Epidemiol. Infect. (2010), **138**, 1114–1125.
doi:10.1017/S0950268809991221

Quantitative risk assessment to compare the risk of rabies entering the UK from Turkey via quarantine, the Pet Travel Scheme and the EU Pet Movement Policy

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(*Accepted 29 October 2009; first published online 17 December 2009*)

SUMMARY

Rabies was eradicated from the UK in 1922 through strict controls of dog movement and investigation of every incident of disease. Amendments were made to the UK quarantine laws and the Pet Travel Scheme (PETS) was subsequently introduced in 2000 for animals entering the UK from qualifying listed countries. European Regulation 998/2003 on the non-commercial movement of pet animals initiated the European Union Pet Movement Policy (EUPMP) in July 2004. The introduction of EUPMP harmonized the movement of pet animals within the EU ($EUPMP_{listed}$) but raised the possibility of domestic animals entering the UK from a non-EU state where rabies is endemic ($EUPMP_{unlisted}$). A quantitative risk assessment was developed to estimate the risk of rabies entering the UK from Turkey via companion animals that are incubating the disease and enter through PETS or EUPMP compared to quarantine. Specifically, the risk was assessed by estimating the annual probability of rabies entering the UK and the number of years between rabies entries for each scheme. The model identified that the probability of rabies entering the UK via the three schemes is highly dependent on compliance. If 100% compliance is assumed, PETS and $EUPMP_{unlisted}$ (at the current level of importation) present a lower risk than quarantine, i.e. the number of years between rabies entry is more than 170 721 years for PETS and 60 163 years for $EUPMP_{unlisted}$ compared to 41 851 years for quarantine (with 95% certainty). If less than 100% compliance is assumed, PETS and $EUPMP_{unlisted}$ (at the current level of importation) present a higher risk. In addition, $EUPMP_{listed}$ and $EUPMP_{unlisted}$ (at an increased level of importation) present a higher risk than quarantine or PETS at 100% compliance and at an uncertain level of compliance.

Key words: Quantitative risk assessment, rabies, Turkey, UK.

INTRODUCTION

Quarantine of dogs entering the UK has been in effect since 1897, when dogs were required to have a licence and be quarantined in the owner's home for a period of 6 months under the Rabies Order and Importation of Dogs Order. In 1901, the impracticalities of this order were recognized and the licensed dogs were

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kept in isolation for 6 months on premises in control of a veterinary surgeon. From 1928, cats were included within the order. The Kennedy Report [1] outlined its recommendations for alternatives to quarantine and in February 2000, the Pet Travel Scheme (PETS) was implemented [2]. The scheme enables companion animals from qualifying listed countries [3] to enter and re-enter the UK without 6 months quarantine. For companion animals to qualify for the scheme, they must be fitted with a microchip, vaccinated against rabies with an approved vaccine, tested serologically to demonstrate an acceptable immunological response, and must wait for 6 months in the country of origin before entry at a recognized official port. Additionally, 48 h prior to entry, companion animals must be treated against tapeworm and ticks (Table 1) [4]. A European Union (EU) pet passport (EU listed country) or a third country official veterinary certificate (non-EU listed country) is required for companion animals to enter UK [5].

Following the implementation of the UK PETS policy, the EU Pet Movement Policy (EUPMP) was introduced under EU Regulation 998/2003 [6] on the non-commercial movement of pet animals. Initially the UK (as well as Ireland, Sweden, Finland and Malta) were allowed to implement additional controls under a derogation lasting until July 2008; however, that derogation was later extended to 2010. For all EU member states without derogation, EUPMP stipulates that companion animals must be microchipped and vaccinated against rabies at least 21 days prior to entry into another EU member state if the country of origin is a listed country ($EUPMP_{listed}$) [4]. If the country of origin is unlisted ($EUPMP_{unlisted}$), the animal must be microchipped, vaccinated, serologically tested that should preferably be at least 30 days after vaccination in a laboratory approved by the EU, and the test must be taken at least 3 months prior to entry into the member state (Table 1) [5]. For the UK, harmonization of pet movement controls under EU Regulation 998/2003 would mean that $EUPMP_{unlisted}$ and $EUPMP_{listed}$ would replace quarantine and PETS respectively.

Currently, Turkey is an unlisted country (for PETS) and therefore companion animals from Turkey enter the UK via quarantine. If EUPMP were to become effective in the UK, companion animals from Turkey may consequently enter via $EUPMP_{unlisted}$. Moreover, Turkey is being considered for inclusion as a listed country, although there is epizootic rabies in terrestrial mammals (Fig. 1), particularly in dogs in urban areas in many regions of the country [7]. In 2007, over 300 cases of rabies were reported in wildlife and domestic animals from Turkey [8]. There could be an opportunity for cats and dogs from Turkey to enter the UK via PETS or, if movement regimens were at some point harmonized across the EU, via $EUPMP_{listed}$, which raises the possibility that the risk of rabies introduction into the UK will change.

Table 1. *Requirements of the schemes*

Scheme	Requirement
Quarantine	6 months quarantine in the UK
PETS	Microchip
	Vaccine
	Serological test
	6 months waiting period
	Tapeworm and tick treatment
$EUPMP_{listed}$	Microchip
	Vaccine
	21 days waiting period
$EUPMP_{unlisted}$	Microchip
	Vaccine
	Serological test
	3 months waiting period

PETS, Pet Travel Scheme; EUPMP, European Union Pet Movement Policy.

The risk question that is defined is 'what is the risk that at least one companion animal from Turkey is infected with rabies and imported through quarantine, PETS and EUPMP?' To estimate the risk of importing rabies via companion animals, i.e. cats and dogs, from Turkey that enter through quarantine, PETS or EUPMP, a quantitative risk assessment (QRA) was undertaken. The model estimates the annual probability of rabies entering the UK and the number of years between rabies entries for each scheme. The model is based on a previous model developed for North America [9]. In this paper, the QRA and results are described.

