

Population Simulation for Red Fox Management in Kentucky

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Abstract: A stochastic computer model was written to simulate the dynamics of red fox (*Vulpes vulpes*) populations in Kentucky. The model consists of the main module equations and 2 submodules: ASMOSU and BIRTH. Main module equations calculate the number and density of individuals in each age class and the total population. ASMOSU calculates all total and age specific mortality rates. BIRTH calculates the number of individuals recruited into the 0.5-year age class. The model is useful for evaluating scenarios for red fox management in Kentucky because, except for minor exceptions, it validly simulates changes in red fox population dynamics. The model is most sensitive to perturbations in the input values of fecundity, the area inhabited by the population, and the parasitism mortality rate.

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Interest in the red fox by the Kentucky Department of Fish and Wildlife Resources (KDFWR) stems from the importance of this species as a renewable fur resource. For example, during the 1983–84 harvest season, 10,047 pelts, with an estimated value of \$295,227, were purchased in Kentucky (KDFWR unpubl. data). While most of these foxes were harvested by trappers, several thousand hunters also exploited the red fox through consumptive hunting and sport hunting with dogs. Because the red fox is so important to the sportsmen of Kentucky, the KDFWR has given it high priority for management considerations.

The lack of adequate censusing techniques and the complex dynamics of furbearer populations make it difficult to estimate furbearer populations accurately (Clark and Andrews 1982); the red fox in Kentucky is no exception. The KDFWR uses various indices, including scent station surveys, fur-trader transaction reports, fur-taker interviews, and various harvest statistics as relative indicators of population trends (T. L. Edwards, pers. commun.). In addition, age structure and repro-

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duction data are often collected from harvested foxes. While such indices yield information useful for monitoring short-term population trends, there is a need for the evaluation of long-term trends and for the development of quantitative techniques that will allow biologists to base management decisions on anticipated population changes instead of simply reacting to such changes (Clark and Andrews 1982). One such technique is the use of computer simulation models to predict population levels and to evaluate the effects of various management regimes on population size and/or dynamics.

The use of computer simulation modeling in the management of furbearers has become increasingly popular, with models having been developed for many furbearer species (Johnson 1982). The red fox has commanded much attention in this respect because of its importance as a furbearer, predator, and disease vector. Five models that deal with various aspects of red fox ecology have previously been developed (Preston 1973, Zarnoch et al. 1974, Johnson and Sargeant 1977, Pils et al. 1981, David 1982).

In order to increase the objectivity of its red fox management program, the KDFWR has chosen simulation modeling as a supplement to traditional monitoring techniques. Because simulation models developed in other states were not applicable to populations in Kentucky, a new simulation modeling study was initiated. Results from previous modeling efforts were not used in this study. The objective of the study was to construct a stochastic computer simulation model that would: 1) simulate changes in population levels and/or parameters on an annual basis, 2) simulate fluctuations in harvest levels with corresponding changes in market dynamics, 3) evaluate the effects of various management strategies on populations in Kentucky.

FARPOP, a stochastic computer simulation model designed to meet the above objective, was written to simulate the population dynamics of red fox, gray fox (*Urocyon cinereoargenteus*), or raccoon (*Procyon lotor*) populations (Cobb 1985). A flow diagram for the entire model is shown in Figure 1. This paper documents the development, validation, and sensitivity testing of the model for red fox populations only. Cobb (1985) gave a complete description of the entire modeling study.

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Methods

All functional relationships in the model were based on information from the literature and on general population theory. The model used data that either were

