjord, K. 2004. Winter range of a red fox (*Vulpes vulpes*) group in a northern birch forest. – Mamm. Biol. 69: 342–348.

43. Goszczynski, J. 1989. Population dynamics of the red fox in central Poland. – Acta Theriol. 34: 141–154.

44. Goszczynski, J. 2002. Home ranges in red fox: territoriality diminishes with increasing area. – Acta Theriol. 47: 103–114.

45. Panek, M. and Bresinski, W. 2002. Red fox *Vulpes vulpes* density and habitat use in a rural area of western Poland in the end of 1990s, compared with the turn of 1970s. – Acta Theriol. 47: 433–442.

46. Korytin, N. S. 2002. Analysis of survival of the red fox (*Vulpes vulpes* L.) at the phases of population growth and decline. – Ekologiya (Mosc.) 3: 201–208.

47. Travaini, A. et al. 1996. Determining the relative abundance of European red foxes by scent-station methodology. – Wildlife Soc. Bull. 24: 500–504.

48. Zapata, S. C. et al. 1998. Reproduction of the red fox, *Vulpes vulpes*, in Donana, southern Spain. – Mammalia 62: 139–142.

49. Gortazar, C. et al. 2003. Habitat related differences in age structure and reproductive parameters of red foxes. – Acta Theriol. 48: 93–100.

50. Englund, J. 1970. Some aspects of reproduction and mortality rates in Swedish foxes (*Vulpes vulpes*), 1961 - 63 and 1966 - 69. – Viltrevy 8: 1–78.

51. Englund, J. 1980. Population dynamics of the red fox (*Vulpes vulpes* L., 1758) in Sweden. – Biogeographica 18: 107–121.

52. von Schantz, T. 1984. Non-breeders in the red fox *Vulpes vulpes* - a case of resource surplus. – Oikos 42: 59–65.

53. Lindström, E. 1981. Reliability of placental scar counts in the red fox (*Vulpes vulpes* L) with special reference to fading of the scars. – Mamm. Rev. 11: 137–149.

54. Lindström, E. 1988. Reproductive effort in the red fox, *Vulpes vulpes*, and the future supply of a fluctuating prey. – Oikos 52: 115–119.

55. Lindström, E. 1989. Food limitation and social regulation in a red fox population. – Holarct. Ecol. 12: 70–79.

56. Lindström, E. et al. 1991. Pattern of spread and effects of sarcoptic mange among red fox populations of Sweden. – Global trends in wildlife management. 18th IUGB Congress, Jagiellonian Univ. Krakow, Poland: August 1987. Trans. Vol. 1: 591–595.

57. Lindström, E. R. 1992. Diet and demographics of the red fox (*Vulpes vulpes*) in relation to population density - the sarcoptic mange event in Scandinavia. – In: McCullough, D. R. and Barret, R. H. (eds). Wildlife 2001: populations. Elsevier, pp. 922–931.

58. Meia, J. S. and Weber, J. M. 1996. Social organization of red foxes (*Vulpes vulpes*) in the Swiss Jura Mountains. – Z. Säugetier. 61: 257–268.

59. Weber, J. M. and Meia, J. S. 1996. Habitat use by the red fox *Vulpes vulpes* in a mountainous area. – Ethol. Ecol. Evol. 8: 223–232.

60. Yoneda, M. and Maekawa, K. 1982. Effects of hunting on age structure and survival rates of red fox in eastern Hokkaido. – J. Wildlife Manage. 46: 781–786.

61. Takeuchi, M. and Koganezawa, M. 1994. Age distribution, sex-ratio and mortality of the red fox *Vulpes vulpes* inTochigi, central Japan - an estimation using a museum collection. – Res. Popul. Ecol. 36: 37–43.

62. Cavallini, P. 1992. Ranging behavior of the red fox (*Vulpes vulpes*) in rural southern Japan. – J. Mamm. 73: 321–325.

63. Sheldon, W. G. 1949. Reproductive behavior of foxes in New York State. – J. Mamm. 30: 236–246.

64. Phillips, R. L. et al. 1972. Dispersal and mortality of red foxes. – J. Wildlife Manage. 36: 237–248.

65. Storm, G. L. et al. 1976. Morphology, reproduction, dispersal and mortality of midwestern red fox populations. – Wildlife Monogr. 49: 3–82.