QUANTITATIVE RISK ASSESSMENT

Model pathways

The pathways by which rabies can enter the UK are illustrated for each scheme (Figs 2–4); it was reasoned that companion animals that are infected but not yet displaying clinical signs would be the only source of rabies entering the country. Clinical signs of rabies include increased aggression, biting, hypersalivation,

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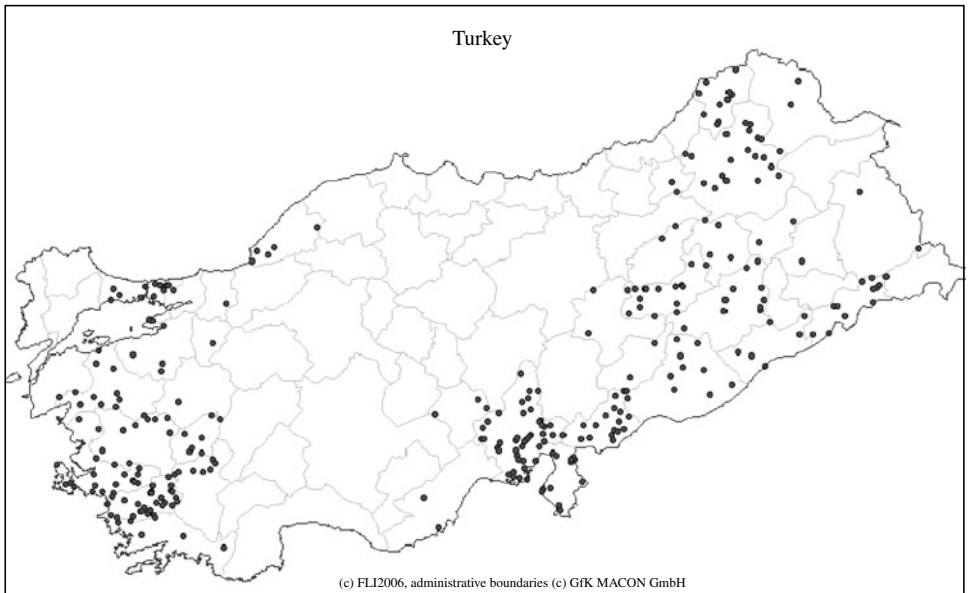

Country	Dog	Cat	Cattle	Equine	Goat/ sheep	Domestic animals	Fox	Wolf	Badger	Fallow deer	Wildlife	Total
Turkey	165	16	79	4	23	287	16	2	1	1	20	307
%	53·7	5·2	25·7	1·3	7·5	93·5	5·2	0·7	0·3	0·3	6·5	100

Fig. 1. Distribution of rabies cases (●) in terrestrial mammals in Turkey for 2007 [8].

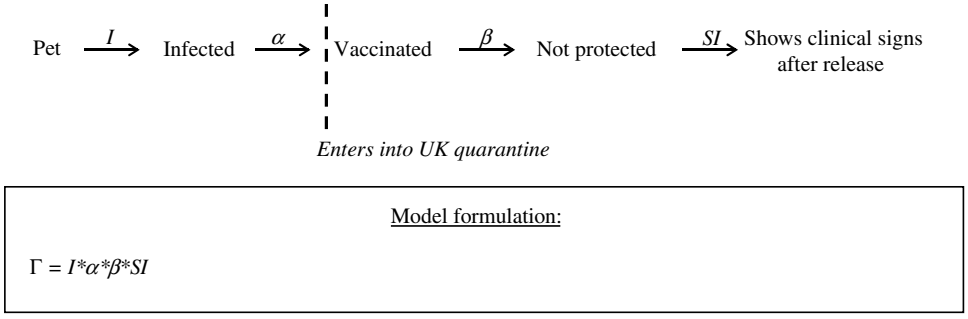

Fig. 2. Pathway for a random companion animal, imported into the UK, to be infected with rabies via quarantine.

etc. [10]. Therefore, it was assumed that animals would be seen by a veterinary surgeon upon displaying signs of rabies, at which point the animal would be diagnosed as rabid and removed from the scheme. An example of this was recently reported in a case of rabies in a quarantined dog [11].

Within the assessment it was assumed that all companion animals enter the UK from Turkey via quarantine, PETS or EUPMP. Figures 2–4 account for the fact that imported animals incubating the disease may be smuggled or enter without the owners fully complying with the specific requirements of the schemes, such as unvaccinated and/or serologically tested (if applicable) for PETS or EUPMP. As the degree to which this type of illegal entry occurs is unknown, an assumption was made as in the previous model developed for North America [9] that the rate of smuggling would not increase or decrease with the implementation of PETS or EUPMP and thus would occur at the same rate for each scheme. Due to the comparative nature of the assessment, smuggling was therefore implicitly addressed.

Model probabilities

The probabilities in Figures 2–4 were estimated using available published and unpublished scientific data, and expert opinion where necessary. Within each