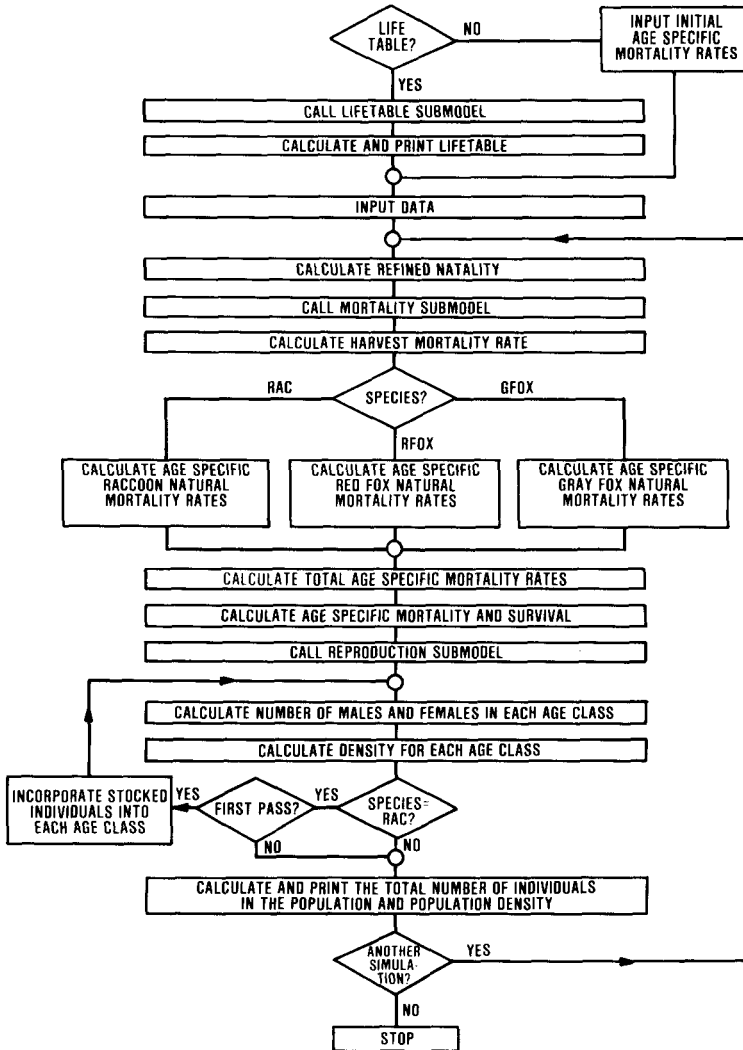


Figure 1. FARPOP flow chart.

being collected by the KDFWR, data that could be collected in the future without a substantial increase in funding or manpower, or data taken from the literature. Once construction of the model was complete, it was validated by comparing actual age structure data with age structures produced from 10 individual simulation runs. Analyses were conducted to test FARPOP's sensitivity to variations of input parameter values. Experimentation with the model is continuing to evaluate the effects of various harvest strategies on the red fox population in Kentucky.

Model Structure

FARPOP was written in FORTRAN 77 computer code for a VAX 11-780 computer. FARPOP consists of the main module equations and 2 submodules: ASMOSU, and BIRTH. Data used in the model are input as normal distributions. Each run of the model is independent and varies randomly based on these input data distributions. Complete model listings are available upon request from the senior author.

In ASMOSU, harvest and natural mortality rates are calculated separately and then combined to determine the total mortality rate within each age class and survival to the next age class. Harvest is based on 3 variables: season length (days), hunter or trapper success rates (animals harvested/hunter or trapper/day), and the number of hunters or trappers. Hunting and trapping harvest mortality rates are calculated separately, but are the product of the above 3 variables divided by the total number of foxes in the population. The season lengths, success rates, and number of hunters are always user-supplied input variables. The number of trappers can either be provided by the user or calculated by a regression equation in the model. This equation was derived through a regression analysis (Ray 1982) of 21 years of unpublished KDFWR hunter and trapper harvest data. The regression equation accounts for 99% of the annual variability in the total number of all trappers based on variability of the price paid for raccoon pelts in the previous year, the number of raccoon pelts purchased in Kentucky during the previous year, and the number of trappers in the previous year. Raccoon harvest data were used because they yielded the most sensitive regression equation for the total number of trappers. No suitable model could be constructed to estimate the number of hunters.

In FARPOP, hunting and trapping mortality rates are considered compensatory to each other. As such, they are combined to yield a total legal harvest mortality rate by summing the two rates and subtracting the product of the two from the total (Caughley 1977). This rate is then added to the user-supplied illegal harvest mortality rate to give the total harvest mortality rate.