66. Sargeant, A. B. 1972. Red fox spatial characteristics in relation to waterfowl predation. – J. Wildlife Manage. 36: 225–236.

67. Pils, C. M. and Martin, M. A. 1978. Population dynamics, predator-prey relationships and management of the red fox in Wisconsin. – Wis. Dept Nat. Resour. Tech. Bull. 105: 1–56.

68. Pils, C. M. et al. 1981. Harvest, age structure, survivorship and productivity of red foxes in Wisconsin. – Wis. Dept Nat. Resour. Tech. Bull. 125: 1–21.

69. Gosselink, T. E. et al. 2007. Survival and cause-specific mortality of red foxes in agricultural and urban areas of Illinois. – J. Wildlife Manage. 71: 1862–1873.

70. Tullar, B. F. and Berchielli, L. T. 1980. Movement of the red fox in central New York. – N. Y. Fish Game J. 27: 179–204.

71. Tullar, B. F. and Berchielli, L. T. 1981. Population characteristics and mortality factors of the red fox in central New York. – N. Y. Fish Game J. 28: 138–149.

72. Tullar, B. F. and Berchielli, L. T. 1982. Comparison of red foxes and gray foxes in central New York with respect to certain features of behavior, movement and mortality. – N. Y. Fish Game J. 29: 127–133.

73. Nelson, B. B. and Chapman, J. A. 1982. Age determination and population characteristics of red foxes from Maryland. – Z. Säugetier. 47: 296–311.

74. Allen, S. H. 1984. Some aspects of reproductive performance in female red fox in North Dakota. – J. Mamm. 65: 246–255.

75. Sargeant, A. B. et al. 1984. Red fox predation on breeding ducks in midcontinent North America. – Wildlife Monogr. 89: 3–41.

76. Zabel, C. J. and Taggart, S. J. 1989. Shift in red fox, *Vulpes vulpes*, mating system associated with El Nino in the Bering sea. – Anim. Behav. 38: 830–838.

77. Dekker, D. 1983. Denning and foraging habits of red foxes, *Vulpes vulpe*s, and their interaction with coyotes, *Canis latrans*, in central Alberta, 1972-1981. – Can. Field-Nat. 97: 303–306.

78. Voigt, D. R. 1987. Red fox. – In: Novak, M. et al. (eds), Wild furbearer management and conservation in North America. Ontario Trappers Ass., pp. 378–392.

79. Adkins, C. A. and Stott, P. 1998. Home ranges, movements and habitat associations of red foxes *Vulpes vulpes* in suburban Toronto, Ontario, Canada. – J. Zool. 244: 335–346.

80. McIntosh, D. L. 1963. Reproduction and growth of the fox in the Canberra district. – Wildlife Res. 8: 132–141.

81. Ryan, G. E. 1976. Observations on the reproduction and age structure of the fox *Vulpes vulpes* in New South Wales Australia. – Aust. Wildlife Res. 3: 11–20.

82. Coman, B. J. 1988. The age structure of a sample of red foxes (*Vulpes vulpes*) taken by hunters in Victoria. – Wildlife Res. 15: 223–229.

83. Coman, B. J. et al. 1991. Home range, dispersal and density of red foxes (*Vulpes vulpes* L) in central Victoria. – Wildlife Res. 18: 215–223.

84. Marks, C. A. and Bloomfield, T. E. 1999. Distribution and density estimates for urban foxes (*Vulpes vulpes*) in Melbourne: implications for rabies control. – Wildlife Res. 26: 763–775.

85. Marks, C. A. and Bloomfield, T. E. 1999. Bait uptake by foxes (*Vulpes vulpes*) in urban Melbourne: the potential of oral vaccination for rabies control. – Wildlife Res. 26: 777–787.

86. Marks, C. A. and Bloomfield, T. E. 2006. Home-range size and selection of natal den and diurnal shelter sites by urban red foxes (*Vulpes vulpes*) in Melbourne. – Wildlife Res. 33: 339–347.

87. McIlroy, J. et al. 2001. The reproductive performance of female red foxes, *Vulpes vulpes*, in central-western New South Wales during and after a drought. – Can. J. Zool. 79: 545–553.

88. Saunders, G. R. et al. 2002. Demography of foxes in central-western New South Wales, Australia. – Mammalia 66: 247–257.