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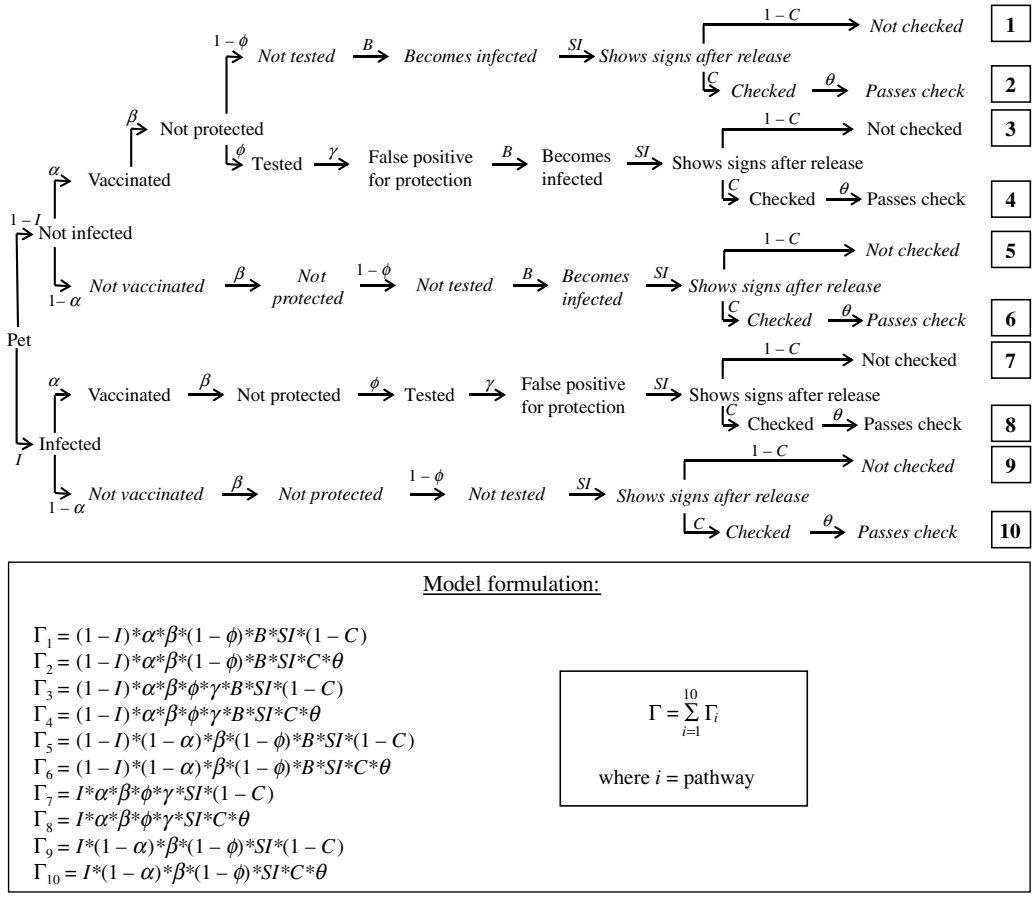

Fig. 3. Pathways for a random companion animal, imported into the UK, to be infected with rabies via PETS or $EUPMP_{unlisted}$. Illegal pathways are highlighted in italic text.

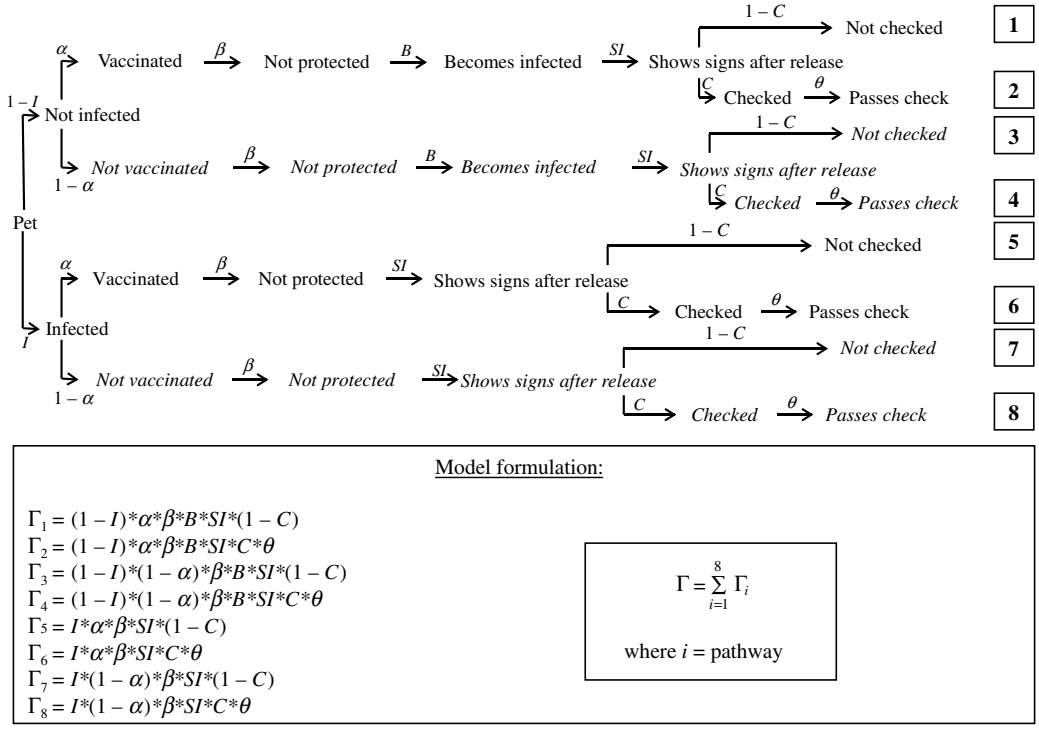

Fig. 4. Pathways for a random companion animal, imported into the UK, to be infected with rabies via $EUPMP_{listed}$. Illegal pathways are highlighted in italic text.

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pathway, the probabilities are conditional upon the previous events that are deemed to have occurred. The combined probabilities for each infected pathway are added to give the overall probability that a random animal is infected and imported. The model calculations have been described previously in the model developed for North America [9] and therefore the focus is on highlighting updates in parameter estimates specific to Turkey. Table 2 outlines the parameters used in the model.

Probability an animal is infected (I) *by incubating rabies*

The probability that a companion animal from Turkey is infected prior to vaccination for quarantine, PETS or EUPMP is based on the number of companion animals, the incubation period of the rabies virus, and the number of rabies cases in cats and dogs.

There were 293 confirmed cases in cats and dogs in the 2-year period of 2006–2007 [8]. Assuming there is no under-reporting of rabies cases the mean number of infected cats and dogs cases per year is equal to 147. The mean incubation period, which is the period of time that an infected animal is not detected, was multiplied by the mean number of infected companion animals per year to estimate the number of cases that are not yet observed.