Four types of natural mortality agents are included in FARPOP: predators, parasites, diseases, and "other" non-harvest factors (i.e., road-kills, accidents, etc). Five species have been reported as possible predators on red foxes (see Cobb 1985). Only dogs, coyotes (*Canis latrans*), and bobcats (*Felis rufus*), however, have the potential to reach population levels in Kentucky that could result in significant declines in red fox populations. Because it does not appear that populations of these species are presently at such high densities, the predation mortality rate was set at zero in control runs of the model.

Studies surveying the parasitic fauna report 39 genera (46 species) of endoparasites and 16 genera (17 species) of ectoparasites from red foxes (see Cobb 1985). Because the influence of sarcoptic mange has been addressed in the disease category of natural mortality and because there have been no other documented cases of significant population declines due to parasite infections, the parasitism mortality rate was set at zero in control runs of the model.

Seventeen diseases have been reported from red fox populations (see Cobb 1985). Of these, only mange, the best known disease (Ables 1975), rabies, and distemper have been shown to cause significant reductions in populations. Mange can be fatal to all infected individuals (Storm et al. 1976) and is usually assumed to be density dependent (Trainer and Hale 1969, Ables 1975, Tullar and Burchielli 1981). The disease is often accelerated by the communal denning tendencies of red fox families (Tullar et al. 1976) and by the effects of mange on the ability of individual pups and/or adults to disperse (Tullar and Burchielli 1980). Based on the data presented by Tullar and Burchielli (1981), and accepted theories on the cycling of mange in fox populations (Tullar et al. 1976; Tullar and Burchielli 1980, 1981), an arctangent function (Parton and Innis 1972) is used in the model to describe the relationship between the rate of mortality due to mange and population density (Cobb 1985). This function is based on 2 assumptions: 1) the spread of mange is density dependent, and 2) there is some threshold density above which the incidence rate of mange rises very quickly. Tullar and Berchielli's (1981) data suggest, however, that changes in density do not always result in similar changes in the incidence of mange. Other factors that affect the incidence of mange, such as variations in animal susceptibility, in the rate of spread of the disease, and in the virulence and pathogenicity of the disease have not been studied sufficiently. To account for the influence of these factors, the actual percentage of the population contracting mange is defined in FARPOP as a normal random deviate about a mean as estimated with the above described function and with a standard deviation of 30% of the mean.

Rabies is the second disease considered in FARPOP. Little information relating the incidence of this disease to actual population parameters is available. The occurrence and cycling of the disease has been described and reviewed by Gier (1948), Wood (1954), Sikes (1970), Winkler (1975), Carey et al. (1978), Carey (1982), and Carey and McLean (1983). The relationships between the factors that influence the epizootic spread of rabies and their variations in actual red fox populations has not been investigated. Therefore, the relationship included in FARPOP is based on the data presented by Gier (1948) and on 4 assumptions: 1) exploited population densities do not normally exceed 0.80 individuals per km² (Preston 1973) and usually have a low incidence of rabies, 2) there is some threshold density above which rabies incidence rates rise sharply, 3) red foxes are approximately 1,000 times as susceptible to rabies as raccoons (McLean 1975), and 4) the relationships between population density and rabies incidence rates are the same for red fox and raccoon populations, except that increases in incidence rates occur at lower densities in fox populations than in raccoon populations. Based on these assumptions and by using relationships derived for rabies cycling in raccoon populations (Cobb 1985), an arctangent function (Parton and Innis 1972) is used in the model to describe the relationship between the rate of mortality due to rabies and population density (Cobb 1985). To account for the influence of factors other than density on incidence levels of this disease (Carey et al. 1978), the actual percentage of the population contracting rabies is defined as a normal random deviate about a mean as calculated with the above described function and with a standard deviation of 30% of the mean.