89. Meek, P. D. and Saunders, G. R. 2000. Home range and movement of foxes (*Vulpes vulpes*) in coastal New South Wales, Australia. – Wildlife Res. 27: 663–668.

90. Kay, B., et al. 2000. Trapping efficiency for foxes (*Vulpes vulpes*) in central New South Wales: age and sex biases and the effects of reduced fox abundance. – Wildlife Res. 27: 547–552.

91. Marlow, N. J. et al. 2000. Demographic characteristics and social organisation of a population of red foxes in a rangeland area in Western Australia. – Wildlife. Res. 27: 457–464.

92. Read, J. and Bowen, Z. 2001. Population dynamics, diet and aspects of the biology of feral cats and foxes in arid South Australia. – Wildlife Res. 28: 195–203.

93. White, J. G. et al. 2006. Home range, habitat selection and diet of foxes (*Vulpes vulpes*) in a semi-urban riparian environment. – Wildlife. Res. 33: 175–180.

Table A2. Demographic parameters from a review of global fox populations. Study numbers refer to Table A1, ± standard deviations, where provided.

Studies from Table A1 that do not report relevant information are omitted. Underlined populations were selected for demographic analysis.

Study no.	Study population	Age definition[1]	Juvenile: adult ratio	Survival (age-specific)	Litter size definition[2]	Breeding probability definition[3]	Litter size[4] (mean - all ages)	Litter size (age-specific)	Percent non-breeding (mean)	Percent non-breeding (age-specific)	Percent dispersing - juvenile males (mean)	Percent dispersing – juvenile females (mean)
1	UK: London	1	0.53:0.47	0+0.38 1+0.43 2+0.49 3+0.44	1	1		0+4.6 1+5.0 2+4.9 3+4.9		0+ 24.6 1+8.1 2+4.9 3+3.5		
2	UK: London	3			2	NA						
3	UK: Bristol	1	0.50:0.50	0+ 0.44 1+0.53 2+ 0.52 3+0.51	1	1		0+4.5 1+4.9 2+4.8 3+4.7		0+24.4 1+17.1 2+19.1 3+2.9	44.0 ± 25.9	22.7 ± 12.6
4	UK: Oxford	NA			1	2			40.6± 25.5			
5	UK: Wales	1		0.75-1: 0.45 1.75-2: 0.43 2.75-3: 0.44 3.75-4: 0.43 4.75-5: 0.50	1	1	4.6**		20.5		25.0 ± 16.2	32.5 ± 1.7
7	UK: Dorset	NA			1	NA	5.8 ± 1.9^					
8	UK	1		0+ 0.45 1+ 0.45 2+ 0.30 3+ 0.45	1	1	5.55 ± 0.98		9.7 ± 13.72			
9	UK: Scotland	1	0.67:0.33	0+ 0.34 1+ 0.45 2+ 0.43 3+ 0.13	1	NA	5.0**					
10	Ireland	3	0.64:0.36		1	3			9.8 ± 2.8		30.0	20.0
12	Belgium	1	0.51:0.49	0+ 0.42 1+ 0.51 2+ 0.63 3+ 0.92 4+0.36	NA	NA						

Table A2 contd.

Study no.	Study population	Age definition[1]	Juvenile: adult ratio	Survival (age-specific)	Litter size definition[2]	Breeding probability definition[3]	Litter size[4] (mean - all ages)	Litter size (age-specific)	Percent non-breeding (mean)	Percent non-breeding (age-specific)	Percent dispersing - juvenile males (mean)	Percent dispersing – juvenile females (mean)
14	France	1	0.54:0.46		NA	NA						
15	Germany	1	0.66:0.34	0+ 0.35 1+ 0.34 2+ 0.35 3+ 0.32 4+ 0.23	2	NA	4.8 ± 1.1* 6.8 ± 0.9**'					
16	Germany	1	0.56:0.44		1	1	4.6*	0+ 4.5^ 1+ 5.3 2+ 4.7 3+ 4.9		0+ 24 1+ 17.9 2+ 0.0 3+ 6.8		
17	Italy	1	0.52:0.48		1	2	4.0 ± 1.3^ 3.9 ± 1.6**		20			
21	Poland	1	0.54:0.46	0-0.167: 0.69 0.167-0.5: 0.76 0.5-1: 0.45 1+ 0.56 2+ 0.428 3+ 0.38 4+ 0.32	1	NA	3.8 (2.7 - 4.5)* 5.5^					
23	Russia	1	0.62:0.38	0+ 0.34 1+ 0.49 2+ 0.52 3+ 0.50 4+ 0.60	2	NA						
24	Spain: Donana	1			1	1	3.1 (2.5-3.6)* 3.3 ±0.7 **		13.2			
25	Spain:Ebro	2	0.58:0.42	1+ 0.56 2+ 0.52 3+ 0.55 4+ 0.64	1	1	3.6 ± 0.4^		10.5 ±12.5			