The mean number of infected companion animals that are currently infected but not yet observed (λ) is calculated as follows [9]

$$\lambda = \frac{38.2}{365} \times 147, \tag{1}$$

where 38·2 is the mean incubation period derived from a lognormal distribution fitted to data describing both experimental and natural infection [9]. The uncertainty associated with the mean number of infected companion animals in equation (1) can be described by a gamma distribution

$$N \sim \text{gamma}(\lambda,\ 1). \tag{2}$$

Thus, the probability that a companion animal selected at random during the year is currently incubating the disease was estimated by dividing N by the estimated pet population

$$I = \frac{N}{730000}. \tag{3}$$

Published information on the number of companion animals in Turkey is limited. However, in 2004, it was reported that the number of dogs and cats was 300 000 and 430 000, respectively [12], which have been combined to give the estimated pet population. The companion animal population is an uncertain parameter where increasing the cat and dog population would increase the risk.

Probability that an animal is vaccinated (α)

All companion animals are vaccinated within 48 h of entering quarantine, thus $\alpha = 1$. For PETS and EUPMP, two scenarios were considered: (1) complete compliance, thus $\alpha = 1$ and (2) an uncertain level of compliance which is described in the Kennedy Report [1] as

$$\alpha \sim \text{pert}(0{\cdot}56,\ 0{\cdot}89,\ 1). \tag{4}$$

It was assumed that companion animals not complying with the scheme would enter with false documentation on vaccination.

Probability that a vaccinated animal is not protected (β)

As a worst-case scenario, it was assumed that a rabies vaccine would fail to elicit a protective immune response for companion animals that are incubating the disease. Hence, in this situation $\beta = 1$ and, by definition, also applies to companion animals that are not vaccinated.

Currently, in the UK there are four registered vaccines that are commercially available, namely Rabisin, Nobivac Rabies, Canigen Rabies and Quantum Rabies [13]. Data on vaccines approved for usage in Turkey is limited, therefore, it was assumed that all available vaccines in Turkey are as efficacious as the UK vaccines. The efficacy of an approved vaccine was estimated using data from two of the studies outlined in the original model developed for North America [9]. Data was available for three vaccines, i.e. Rabisin, Nobivac and Madivak [14] (VLA, unpublished study). In these studies (Table 3), a serological test was performed on blood taken between 30 and 40 days after vaccination to detect rabies virus neutralizing antibodies. Under EU Regulation 998/2003, an animal must have a neutralizing antibody titration at least equal to 0·5 international units per ml (IU/ml) [6]. Given this, it is assumed that the animal has seroconverted and the vaccine is deemed efficacious.

The number of companion animals that are considered to be protected (P) was corrected to account for test specificity (Sp) of $<100\,\%$ to estimate the number of companion animals that are actually

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Table 2. *Model parameters*

Parameter	Probability	Scenario	References
Pet is infected	$I \sim \text{gamma}(\lambda, 1)/730\,000$ $\lambda = 15{\cdot}4$	Quarantine, PETS, EUPMP	[8, 12]
Pet is vaccinated	$\alpha = 1$ $\alpha \sim \text{pert}(0{\cdot}56, 0{\cdot}89, 1{\cdot}0)$, $\alpha = 1$ if compliant	Quarantine, PETS, EUPMP	[1, 9]
Pet is not protected (infected before vaccination or not vaccinated)	$\beta = 1$	Quarantine, PETS, EUPMP	[9]
Pet is not protected (not infected before vaccination)	$\beta = 1 - (\frac{1}{2}Pa + \frac{1}{2}Pn)$ Rabisin: $Pa \sim \text{discrete}([Pa_x, N_x/\sum_{x=1}^{2} N_x])$ $Pa_x \sim \text{beta}(Pr_x + 1,\ N_x - Pr_x + 1)$ $x = 1,\ N = 2631,\ Pr = 2592$ $x = 2,\ N = 83,\ Pr = 80$ Nobivac: $Pn \sim \text{beta}(2820 + 1,$ $2856 - 2820 + 1)$ $\beta = 1 - (1/3Pa + 1/3Pn + 1/3Pm)$ Madivak: $Pm \sim \text{beta}(46 + 1,\ 47 - 46 + 1)$	Quarantine, PETS, EUPMP	VLA, unpub. results [14]
Pet is serologically tested (vaccinated previously)	$\phi \sim \text{pert}(0{\cdot}8, 0{\cdot}98, 0{\cdot}998)$ $\phi = 1$ if compliant $\phi = 0$ if not vaccinated previously	PETS, $\text{EUPMP}_{\text{unlisted}}$	[1, 9]
Serological test gives false positive result	$\gamma = \frac{1}{2}\gamma_{\text{FAVN}} + \frac{1}{2}\gamma_{\text{RFFIT}}$ $\gamma_{\text{FAVN}} = \text{beta}(4 + 1,\ 14 - 4 + 1)$ $\gamma_{\text{RFFIT}} = \text{beta}(8 + 1,\ 30 - 8 + 1)$	PETS, $\text{EUPMP}_{\text{unlisted}}$	[15]
Pet becomes infected	$B = 0$	Quarantine	[9]
Pet becomes infected (vaccinated and serologically tested)	$B = 1 - (1 - p)^{kd}$ $p = \lambda_w/4032242$ $\lambda_w \sim \text{gamma}(167/365, 1)$ $k \sim \text{pert}(0, 1, 2)$ $d = 211$	PETS	[8, 17]
Pet becomes infected (vaccinated)	$B = 1 - (1 - p)^{kd}$ $d = 1$	PETS, $\text{EUPMP}_{\text{unlisted}}$	
Pet becomes infected (no compliance)	$B = 1 - (1 - p)^{kd}$ $d = 1$	PETS, EUPMP	
Pet becomes infected (vaccinated and serologically tested)	$B = 1 - (1 - p)^{kd}$ $d = 120$	EUPMP-$_{\text{unlisted}}$	
Pet becomes infected (vaccinated)	$B = 1 - (1 - p)^{kd}$ $d = 20$	$\text{EUPMP}_{\text{listed}}$	
Pet shows clinical signs	$S = 0{\cdot}02$ $S = 0{\cdot}01$ if infected prior to vaccination $S = 0{\cdot}18$ if infected post-vaccination $S = 0{\cdot}04$ if infected prior to vaccination $S = 0{\cdot}30$ if infected post-vaccination $S = 0{\cdot}56$ if infected prior to vaccination $S = 0{\cdot}83$ if infected post-vaccination $S = 0{\cdot}9997$ for non-compliance	Quarantine PETS $\text{EUPMP}_{\text{unlisted}}$ $\text{EUPMP}_{\text{listed}}$ PETS, EUPMP	
Pet is checked	$C = 1$	PETS, EUPMP	[9]
Pet passes documentation checks	$\theta \sim \text{beta}(P + 1,\ C - P + 1)$ $P = 19\,241$ $C = 22\,120$	PETS, EUPMP	[2–5, 13]