Distemper is the final disease considered in FARPOP. Although susceptibility to distemper evidently varies among fox populations, mortality can be significant (Budd 1979). Because diagnosis is difficult, mortality rates due to distemper are often underestimated and the impact of this disease on red fox populations is uncertain (Budd 1970, Andres 1981). In FARPOP, mortality rates due to distemper are a function of population density and are based on 3 assumptions: 1) there is some threshold density above which incidence rates rise sharply, 2) the disease is fatal to all infected individuals, and 3) the disease has similar effects in both red fox and gray fox populations. Based on these assumptions, and on data presented by Nicholson (1982) for gray foxes, an arctangent function (Parton and Innis 1972) is used in the model to describe the relationship between the rate of mortality due to distemper and population density (Cobb 1985). Incidence rates of distemper are probably not a function of density alone. Other factors, as described for mange and rabies, probably play a role in determining mortality due to this disease. Therefore, the actual percentage of the population contracting distemper is defined as a normal random deviate about a mean as calculated with the above described function and with a standard deviation of 30% of the mean.

The final type of natural mortality considered in FARPOP is that attributable to "other" mortality agents. Reports of the proportion of total mortality attributable to "other" natural causes range from 12.6% to 38.5% for juveniles, and from 3.8% to 33.0% for adults (Bennitt and Nagel 1937, Englund 1970, Phillips et al. 1972, Storm et al. 1976, Tullar and Burchielli 1981). Because the natural mortality of red foxes in Kentucky has not been investigated, the relationships used in FARPOP are based on these previously reported mortality rates. The mortality attributable to "other" natural causes is defined in the model as a normal random deviate about a mean of 12.0 and 7.0, and a standard deviation of 4.3 and 5.6 for juveniles and adults, respectively.

Total age-specific natural mortality rates are calculated as the compensatory relationship (Caughley 1977) between the predation, parasitism, disease, and "other" natural mortality rates. Total age-specific mortality rates are calculated as the compensatory relationship between total harvest and total natural mortality rates. The complements of these finite mortality rates are used to calculate the actual number of individuals that survive to subsequent age classes.

BIRTH calculates the number of individuals recruited into the 0.5-year age class. Since the population values produced by FARPOP represent pre-harvest levels, females in each age class are subjected to a complete season of harvest mortality and to 15% of the total annual natural mortality before they breed. The remaining number of females in each age class is then multiplied by the fecundity value for that age class to yield the number of young born to these females. A litter size of 5.0 young per breeding female (Samuel and Nelson 1982) is used in the model. Although some females may be barren in a particular season (Layne and McKeon 1956), all females are assumed to breed.

Once all submodule calculations are completed, the main module statements calculate the number of males and females in each age class. The individuals born

into the population are subjected to 85% of their annual natural mortality rate and all of their illegal harvest mortality rate before being recruited into the 0.5 year age class. This relationship is used because: 1) the majority of juvenile natural mortality is associated with summer and fall dispersal (Storm et al. 1976) and, therefore, occurs before the first harvest season, and 2) the majority of the illegal harvest mortality in Kentucky occurs in the summer and early fall during dog training seasons (T.L. Edwards, pers. commun.). Following these adjustments, and assuming a 1:1 juvenile sex ratio (T. L. Edwards, pers. commun.), the surviving individuals are assigned to each sex category within the 0.5-year age class. The total number of individuals in this age class and its density (per km²) are then calculated.

FARPOP defines the number of males and females to be assigned to each adult (>1-year-old) age class as the number of individuals that survive from the previous age class. Final output includes the total number of individuals and density (per km²) in each age class, the number of males and females in the population, the number of individuals in the population, and the population density (per km²).

Validation

Reynolds et al. (1981) have described several parametric and non-parametric tests that are often used to validate natural resources simulation models. Each of these procedures was considered for use in validating FARPOP, but none were deemed appropriate due to a lack of necessary data. The only age data available for testing the model were the 1983–84 age structure. Because the 1982–83 age structure data were used to initialize the control population used in running FARPOP, we assumed that the model would be valid if the age structure produced after 1 year of simulation was not significantly different from the age structure for the 1983–84 season. This assumes, of course, that both the 1982–83 and 1983–84 samples yielded unbiased estimates for the age structure of the living portion of the population. Based on this assumption, 95% confidence intervals were constructed around the percentage of individuals in each age class in the 1983–84 sample (Rohlf and Sokal 1981, Sokal and Rohlf 1981). The values produced from 10 simulation runs were compared to these intervals, with the model being considered valid if 95% of the values from the 10 simulations fell within these 95% confidence intervals.

