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POPULATION VIABILITY ANALYSIS OF FERAL RACCOON DOG (*NYCTEREUTES PROCYONOIDES*) IN DENMARK

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Abstract - To assess the effects of actions implemented by the Danish Action Plan (DAP) for eradication of the raccoon dog, the population dynamics of the raccoon dog in Denmark was simulated. A population viability analysis (PVA) was generated with the stochastic simulation program, VORTEX, based on population parameters of raccoon dog in other European countries (Poland, Finland and Germany), combined with statistics on dead raccoon dogs reported to the Danish National Veterinary Institute between 2008 and 2012. Simulations showed that the present feral population of raccoon dogs would expand markedly and reach an assessed carrying capacity of 30 000 individuals with no intervention within 10 years. Simulations of the current culling strategy showed that the raccoon dog in Denmark would reach the carrying capacity with only a few years' delay compared to simulations with no intervention. This indicates that more efficient and intensive actions are needed to reach the goal of the DAP, aiming at eradicating the breeding population of raccoon dogs in Denmark within 2015. Simulations suggested that around 950 individuals should be culled a year from 2012 to 2015. Sensitivity analysis that was performed showed that the only parameter that had a strong influence on the population dynamic was the first year mortality.

Key words: Population Viability Analysis; VORTEX; invasive species; eradication; *Nyctereutes procyonoides*; raccoon dog

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INTRODUCTION

Raccoon dogs are considered an invasive species in Europe (Baagøe and Ujvári, 2007; Kauhala and Kowalczyk, 2011). They originated from eastern Asia, but between 1928 and 1955, 9 000 raccoon dogs were introduced mainly to the western parts of the former Soviet Union as fur animals (Baagøe and Ujvári, 2007; Kauhala and Kowalczyk, 2011). Raccoon dogs have the ability to colonize new areas rapidly, and the introduced animals started dispersing north- and westwards. From 1935 to 1984, raccoon dogs spread into 1.4 million km^2 of Eastern Europe (Kauhala and Kowalczyk, 2011).

Feral raccoon dogs were recorded sporadically in Denmark since 1980, and from 1995 to 2003, 25 individuals were recorded (Asferg, 1991, Baagøe and

Ujvári, 2007). These findings were widely spread in Jutland and Funen and were presumed to be individuals that escaped from fur farms or private holds (Baagøe and Ujvári, 2007). Since 2008, observations of raccoon dogs increased markedly, indicating that a feral population had established itself.

In 1982, the first raccoon dog was culled in Schleswig-Holstein, the German region adjacent to the Danish/German border, followed by sporadic culls (Jagd und Artenschutz, 2012). Since 1996, the number of culled individuals increased and during the hunting season 2011/12, 1 145 individuals were culled in Schleswig-Holstein (Jagd und Artenschutz, 2012). The number of raccoon dogs migrating from Germany to Denmark would probably increase as the population size in northern Germany continually expands (Baagøe and Ujvári, 2007).

As the feral raccoon dog population in Denmark increased, the Danish Nature Agency implemented an action plan (DAP) aiming to eradicate any breeding raccoon dog population by 2015 (Danish Nature Agency, 2010). Regulatory actions consisted of culling as many individuals as possible through hunt and traps. Additionally, a special control method was adapted from Sweden consisting of capturing raccoon dogs that were sterilized, marked and equipped with a GPS transmitter, and then released (Danish Nature Agency, 2010; Dahl et al., 2013). The GPS-collared animal would find its old partner or a new partner, which then could be traced and eliminated (Danish Nature Agency, 2010; Dahl et al., 2013). Furthermore, it became illegal in 2011 to acquire raccoon dogs, and those in private holds have to be registered, chip marked and sterilized (Ministry of the Environment, 2011).

The aim of this study was to simulate the development of the feral raccoon dog population in Denmark, without (as a control) and with various culling rates. In addition, a sensitivity analysis was conducted in order to identify which parameters were the most critical for the raccoon dog population.

MATERIALS AND METHODS

Population Viability Analysis (PVA)

Simulation of raccoon dog dispersal in Denmark was made in the stochastic simulation program, VORTEX 9.99 (Lacy et al., 2005; Bach et al., 2010; Pertoldi et al., 2013). Values for demographic parameters of raccoon dogs were based on values from Germany, Poland and Finland (Table 1).