Table A2 contd.

Study no.	Study population	Age definition[1]	Juvenile: adult ratio	Survival (age-specific)	Litter size definition[2]	Breeding probability definition[3]	Litter size[4] (mean - all ages)	Litter size (age-specific)	Percent non-breeding (mean)	Percent non-breeding (age-specific)	Percent dispersing - juvenile males (mean)	Percent dispersing – juvenile females (mean)
26	Sweden(South)	1	0.60:0.40	0+ 0.43 1+ 0.53 2+ 0.75 3+ 0.55	1	1		0+ 3.93^ 1+ 4.77 2+ 4.53 3+ 4.20		0+ 46 1+ 62 2+ 81		
27	Sweden(North)	1	0.54:0.46	0+ 0.33 1+ 0.71 2+ 0.50 3+ 0.59	1	1		0+ 4.17^ 1+ 4.30 2+ 4.77 3+ 4.20		0+ 59 1+ 48 2+ 33		
28	Sweden	NA			1	2	4.8 ± 0.7*		50			
29	Sweden	1		0+ 0.53 1+ 0.67 2+ 0.66 3+ 0.61 4+ 0.66	1	NA	4.1 ± 0.5^					
30	Switzerland	NA			2	NA	3.9 ± 0.4*					
31	Japan	2	0.70:0.30	0+ 0.19 1+ 0.51 2+ 0.53 3+ 0.40 4+ 0.75	NA	NA						
32	Japan	1	0.62:0.38	0+ 0.20 1+ 0.88 2+0.43 3+ 0.70	NA	NA						
34	USA: New York State	NA			1	2	5.4 (1-9) **		4.7			
35	USA: Indiana	NA			2	2	6.8 ± 0.3		40			

Table A2 contd.

Study no.	Study population	Age definition[1]	Juvenile: adult ratio	Survival (age-specific)	Litter size definition[2]	Breeding probability definition[3]	Litter size[4] (mean - all ages)	Litter size (age-specific)	Percent non-breeding (mean)	Percent non-breeding (age-specific)	Percent dispersing - juvenile males (mean)	Percent dispersing – juvenile females (mean)
36	USA: Midwest	1	0.64:0.36	0+ 0.35 1+ 0.53 2+ 0.80 3+ 0.80 4+ 0.86	1	3	4.2 ± 0.1* 7.1 ± 1.9^ 6.8 ± 0.1**				87.4 ± 9.2	44.6 ± 11.5
38	USA (Midwest): Wisconsin	1	0.59:0.41	1+ 0.33 2+0.40 3+0.95 4+0.43	1	2		0+ 5.9** 1+ 5.4 2+ 6.8 3+ 5.3 4+ 8.0		0+ 41 1+ 10 2+11 3+ 25 4+ 0		
39	USA: Illinois	3		0+ 0.27 1+ 0.35	NA	NA						
40	USA: New York State	1	0.69:0.31	0+ 0.63 1+ 0.33 2+ 0.57 3+ 0.25 4+ 0.58	NA	NA					58.3 ± 14.0	47.5 ± 26.7
41	USA (East): Maryland	2	0.55:0.45	0+ 0.34 1+ 0.87 2+ 0.56 3+ 0.63 4+ 0.58	2	2	0+ 5.32^ 1+ 6.68 2+ 6.26 3+ 6.10			0+ 83 1+ 17		
42	USA: North Dakota	2	0.44:0.56		1	1		0+ 3.1±2.3 1+ 4.7±2.2 2+ 4.9±2.2 3+ 5.6±1.9 4+ 4.8±1.3		0+ 28.3 1+ 7.7 2+ 7.7 3+ 5.3 4+ 0.0	62.0± 10.1	31.0 ± 34.7
43	USA: Alaska	3			2	2	4.2 ± 0.2*		78.8 ± 14.1			
44	Canada: Alberta	3			NA	NA	5.0*					
45	Canada: Ontario	3	0.79:0.21	Juv+ 0.20 1.5+ 0.40 2.5+ 0.83	2	3	8.0^				90.5	77.0

Table A2 contd.