Sensitivity Analyses

Although several sensitivity analysis techniques have been described (Rose and Swartzman 1981), the individual parameter perturbation method was used in this study. The model was considered sensitive to an input variable if the output value of any of 3 indicator variables showed a change proportional to or greater than the change of the input variable (Rose and Swartzman 1981). Indicator variables were: harvest mortality rates, the number of individuals recruited into the 0.5-year age class, and population density. The model was tested against perturbations in the following randomly- and subjectivity-chosen input variables: the number of hunters and trappers, the price paid for raccoon pelts in the previous year, the number of trappers in the previous year, the total area inhabited by the population, hunting and

trapping season lengths, fecundity values, hunting and trapping success rates, illegal harvest mortality rates, and predation and parasitism mortality rates. Control values for all variables except the predation and parasitism mortality rates were perturbed by + and - 1% and + and - 15% in nonstochastic runs of the model. Because the predation and parasitism mortality rates were set at 0 in control runs of the model, they were increased in the sensitivity tests to 0.02 and 0.05, respectively. These values represented the estimated maximum predation and parasitism rates in Kentucky.

Results and Discussion

Validation

All of the age-class estimates produced by FARPOP fell within the 95% confidence intervals for the 1983–1984 sample except those for the 1.5-, 4.5-, and 5.5-year age classes (Table 1). The maximum deviation from the 95% confidence interval for the 1.5-year age class estimate was only 0.54 percent. The model is evidently slightly underestimating the mortality rates of the 0.5-year age class so evaluating the relationships involved in juvenile mortality rates should be an area of future data collection and subsequent model refinement.

FARPOP consistently underestimated the percentage of individuals belonging to the 4.5-year age class, with the maximum deviation from the confidence interval limits being only 0.56 percent. This is probably due to a peculiarity in either the 1982–83 or 1983–84 sample. Because the sample sizes increased between subsequent years ($N = 135$ for 1982–83; $N = 185$ for 1983–84), and because the percentage of individuals belonging to the 3.5- and 4.5-year age classes was the same in the 1982–83 sample, the model could not estimate the increase seen in the 1983–84 sample.

Only 3 of the 10 estimates for the 5.5-year age class fell outside the 95% confidence interval. Because the outliers were only 0.01 percent away from the lower

Table 1. Comparison of red fox population structures estimated through annual sampling and with FARPOP.

Age Class (years)	1982–83 Sample ^a	Estimated 1983–84 Age Structure ^b		1983–84 Sample ^a	95% CI ^c	Percent of Simulated Values in 95% CI
		Minimum	Maximum			
0.5	68.15	66.57	66.65	65.95	58.74–72.74	100
1.5	20.00	22.52	22.59	16.22	11.08–22.05	0
2.5	7.41	6.92	7.00	6.49	3.10–10.40	100
3.5	1.48	2.55	2.60	5.40	2.37–9.19	100
4.5	1.48	0.51	0.52	3.24	1.07–6.59	0
5.5	0.74	0.51	0.52	1.62	0.52–5.20	70
6.5	0.74	0.26	0.26	1.08	0.11–3.72	100

^aAge structure is expressed as the percentage of all individuals belonging to each age class.

^bAge structure is estimated from 10 simulation runs and expressed as the percentage of all individuals belonging to each age class.

^c95% confidence interval references the 1983–84 age structure.

confidence interval limit, and because less than 2% of the population was in this age class in either of the 2 samples, the differences were considered insignificant.

Although the model did not pinpoint all changes in the 1.5-, 4.5-, and 5.5-year age classes, the authors feel that FARPOP validly simulates the population dynamics of red foxes in Kentucky for 2 reasons: 1) changes in those age classes containing approximately 80% of the population samples were correctly estimated using the model, and 2) deviations from the 95% confidence intervals were less than 1% of all age classes, suggesting only slight miscalculations by using the model. As additional data pertaining to age specific survival and reproduction are collected, the validity and accuracy of the model will increase. As with any simulation model, as additional data is collected FARPOP should be re-evaluated and model output should be compared to actual population data. If discrepancies are found, the model should be refined. In this way, its validity and accuracy can be increased, and the model can be kept up-to-date as factors affecting the population dynamics of red foxes change in the future.