Demographic parameters

Values for the population size and annual culling rates were assessed from the number of raccoon dog carcasses submitted to the Danish National Veterinary Institute for autopsy (Al-Sabi et al., 2013) as recommended in the DAP for eradication of the raccoon dog. The number of raccoon dogs increased during 2008-2012 from 5 individuals recorded in 2008 to 106 in 2012, which fit in a power regression providing the model N=1.036E-06x^7.5164 (R^2=0.944), where N was the number of raccoon dogs and x was the number of years after 2013. Following the model, 244 raccoon dogs would be culled in 2013 and 427 in 2014. It was assumed that 1/5 of the population was culled and submitted to the Danish National Veterinary Institute annually, which argued that population size might be set to 1 222 individuals in 2013 (Table 1). Supplementation was defined as the number of raccoon dogs added to the population, both through migrations across the border and/or as potential escapees from private holds. Supplementation was set to 50 individuals annually (Table 1), based on the high migratory ability of the raccoon dog, combined with the knowledge of high population densities in Schleswig-Holstein (Kauhala and Kowalczyk, 2011; Jagd und Artenschutz, 2012). In mosaic-structured landscapes, with fields, woods and water bodies in northern Germany, the density of raccoon dogs were approximately 1 raccoon dog per km^2 (Drygala et al., 2008; Kauhala and Kowalczyk, 2011). This density was used to determine a carrying capacity of 30 000 individuals in Jutland, based on a surface area of 30 000 km^2 (Table 1) (Danmarks Statistik, 2013).

Table 1. Input parameters for VORTEX 9.99 simulations of the raccoon dog populations.

Variable	Value	Source
Reproductive system	long-time monogamy	Helle and Kauhala, 1993; Helle and Kauhala, 1995; Kauhala and Kowalczyk 2011
Age of first reproduction (F/M)	1/1 year	Helle and Kauhala, 1995; Kauhala and Kowalczyk, 2011
Maximum age of reproduction	5 year	Helle and Kauhala, 1993; Kauhala and Kowalczyk, 2011
Litter size	9±3	Helle and Kauhala, 1995; Kowalczyk et al., 2009; Kauhala and Kowalczyk, 2011
Sex ratio at birth (F:M)	1:1	Helle and Kauhala, 1993
Inbreeding depression	no	
Density dependent reproduction	no	
Adult females breeding annually	78 ± 10%	Helle and Kauhala, 1995
First year mortality	70 ± 20%	Drygala et al., 2010
Adult mortality (>1y)	57 ± 20%	Kowalczyk et al., 2009
Age distribution	Stable	
Initial population size	1222	(A)
Carrying capacity	30000 ± 10%	(B)
First year cull	year 0	
Interval between culls	1 year	
Adults culled per year	244	(C)
First year supplementation	year 0	
Interval between supplementations	1 year	
Adults supplemented per year	50	(D)

(A) Population size assessed as 5 times the number of raccoon dogs submitted to the Danish National Veterinary Institute in 2012. (B) Carrying capacity was calculated from 1 raccoon dog per km^2 (Drygala et al., 2008; Kauhala and Kowalczyk, 2011) times the surface areas of Jutland, approximately 30,000 km^2 (Danmarks Statistik, 2013). (C) Culling rates determined as the annual number of dead raccoon dogs delivered to National Veterinary Institute during 2008-2012. (D) Supplementation number of adult raccoon dogs was based on high migratory ability combined with high population densities in Schleswig-Holstein (Jagd und Artenschutz, 2012)

Simulations

All simulations were done with 1 000 iterations with duration of 25 years. Three key scenarios were simulated. Scenario 1: current development – simulation of current conditions and a presumption of how the population would expand, if the present culling efforts were continued. All values are presented in Table 1. Scenario 2: no intervention – this scenario predicted the population expansion and dynamics, in absence of intervention. All parameter values were set as described in Table 1, excluding culling. Scenario 3: eradication within timeframe – simulations of varied hunting pressures was performed, to show the necessary culling effort to meet the aim of the DAP. All values were set as described in Table 1, except culling, which varied between 650 and 1 200 individuals per year, with an interval of 50 individuals per year.

To assess the degree of uncertainty of the simulations, the mean and the 95% confidence intervals of iteration outputs were defined. In addition, ANOVA and Tukey's test (Microsoft Excel) were performed in scenario 3, in order to compare significant differences between the varied culling efforts. However, these simulations might be subject to biased inputs of assessed population variables, such as population