Study no.	Study population	Age definition[1]	Juvenile: adult ratio	Survival (age-specific)	Litter size definition[2]	Breeding probability definition[3]	Litter size[4] (mean - all ages)	Litter size (age-specific)	Percent non-breeding (mean)	Percent non-breeding (age-specific)	Percent dispersing - juvenile males (mean)	Percent dispersing – juvenile females (mean)
47	Australia: Canberra	3			2	3	3.8 (1-8)* 4.3 (1.8)^ 3.8 (1-6) **		2.6	3		
48	Australia: NSW	2			2	3	3.7 ± 1.5^ 4.0 ± 1.6**		30			
49	Australia: Victoria	1	0.55:0.45		1	NA	3.3*				31.0	23.5
50	Australia: Melbourne	1			1	NA	4.4 ± 0.2* 4.6^					
51	Australia (Hunted): NSW	1	0.61:0.39	0+ 0.29 1+ 0.38 2+ 0.55 3+ 0.64 4+ 0.70	1	3		0+ 3.0 ± 1.8 1+ 3.9± 1.5 2+ 4.8± 1.3 3+ 4.1± 2.0 4+5.2± 1.8		0+30.6 1+14.8 2+13.3 3+8.3 4+8.3		
53	Australia: NSW	1			NA	NA						
54	Australia (Non-hunted): Western	1	0.54:0.46	0+ 0.39 1+ 0.65 2+ 0.92 3+ 0.17 4+ 0.5	1	2		0+ 3.5^ 1+ 3.9 2+ 3.1 3+ 4.5 4+3.0		0+ 0 1+ 0 2+ 0 3+ 0 4+ 0		

[1] Age definition: 1 – well defined: clear description of technique, with juveniles clearly defined; 2 – adequately defined: technique stated, but juveniles poorly defined; 3 – poorly defined: no definition provided.

[2] Litter size definition: 1 – well defined: clear description of technique, e.g. defining grades of placental scars, or live embryos; 2 – adequately defined: technique stated but lack of detail; 3 – poorly defined: no definition provided. NA – not applicable for study purpose.

[3] Breeding probability: 1 – well defined: clear description of technique, e.g. stating inclusion of post-implantation loss/reabsorptions; 2 – adequately defined: technique stated but lack of detail; 3 – poorly defined: no definition provided.

[4] Litter size: ^placental scars; *direct counts; ** embryos

Table A3. Coefficients of variation for age-specific survival (P_x) and fecundity (F_x) across matrix replicates for eight fox populations (study number refers to study population in Table A1 and A2).

Study no.	Population	P_0	P_1	P_2	P_3	F_0	F_1	F_2	F_3
51	Australia (Hunted)	0.08	0.13	0.14	0.08	0.10	0.15	0.18	0.10
54	Australia (Non-hunted)	0.17	0.16	0.10	0.42	0.21	0.21	0.21	0.56
3	Bristol	0.04	0.05	0.06	0.07	0.07	0.09	0.13	0.12
1	London	0.05	0.07	0.10	0.10	0.06	0.09	0.12	0.12
26	Sweden (North)	0.02	0.03	0.04	0.03	0.03	0.04	0.05	0.05
27	Sweden (South)	0.06	0.05	0.08	0.06	0.11	0.11	0.11	0.11
38	USA (Midwest): Wisconsin	0.06	0.07	0.06	0.07	0.11	0.11	0.10	0.11
41	USA (East): Maryland	0.11	0.17	0.06	0.18	0.20	0.21	0.16	0.26

Figure A2. Correlation between mean matrix replicates for survival and fecundity for eight fox populations. (A) Juveniles 0+ (r^2 = 0.20, p = 0.23); (B) Adults 1+ (r^2 = 0.51, p = 0.03); (C) Adults 2+ (r^2 = 0.56, p = 0.02); (D) Adults ≥3 (r^2 = 0.64, p = 0.01).