PETS, Pet Travel Scheme; EUPMP, European Union Pet Movement Policy.

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Table 3. *Summary of the data from the vaccination studies*

Vaccine	Reference of study	Number tested (N)	Number $\geqslant$0·5 IU/ml (P)	Number actually protected (ω)
Rabisin ($x=1$)	Study 1 (VLA, unpub. results)	2631	2597	2592
Rabisin ($x=2$)	Study 2 [14]	83	80	80
Nobivac	Study 1 (VLA, unpub. results)	2856	2825	2820
Madivak	Study 2 [14]	47	46	46

protected (ω) under EU Regulation 998/2003 (Table 3) [9]. This was undertaken by using the mean specificity of the respective serological tests (discussed below) to correct for false positives. The sensitivity of the tests (Se) does not influence the risk of rabies entering the UK as protected animals that test negative (false negatives) will be re-vaccinated and tested. Hence, it was assumed that the sensitivity of the tests is 100%. Moreover, from the Cliquet *et al*. study [15] it can be assumed that the sensitivity of the test is 100% as none of the vaccinated animals yielded a false-negative result.

For each study, the uncertainty associated with the probability that an animal is protected is represented by a beta distribution [9]. Due to using data from two studies to estimate the probability that a companion animal is protected following vaccination with Rabisin (Pa), the two studies were combined using a discrete distribution

$$Pa \sim \text{discrete}\left(Pa_x, \frac{N_x}{\sum_{x=1}^{2} N_x}\right), \quad (5)$$

where x refers to each of the Rabisin studies, $x=1, 2$.

The probabilities for each vaccine were combined to yield $1-\beta$, i.e. the probability that an animal is protected following vaccination. Due to the limited information of the frequency of the use of each vaccine, the respective probabilities were equally weighted in the combination. The probability that an animal was not protected after vaccination was therefore β.

Probability that an animal is serologically tested (ϕ)

As earlier, two scenarios were considered: (1) 100% compliance, thus $\phi=1$ and (2) an uncertain level of compliance which was described in the Kennedy Report [1] as

$$\phi \sim \text{pert}(0{\cdot}8,\ 0{\cdot}98,\ 0{\cdot}998). \quad (6)$$

It was assumed that any pet owner who fails to test his or her animal would present false documentation on arrival.

Probability that the serological test produces a false-positive result given that the animal is vaccinated (γ)

As outlined in the model developed for North America [9], the specificity of the fluorescent antibody virus neutralization (FAVN) test and rapid fluorescent focus inhibition test (RFFIT) was estimated by using data from vaccinated dogs in the Cliquet *et al*. study [15]. In this study, the effectiveness of FAVN was compared to the mouse neutralizing test (MNT). Assuming the MNT is the gold standard, FAVN results in four false positives from 14 tested animals. Therefore, the probability that an animal is unprotected based on FAVN (γ_{FAVN}) can be described by

$$\gamma_{\text{FAVN}} \sim \text{beta}(4+1,\ 14-4+1). \quad (7)$$

Furthermore, RFFIT was compared to FAVN which results in six false positives from a total of 30 unprotected animals (i.e. six animals were negative to FAVN but positive to RFFIT). As it is assumed that MNT is the gold standard, the probability that an animal produces a false positive based on RFFIT (γ_{RFFIT}) can be estimated by using the conversion factor $6x(1+4/14)$ which is $\sim$8, thus

$$\gamma_{\text{RFFIT}} \sim \text{beta}(8+1,\ 30-8+1). \quad (8)$$

Due to the limited information of the frequency of the use of each serological test, the respective probabilities were equally weighted to obtain the mean probability that the serological test produces a false-positive result given that the animal is vaccinated.

Probability that an uninfected animal becomes infected (B)

The principal vector of rabies in Turkey is the domestic dog; however, cases in wildlife species have been recorded [16]. For companion animals that are not infected prior to vaccination and the vaccine fails to protect against rabies, the unprotected animal may become infected during the period before entry via contact with infected wildlife or other infected

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companion animals. It is assumed that this probability depends on three factors: (1) the prevalence of rabies in Turkey; (2) the number of contacts with animals during the waiting period; and (3) the probability that contact with an infected animal will result in transmission of the rabies virus. Given the infectious nature of rabies, it was assumed that contact with an infected animal will result in infection; this is considered a worst-case scenario. Hence, assuming that infection follows a binomial process, the probability that an animal will become infected after k contacts during the period between vaccination and entry into UK can be determined as

$$B = 1 - (1-p)^{kd}, \tag{9}$$

where p is the prevalence of rabies in Turkey, k is the average number of contacts with wild or domestic animals per day and d is the number of days before entry. The prevalence can be estimated by determining the mean number of animals that are clinically infected in Turkey on a particular day (λ_w) divided by the animal population. It was estimated that there was a total of 333 infected animals (40 wild animals and 293 companion animals) during the 2-year period 2006–2007 [8]. Therefore, the mean number of infected animals in Turkey per year was estimated, i.e. $n = 167$. The uncertainty about the mean number of clinically infected animals per day is thus

$$\lambda_w \sim \text{gamma}\left(\frac{167}{365}, 1\right). \tag{10}$$

The animal population of Turkey was ascertained by combining the data on the wild animal population [17], and the companion animal population as described earlier. As a result, it was estimated that there were about 4 032 242 wild and domestic animals in Turkey.