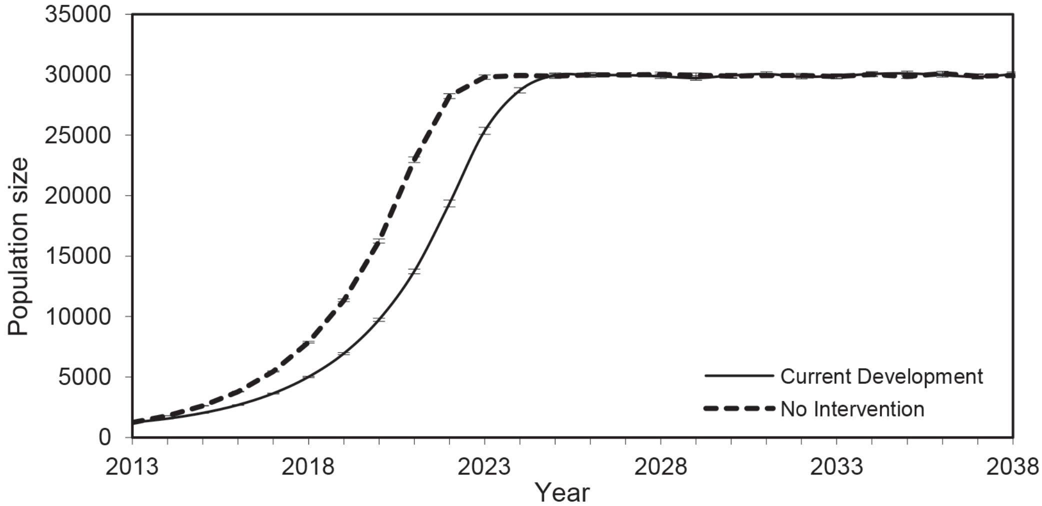

Fig. 1. Current development of the raccoon dog population in Denmark. Mean population size ($\overline{x}$) ± 95% confidence limit of the raccoon dog population (1,000 iterations) simulated for two scenarios: current development (full line) vs. no intervention (dotted line).

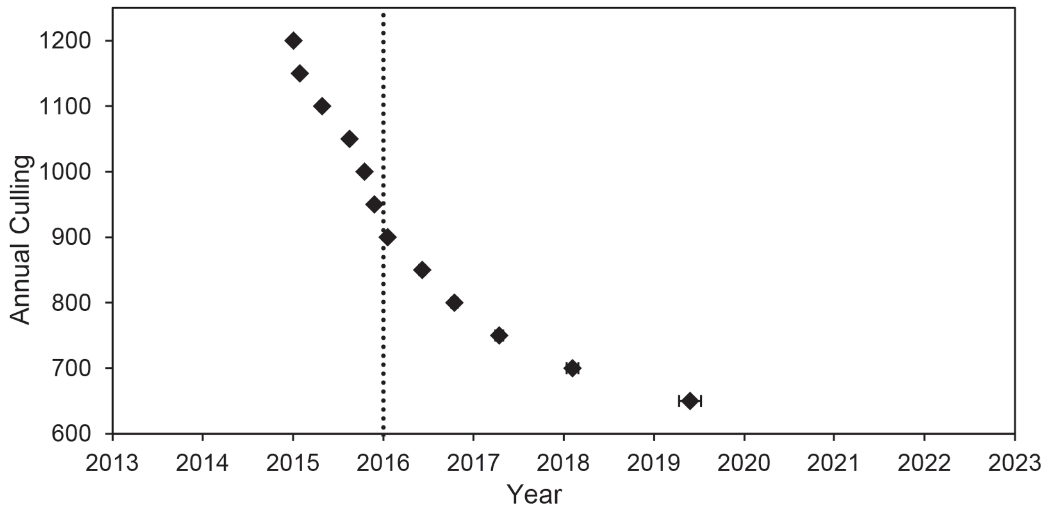

Fig. 2. Eradication within timeframe. Mean time ($\overline{x}$) ± 95% confidence limits of population eradication (1,000 iterations) with different annual culling rates (from 650 to 1,200 individuals).

size, culling, migration and escapes, which were assessed based on statistics from other countries and assumptions.

Sensitivity analysis

Simulations were limited by the uncertainty of different parameters. A sensitivity analysis was conducted to identify which parameters in the simulations were most susceptible and sensitive to stoc-r (the "stochastic growth rate"). Stoc-r identified which parameters were the most sensitive to regulation (high values). Sensitivity was verified by applying a sensitivity index, $S_x = |(\Delta p/p)/(\Delta v/v)|$. Δp was the difference between the examined parameter and the current development, p was the value in the current development (Table 1), Δv was the difference between the examined variable and the current development, and

Table 2. Results of the sensitivity analysis for different parameters used in VORTEX 9.99 simulation performed on the raccoon dog populations. The sensitivity index was applied on two years (2018 and 2023) and on all simulations (scenario summery) of the stochastic growth rate (stoc-r).