Sensitivity Analyses

FARPOP was found to be sensitive to changes in only 3 of the 14 input variables tested. The model was sensitive to all changes in the fecundity values, with the indicator variables consistently showing a linear response to these changes. The model was sensitive to perturbations of - 1% and -15% in values representing the total area inhabited by the population. FARPOP was also sensitive to increasing the parasitism mortality rate to 0.05. Although FARPOP was not deemed sensitive to changes in other input variables, having accurate data on variables such as the success rates of hunters and trappers, the illegal harvest mortality rates, and those sensitive variables listed above, is vital to assuring the accuracy of the model and to increasing its practicality for predicting changes in red fox population values.

Based on these testing procedures, the authors feel that FARPOP is of value in both suggesting areas where additional data about the ecology of red foxes in Kentucky are needed and in evaluating the effects of management scenarios before their implementation. It could take years to accumulate these data by more traditional techniques. There is a lack of basic data about red fox population dynamics in Kentucky, but FARPOP can now be used to help managers increase their understanding of this species.

Literature Cited

- Ables, E. B. 1975. Ecology of the red fox in North America. Pages 216-236 in M. W. Fox, ed. *The wild canids: their systematics, behavioral ecology, and evolution*. Van Nostrand Reinhold Co., New York.
- Andrews, R. D. 1981. The red fox in Iowa. *Iowa Conserv. Comm.*, Des Moines. 102pp.
- Bennitt, R. and W. O. Nagel. 1937. A survey of the resident game and furbearers of Missouri. *Univ. of Mo. Studies*. 12:1-215.
- Budd, J. 1970. Distemper. Pages 36-49 in J. W. Davis, L. K. Karstad, and D. O. Trainer, eds. *Infectious diseases of wild mammals*. Iowa State Univ. Press, Ames.