The average number of contacts (k) (i.e. an incident where transmission can occur) that a companion animal is likely to have with another animal on a random day was not available, therefore it was assumed [9] that the uncertainty of the parameter would be described by a pert distribution with 0 as the minimum, 1 as the most likely and 2 as the maximum. The number of days that a pet can become infected after vaccination but before entry into the UK (d) is dependent on compliance with PETS or EUPMP. For companion animals that are in complete compliance with PETS, $\text{EUPMP}_{\text{unlisted}}$ or $\text{EUPMP}_{\text{listed}}$, d is 211 days, 120 days or 20 days, respectively. For companion animals that are not in complete compliance, this time period was assumed to be 1 day. Furthermore, for an animal entering the UK via quarantine, d is 182 days, k is 0 contacts and p is the probability that an animal in quarantine is infected. The probability (B), therefore, that an animal becomes infected in quarantine is equal to zero.

Probability that a companion animal shows clinical signs after release (*SI*)

It is possible for a pet that is incubating the disease and not displaying clinical signs to enter the UK. The probability that an infected pet displays clinical signs after release into the UK is dependent on the time between infection and entry (t) and the mean incubation period (i_{p}). For companion animals that are in complete compliance with the scheme and are infected prior to vaccination t is equal to 212 days, 121 days, 21 days and 182 days for PETS, $\text{EUPMP}_{\text{unlisted}}$, $\text{EUPMP}_{\text{listed}}$ and quarantine, respectively. For companion animals that become infected after vaccination (i.e. vaccination failure), the time period is variable and depends on the day infection occurred. Due to the fact that infection is likely to occur on any day after vaccination and before entry, the day of infection can thus be described by a uniform distribution $U(1, 211)$ for PETS, $U(1, 120)$ for $\text{EUPMP}_{\text{unlisted}}$ and $U(1, 20)$ for $\text{EUPMP}_{\text{listed}}$. Consequently, t was estimated by subtracting the day of infection from 212 for PETS, from 121 for $\text{EUPMP}_{\text{unlisted}}$ and from 21 for $\text{EUPMP}_{\text{listed}}$. Data from the model developed for North America [9] was utilised to estimate i_{p} by fitting a lognormal distribution to naturally and experimentally occurring incubation periods as given by

$$i_{\text{p}} \sim \text{lognormal}(38{\cdot}12,\ 45{\cdot}59), \tag{11}$$

where 38·12 is the mean and 45·59 is the standard deviation of the combined studies. The fitted distribution did not account for dose dependencies due to the lack of data. The probability that an animal displays clinical signs after release (*SI*) was estimated using Monte Carlo simulation. A sub-model was run for 10 000 iterations and on each iteration a 1 result was obtained if $i_{\text{p}} > t$ otherwise a 0 resulted. The mean value from this sub-model was then equal to *SI*. For animals infected prior to vaccination *SI* is equal to 0·01 for PETS, 0·04 for $\text{EUPMP}_{\text{unlisted}}$, 0·56 for $\text{EUPMP}_{\text{listed}}$ and 0·02 for quarantine. Whereas for companion animals infected post-vaccination, *SI* is

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equal to 0·18, 0·30 and 0·83 for PETS, $EUPMP_{unlisted}$ and $EUPMP_{listed}$, respectively. For animals that are not in compliance, $SI = 0{\cdot}9997$.

Probability that an animal is checked at port (C)

It was assumed that all animals for each scheme are checked at the port of entry to ensure the correct documentation is provided, hence $C = 1$.

Probability that an animal passes import checks (θ)

An animal may be denied access to the UK due to unsatisfactory documentation. It was assumed that the pass rate would be similar for companion animals entering from Turkey compared to animals entering from European countries. Therefore, θ was estimated by using data (from Defra for 2000–2001) on the number of companion animals arriving from European countries that pass checks ($n = 19241$) and fail checks ($n = 2879$). The uncertainty for the probability that an animal passes documentation checks is thus

$$\theta \sim \text{beta}(19241 + 1,\ 22120 - 19241 + 1). \quad (12)$$

Estimating the risk

The risk for each scheme was assessed by (1) estimating the annual probability of rabies entering the UK (ψ) and (2) the number of years between rabies entry (η). It was assumed that each animal was independent from all other animals being imported and that each imported animal had the same probability of being infected. The probability of a random animal being infected upon entry and imported (Γ), which is scenario specific, was calculated by adding the probabilities associated with all infected pathways (Figs 2–4). Consequently, the annual probability of importing at least one infected companion animal is estimated as follows

$$\psi = 1 - (1 - \Gamma)^{\Omega}, \quad (13)$$

where Ω is the estimated number of companion animals imported per year. The number of imported companion animals via quarantine in 2006 and 2007 from Turkey was 52 and 69, respectively (Defra, 2008). There are no data on the number of companion animals that would be imported via PETS or EUPMP. However, since the implementation of PETS in the UK, eligible countries now import more companion animals to the UK than under the previous quarantine scheme. As such, two scenarios were considered: (1) there would be no increase in the number of animals imported via PETS or EUPMP compared to quarantine ($\Omega = 69$); and (2) the increase in importation levels via PETS and EUPMP would be 433% [9] which is the mean observed increase in importation from countries that became eligible for PETS ($\Omega = 299$). The number of years between rabies entry η, is determined by

$$\eta = \frac{1}{\Gamma\Omega}. \quad (14)$$

Model construction

The Monte-Carlo simulation, which has been developed using Microsoft Excel (Microsoft, USA) together with an add-in package @Risk version 4.5.2 (Palisade Corp., USA) was run for 50 000 iterations. This number of iterations was considered sufficient for convergence of the uncertain distributions associated with the probabilities in Figures 2–4. For each scheme, the mean probability, 5th and 95th percentiles were calculated. The 95th percentile represents the value at which the probability a random pet is infected upon entry is equal to or below with 95% certainty.