	stoc-r year 2018	stoc-r year 2023	stoc-r all simulation
Maximum age of reproduction +20%	0.09	0.21	0.03
Maximum age of reproduction +60%	0.01	0.04	0.01
First year mortality -20%	4.93	0.16	1.76
First year mortality +10%	8.39	7.84	7.24
Adult mortality (>1y) -20%	1.30	0.46	1.26
Adult mortality (>1y) +20%	1.82	1.50	1.38
Initial population size -20%	0.44	0.02	0.02
Initial population size +20%	0.20	0.07	0.00
Adults harvested per year -20%	0.08	0.08	0.08
Adults harvested per year +20%	0.26	0.33	0.18
Adults supplemented per year -100%	0.10	0.01	0.02
Adults supplemented per year -60%	0.02	0.05	0.02
Adults supplemented per year +100%	0.06	0.01	0.02
Adults supplemented per year +200%	0.03	0.01	0.02

v was the value of the variable in the current development

RESULTS

Simulation output

In the period 2014-2024 there is a significant difference ($P<0.05$) in the population size between the scenarios “current development” and “no intervention” (Fig. 1). The simulations suggested that the current culling level only delayed the period necessary for the population to reach the carrying capacity, but it cannot eradicate the population (Fig. 1). After the year 2024, the differences between the two scenarios disappeared.

The simulations of eradication within a limited timeframe (Fig. 2) showed a need to cull a minimum of 950 adult individuals each year in order to reach the goal ($P<0.05$). The level of uncertainty of the simulated mean time of eradication (x) increased with the decreasing number of culled individuals per year, evidenced by the increased standard deviations with decreasing annual culling.

Sensitivity analysis

Table 2 shows the sensitivity index for stoc-r in the years 2018 and 2023, as well as all simulations (n=1,000). It was clear that the first year mortality was the most sensitive parameter, followed by adult mortality. This suggests that mortality was the most important factor in simulations of the raccoon dog population development. The other parameters were not markedly sensitive to changes, suggesting that these values did not have a great influence on population dynamics.

DISCUSSION

The first two scenarios presented in this analysis (1: current development and 2: no intervention) indicated that a major culling effort was necessary to eradicate the increasing raccoon dog population. The current culling would only decrease the population size in the first years (2013-2023), after which the population would reach the carrying capacity; thus the culling has to be much higher in order to have any chance of limiting the population size. This suggests that it would not be possible to eradicate the breeding raccoon dog population, certainly not within the goal of the DAP. Scenario 3: eradication within timeframe reveals that there is a need to cull an average of 950 adults annually to eradicate the population by 2015, which corresponds to the culling of almost the whole population each year; this is not realistic, considering the actual annual culling rate. Furthermore, the difficulty of culling individuals would increase with decreasing population density, as the probability of encountering individuals would be reduced in this way.

Sensitivity analysis showed that first year mortality was the most influential parameter. This indicated that a large interference in population size could be done by focusing on culling litters and 1-year-old raccoon dogs (hunting is therefore important during spring). This action would indeed decrease the number of females reproducing the next summer and therefore the population size would not increase to the same extent. The sensitivity analysis also showed that supplementation was only partially sensitive to regulation by different values (Table 2). This suggests that migration did not have a substantial effect on the options for eradication. However, it could be possible that even if the population was constantly kept at a low level in Denmark while the population in northeastern Germany was increasing, Denmark would continuously be the target for migration (source-sink dynamics).

Implementation of GPS-collared animals has been promoted as an effective way of controlling raccoon dogs (Danish Nature Agency, 2010; Dahl et al., 2013). When all the collected data has been analyzed, it might contribute to an increased knowledge about raccoon dog dispersal, home range and habitat use. This information could then be used to optimize the management, and improve the possibility of tracking more raccoon dogs, which could either be culled or sterilized and GPS collared (Dahl et al., 2013). Collared individuals have been efficiently implemented in program to eradicate isolated populations of feral goat on islands (Campbell and Donlan, 2005). However, it was questionable whether the method could be as efficient in the case of a non-congregatory species at low population densities such as the raccoon dog, and in an open population with a constant supplementation of individuals from neighboring regions.

To set a more realistic timeframe for the eradication of raccoon dogs in Denmark, these simulations suggest that the raccoon dog could be eradicated if the time period was extended by 5 years (year 2020) and the annual culling rate increased to a minimum of 650 individuals per year (Fig. 2). However, this prediction is uncertain considering the relatively large standard deviations of the iterations (Fig. 2), which indicate that the raccoon dog had invaded Denmark to stay. It is important to keep in mind that the population size would increase until it reaches the carrying capacity, and when this happens, it would probably be practically and financially difficult, if not impossible, to eradicate the raccoon dog population in Denmark.

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Authors' contributions

All authors have contributed to the elaboration of the data, the writing process and the discussion of the results. The authors have no conflict of interest.

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