- Carey, A. B. 1982. The ecology of red foxes, gray foxes, and rabies in the eastern United States. *Wildl. Soc. Bul.* 10:18–26.
- , R. H. Giles, and R. G. McLean. 1978. The landscape epidemiology of rabies in Virginia. *Am. J. Trop. Med. Hyg.* 27:573–580.
- and R. G. McLean. 1983. The ecology of rabies: evidence of co-adaptation. *J. Appl. Ecol.* 20:777–800.
- Caughley, G. 1977. *Analysis of vertebrate populations*. John Wiley and Sons, New York. 234pp.
- Clark, W. R. and R. D. Andrews. 1982. Review of population indices applied in furbearer management. Pages 11–22 in G. C. Sanderson, ed. *Midwest Furbearer Management, Proc. Symp. North Cent. Sect., Cent. Mtns. and Plains Sect. and Kansas Chap., The Wildl. Soc.*
- Cobb, D. T. 1985. Computer simulation modeling of raccoon, *Procyon lotor*, red fox, *Vulpes vulpes*, and gray fox, *Urocyon cinereoargenteus*, populations in Kentucky. M.S. Thesis, Eastern Kentucky Univ., Richmond, 147pp.
- David, J. M. 1982. Computer simulation model of the epi-enzootic disease of vulpine rabies. *Ecol. Model.* 15:107–125.
- Englund, J. 1970. Some aspects of reproduction and mortality rates in Swedish foxes *Vulpes vulpes*, 1961–63 and 1966–69. *Viltrevy.* 8:1–82.
- Gier, H. T. 1948. Rabies in the wild. *J. Wildl. Manage.* 12:142–153.
- Johnson, D. H. and A. B. Sargeant. 1977. Impact of red fox predation on the sex ratios of prairie mallards. U.S. Dept. Int. Fish Wildl. Serv. Wildl. Res. Rep. 6. 56pp.
- . 1982. Population modeling for furbearer management. Pages 25–37 in G. C. Sanderson, ed. *Midwest Furbearer Management, Proc. Symp. North Cent. Sect., Cent. Mtns. and Plains Sect. and Kansas Chap., The Wildl. Soc.*
- Layne, J. N. and W. H. McKeon. 1956. Some aspects of red fox and gray fox reproduction in New York. N.Y. Fish and Game J. 3:44–74.
- McLean, R. G. 1975. Raccoon rabies. Pages 53–77 in G. M. Baer, ed. *The natural history of rabies, Vol. II*. Academic Press, New York. 397pp.
- Nicholson, W. S. 1982. An ecological study of the gray fox in east central Alabama. M.S. Thesis, Auburn Univ., Auburn. 93pp.
- Parton, W. J. and G. S. Innis. 1972. Some graphs and their functional forms. Colorado State Univ. Nat. Res. Ecol. Lab. Tech. Rep. 153. 41pp.
- Phillips, R. L., R. D. Andrews, G. L. Storm, and R. A. Bishop. 1972. Dispersal and mortality of red foxes. *J. Wildl. Manage.* 36:237–248.
- Pils, C. M., M. A. Martin and E. L. Lange. 1981. Harvest, age structure, survivorship, and productivity of red foxes in Wisconsin, 1975–78. *Wis. Dep. Nat. Resour. Tech. Bul.* 125. 21pp.
- Preston, E. M. 1973. Computer simulated dynamics of a rabies-controlled fox population. *J. Wildl. Manage.* 37:501–512.
- Ray, A. A., ed. 1982. *SAS user's guide: statistics*. SAS Inst., Inc. Cary, N.C. 584pp.
- Reynolds, M. R., H. E. Burkhart, and R. F. Daniels. 1981. Procedures for statistical validation of stochastic simulation models. *For. Sci.* 27:349–364.
- Rohlf, F. J. and R. R. Sokal. 1981. *Statistical tables*, 2nd ed. Freeman and Co., San Francisco. 219pp.
- Rose, K. A. and G. L. Swartzman. 1981. A review of parameter sensitivity methods applicable to ecosystem models. U.S. Nuclear Reg. Comm. NUREG/CR-2016. 53pp.
- Samuel, D. E. and B. B. Nelson. 1982. Foxes. Pages 475–490 in J. A. Chapman and G. A.

- Feldhamer, eds. Wild mammals of North America; biology, management, and economics. Johns Hopkins Univ. Press, Baltimore.
- Sikes, R. K. 1970. Rabies. Pages 3–19 in J. W. Davis, L. H. Karstad, and D. O. Trainer, eds. Infectious diseases of wild mammals. Iowa State Univ. Press, Ames.
- Sokal, R. R. and F. J. Rohlf. 1981. Biometry. 2nd ed. Freeman and Co., San Francisco. 859pp.
- Storm, G. L., R. D. Andrews, R. L. Phillips, R. A. Bishop, D. B. Siniff, and J. R. Tester. 1976. Morphology, reproduction, dispersal, and mortality of midwestern red fox populations. Wildl. Mono. 49. 82pp.
- Trainer, D. O. and J. B. Hale. 1969. Sarcoptic mange in red foxes and coyotes of Wisconsin. Bul. Wildl. Dis. Assoc. 5:387–391.
- Tullar, B. F. and L. T. Berchielli. 1980. Movement of the red fox in central New York. N.Y. Fish and Game J. 27:179–204.
- and ———. 1981. Population characteristics and mortality factors of the red fox in central New York. N.Y. Fish and Game J. 28:138–149.
- , ———, and E. P. Saggese. 1976. Some implications of communal denning and pup adoption among red foxes in New York. N.Y. Fish and Game J. 23:92–95.
- Winkler, W. G. 1975. Fox rabies. Pages 53–77 in G. M. Baer, ed. The natural history of rabies. Vol. II. Academic Press, New York.
- Wood, J. E. 1954. Investigations of fox populations and sylvatic rabies in the southeast. Trans. North Am. Wildl. Nat. Resour. Conf. 19:131–141.
- Zarnoch, S. J., R. G. Anthony, and G. L. Storm. 1974. Computer simulation of population dynamics of red foxes. Trans. Northeast Fish and Wildl. Conf. 31:182–204.