RESULTS

Probability of importing rabies per year

The annual probabilities of importing rabies via quarantine, PETS and EUPMP with varying levels of importation and compliance are outlined in Table 4. At the current level of importation and uncertain compliance, the annual probability is lower for quarantine ($2{\cdot}39 \times 10^{-5}$) than for PETS ($3{\cdot}47 \times 10^{-4}$), $EUPMP_{unlisted}$ ($4{\cdot}13 \times 10^{-4}$) and $EUPMP_{listed}$ ($8{\cdot}93 \times 10^{-4}$) with 95% certainty. However, if all companion animals are in complete compliance with the schemes, then the annual probability is higher for quarantine than the schemes. As may be expected, increasing the current level of importation by 433% increases the risk of rabies entry. This is highlighted by the fact that the annual probability is higher (at complete compliance) for PETS at an increased level of importation ($2{\cdot}53 \times 10^{-5}$), compared to PETS at the current level of importation ($5{\cdot}86 \times 10^{-6}$) with 95% certainty.

Estimating the number of years between rabies entries

Similar trends are observed for the number of years between rabies entries (Table 5) compared to the

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Table 4. *Annual probabilities of importing rabies via quarantine, PETS and EUPMP*

Scenario	Importation level	Compliance level	5th percentile	Mean	95th percentile
Quarantine	Current	n.a.	$8{\cdot}78 \times 10^{-6}$	$1{\cdot}56 \times 10^{-5}$	$2{\cdot}39 \times 10^{-5}$
PETS	Current	Uncertain	$5{\cdot}47 \times 10^{-5}$	$1{\cdot}74 \times 10^{-4}$	$3{\cdot}47 \times 10^{-4}$
PETS	Current	Complete	$9{\cdot}29 \times 10^{-7}$	$2{\cdot}60 \times 10^{-6}$	$5{\cdot}86 \times 10^{-6}$
PETS	Increase	Uncertain	$2{\cdot}37 \times 10^{-4}$	$7{\cdot}51 \times 10^{-4}$	$1{\cdot}50 \times 10^{-3}$
PETS	Increase	Complete	$4{\cdot}02 \times 10^{-6}$	$1{\cdot}12 \times 10^{-5}$	$2{\cdot}53 \times 10^{-5}$
$EUPMP_{unlisted}$	Current	Uncertain	$7{\cdot}45 \times 10^{-5}$	$2{\cdot}15 \times 10^{-4}$	$4{\cdot}13 \times 10^{-4}$
$EUPMP_{unlisted}$	Current	Complete	$3{\cdot}62 \times 10^{-6}$	$8{\cdot}70 \times 10^{-6}$	$1{\cdot}66 \times 10^{-5}$
$EUPMP_{unlisted}$	Increase	Uncertain	$3{\cdot}22 \times 10^{-4}$	$9{\cdot}32 \times 10^{-4}$	$1{\cdot}78 \times 10^{-3}$
$EUPMP_{unlisted}$	Increase	Complete	$1{\cdot}57 \times 10^{-5}$	$3{\cdot}77 \times 10^{-5}$	$7{\cdot}19 \times 10^{-5}$
$EUPMP_{listed}$	Current	Uncertain	$3{\cdot}27 \times 10^{-4}$	$5{\cdot}80 \times 10^{-4}$	$8{\cdot}93 \times 10^{-4}$
$EUPMP_{listed}$	Current	Complete	$2{\cdot}96 \times 10^{-4}$	$5{\cdot}21 \times 10^{-4}$	$7{\cdot}98 \times 10^{-4}$
$EUPMP_{listed}$	Increase	Uncertain	$1{\cdot}41 \times 10^{-3}$	$2{\cdot}51 \times 10^{-3}$	$3{\cdot}86 \times 10^{-3}$
$EUPMP_{listed}$	Increase	Complete	$1{\cdot}28 \times 10^{-3}$	$2{\cdot}25 \times 10^{-3}$	$3{\cdot}45 \times 10^{-3}$

PETS, Pet Travel Scheme; EUPMP, European Union Pet Movement Policy.

Table 5. *Number of years between rabies entry via quarantine, PETS and EUPMP*

Scenario	Importation level	Compliance level	5th percentile	Mean	95th percentile
Quarantine	Current	n.a.	41 851	70 608	113 935
PETS	Current	Uncertain	2879	7967	18 277
PETS	Current	Complete	170 721	529 029	1 076 001
PETS	Increase	Uncertain	665	1841	4223
PETS	Increase	Complete	39 447	122 238	248 621
$EUPMP_{unlisted}$	Current	Uncertain	2423	6122	13 428
$EUPMP_{unlisted}$	Current	Complete	60 163	142 771	276 444
$EUPMP_{unlisted}$	Increase	Uncertain	560	1414	3103
$EUPMP_{unlisted}$	Increase	Complete	13 901	32 989	63 875
$EUPMP_{listed}$	Current	Uncertain	1120	1896	3062
$EUPMP_{listed}$	Current	Complete	1252	2102	3376
$EUPMP_{listed}$	Increase	Uncertain	259	438	708
$EUPMP_{listed}$	Increase	Complete	289	486	780

PETS, Pet Travel Scheme; EUPMP, European Union Pet Movement Policy.

annual probability of importing rabies. PETS at complete compliance results in a lower risk of importing rabies at both current level of importation (1 076 001 years) and increased level of importation (248 621 years) compared to quarantine (113 935 years) with 95% certainty. Furthermore, $EUPMP_{unlisted}$ at current importation level and complete compliance results in a lower risk (276 444 years) than quarantine with 95% certainty. All other scenarios result in an increased risk of importing rabies compared to quarantine. In the worst-case scenario, infection is imported at least once every 259 years (with 95% certainty) by $EUPMP_{listed}$ at an increased level of importation and uncertain compliance.

DISCUSSION

Currently, companion animals from Turkey enter the UK via 6 months quarantine. However, Turkey is being considered for inclusion in the list of third countries in Annex II of EU Regulation 998/2003 [6] and, in the longer term, possible inclusion into the EU, which would result in pet owners having the option to import their companion animals via PETS. If the UK were to harmonize its movement regimen with that applied in most other EU countries under EU Regulation 998/2003, $EUPMP_{unlisted}$ and $EUPMP_{listed}$ could replace quarantine and PETS, respectively. Based on the model assumptions, there is an increased risk of the rabies virus entering the UK

https://doi.org/10.1017/S0950268809991221 Published online by Cambridge University Press

by importing companion animals via PETS and EUPMP, assuming uncertain compliance, compared to quarantine and due to the less stringent rules of $EUPMP_{listed}$. Full compliance and stringent import rules are important as Turkey has epizootic rabies in terrestrial mammals (Fig. 1), particularly in dogs in urban areas [7]. In 2007, for example, over 300 cases of rabies were reported in terrestrial mammals in Turkey, of which 165 cases were in domestic dogs [8]. The number of rabies cases that are not reported in Turkey is unknown, thus a higher prevalence than estimated previously is possible which would increase the risk of rabies entering the UK. It was considered important to include the risk not only from infected companion animals that are incubating the disease but also from unprotected companion animals that contact infected wildlife or other infected companion animals and acquire infection during the waiting period prior to entry.

The risk of importing rabies via cats and dogs from Turkey, that enter through quarantine, PETS or EUPMP was estimated by developing a QRA model which is based on a previous model developed for North America [9]. A number of assumptions were made due to the lack of available data. These include uncertainty associated with the estimated number of observed infected companion animals, vaccine usage, companion animal and wild animal populations, compliance with the schemes and uncertainty with the number of imported companion animals.

The estimate of risk in this model is influenced by the importation level and degree of compliance for each scheme. The model does not consider that compliance between the schemes may vary depending on the time period for entering the UK; i.e. if the time period for entering the UK decreases, then compliance may increase. PETS and $EUPMP_{unlisted}$ (at the current level of importation) presents a lower risk than quarantine if pet owners fully comply with the scheme by having their companion animals' microchipped, vaccinated and serologically tested. Furthermore, the results of PETS suggest a very low risk given current PETS regulatory measures. If $<100\%$ compliance is assumed, as shown in Figures 2 and 3, PETS and $EUPMP_{unlisted}$ (at the current level of importation) present a higher risk than quarantine. In the worst-case scenario, which is by $EUPMP_{listed}$ at an increased level of importation and uncertain compliance, the annual risk of rabies entry can be considered low (at least 259 years between rabies entries with 95% certainty). The overall result of the model suggests that the risk of rabies entering the UK from Turkey is very low. The result is consistent with the fact that from 2006 to 2007 there was a total of 121 companion animals (Defra, 2008) imported from Turkey via quarantine to the UK without an incident of rabies occurring.

In a previous, more general approach for an assessment of the risk of rabies introduction into the UK, Ireland, Sweden and Malta, requested by the European Commission [18, 19], serological testing was shown to be only beneficiary for risk reduction when waiting periods exceeded 100 days. As such, serologically testing companion animals is favourable for schemes such as PETS and $EUPMP_{unlisted}$ and not for $EUPMP_{listed}$, where the waiting period may at least be 21 days. However, it can be concluded that having a long waiting period and serologically testing companion animals in the schemes will decrease the probability of importing rabies into the UK. This is because a waiting period that is greater than the incubation period of the rabies virus will allow clinical signs to be observed.

European countries considered free of rabies sporadically report imported cases of rabies in cats, dogs and other domestic animals. In most of these cases, affected animals are unvaccinated puppies or young dogs that are illegally transported from enzootic areas via illegal routes (as highlighted in italic in Figs 3 and 4) [18]. For example, in Germany, rabies was diagnosed in a vaccinated puppy imported from Azerbaijan in 2003 [20]. Recently, two cases of imported canine rabies smuggled from Morocco and The Gambia, respectively, to the Brussels area were reported within a 6 months interval of which one was further moved into France [21]. In 2008, a rabies-infected dog was illegally transported into France from Morocco via Spain which caused secondary cases in dogs and led to intense epidemiological investigations [22]. In none of these cases were the EU regulations for pet movement adhered to and the incidents in France, specifically, led to the country losing its rabies-free status in 2008. In contrast, a puppy with rabies was imported into the UK from Sri Lanka in 2008 and identified as infected in quarantine [11]; hence the UK remains officially rabies-free. Therefore, it is important to highlight the need for ongoing awareness among travellers, for high vigilance at customs control and for adequate rabies surveillance for any companion animals with clinical signs indicative of rabies.

https://doi.org/10.1017/S0950268809991221 Published online by Cambridge University Press

ACKNOWLEDGEMENTS

The authors wish to thank Dr Nicholas Johnson and Balazs Toth for helpful comments and for critical reading of the manuscript. This work was supported by a grant from the UK Department for Environment, Food and Rural Affairs (Defra grant SV3500).

DECLARATION OF INTEREST

None.

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