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Behavioural responses to perceived risk of tick-borne encephalitis: Vaccination and avoidance in the Baltics and Slovenia

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Summary Tick-borne encephalitis (TBE) incidence increased markedly in the Baltics and Slovenia in the early 1990s, but then declined again in some places. Our analyses of temporal and spatial data on TBE incidence and vaccination revealed that over 1970—2005 up-take of vaccination varied in both time and space according to incidence, i.e. was apparently responsive to perceived risk. Since 1999, however, decreases in incidence in many counties within each country have far exceeded vaccination rates or immunity through natural exposure, and in Latvia and Lithuania these changes are correlated with previous incidence. Survey data on human activities in Latvia revealed that people in socio-economic groups whose behaviour put them at highest risk of exposure to ticks in forests, including people with lower education and lowest incomes, are least likely to be vaccinated. We conclude that risk avoidance through changing human behaviour has driven incidence-dependent decreases in TBE infection, but targeted vaccination campaigns could provide more secure protection.

Introduction

Epidemiologists increasingly recognize that human behavioural responses to perceived risk of infection are important in determining epidemic patterns [1]. The viral zoonosis tick-borne encephalitis (TBE) is an excellent system within which to explore this because exposure to infected ticks, mainly in forest habitats, can be reduced

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or avoided. Alternatively, safe and up to 96—99% effective vaccines may be deployed [2]: in Europe 'FSME Immun™' is produced by Baxter [formerly Immuno] using an Austrian isolate (strain Neudoerfl), and 'Encepur™' is produced by Novartis [formerly Chiron, formerly Behring] using a German isolate (strain K23), and a Russian vaccine is produced by Virion, Tomsk and the Institute of Polyomyelitis and Viral Encephalitis, Moscow. Nevertheless, TBE incidence increased markedly in most countries during the 1990s. With no specific treatment, it is one of the most serious vector-borne infections of humans in many parts of Europe, Russia and some parts of northern Asia; the Western virus subtype in Europe causes a ca. 1% case fatality rate, long recovery processes, neurological sequelae and severely decreased quality of life [3,4].

For vector-borne zoonoses, where humans do not play a role as natural amplifying hosts, there is a simple relationship between the percent vaccination in the human population and the percent reduction in incidence of infection as long as conditions are homogenous and risk factors do not change. This is well illustrated in Austria (Fig. 1) where ca. 85% reduction in annual TBE cases from ca. 300—700 in 1975—1982 to 40—100 in 1998—2005 was achieved by improving the vaccination coverage of the at-risk population to nearly 90% [2]. This is exceptional; vaccination in other European countries, including Switzerland, Sweden, and the Czech Republic, rarely exceeds ca. 10% [2,5—7]. Populations, however, are rarely homogenous. The public health impact of even a modest degree of vaccination will be disproportionately increased if it is targeted correctly at people who are at high risk due to geographic location or work and leisure activities. Conversely, vaccinating people who are not at risk is wasteful and may also undermine confidence in the vaccine if the population impact is less than predicted. Knowing who is most at risk and who is least likely to use vaccines will improve targeting, and also throw light on behavioural responses to perceived risk.

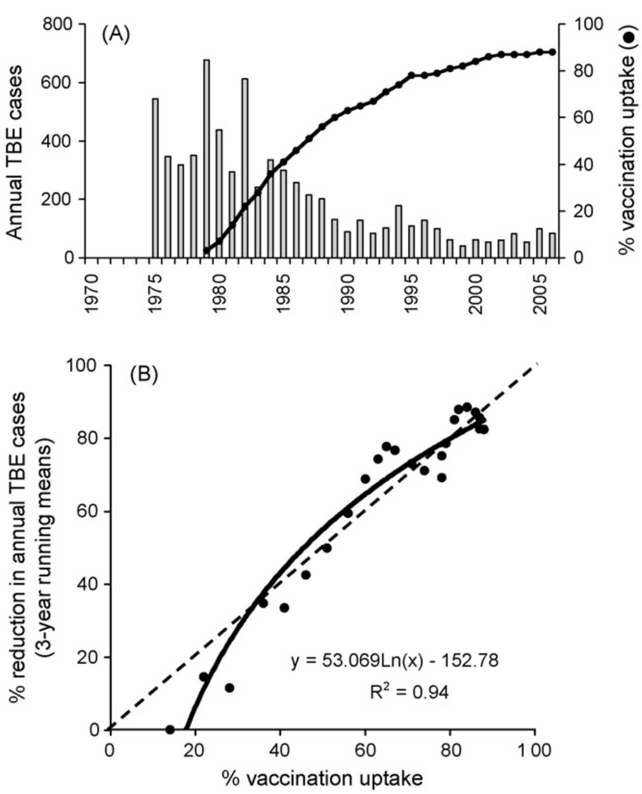

Figure 1 (A) The decrease in annual number of cases of TBE in Austria reflects the increased uptake of at least one dose of vaccine by the population. (B) The percent reduction in annual TBE case numbers (smoothed as 3-year running means) relative to mean levels in 1975—1979 equalled the percent vaccination uptake. The dashed line indicates parity. Data reproduced with permission of Pamela Rendi-Wagner.

In the Baltic States (Estonia, Latvia and Lithuania) and Slovenia, TBE incidence showed a particularly marked, but spatially variable, upsurge to reach the highest incidence levels (18—54 cases per 100,000 population) in Europe by the mid 1990s [8,9]. In some areas, incidence then declined equally sharply. In this paper we examine the reciprocal relationships, both temporal and spatial, between vaccination up-take and TBE incidence in these countries. We also analyse socio-economic indicators of individual behaviour associated with exposure to ticks, and of the probability of being vaccinated. Altogether, the results highlight the influence of human behaviour in determining, and thereby potentially avoiding, the risk of infection.

Data and methods

TBE incidence and vaccination

Annual case numbers of TBE in each 'county' (admin level 1) of Estonia, Latvia, Lithuania and Slovenia, based on serological confirmation of all notified cases, mandatory from the 1970s to the present, were provided by each national Public Health Institute. These were converted to incidence per 100,000 of the population.

The same Public Health Institutes also provided official data, based on doctors' returns, on the number of people vaccinated against TBE, or the number of vaccination doses utilized. Complete vaccination data for individual counties were available only for Latvia (from 1999) and Lithuania (from 2001). From the early 1970s the Russian vaccine was used; this offers good protection, but with more side-effects, so was gradually replaced by the more expensive Austrian and German vaccines after the end of Soviet rule.

The basic vaccination protocol comprises three initial doses at approximately 1—3 and 9—12 month intervals, followed by a booster every 3—5 years [2]. The longest series of data on third primary and booster doses are available from the 1970s, but data on first and second primary doses are available only from 1997 for Latvia and Lithuania, 2001 for Slovenia and not at all for Estonia. The annual number of third primary doses indicates the number of people completing the vaccination course for the first time. In addition, where possible, the number of people fully protected by vaccination in any given year was conservatively estimated as the total number of third primary and booster immunisations in that year and the previous 2 years, plus the number of second primary doses for that year, as a high degree of protection is achieved in the year following two primary doses [2,10].

For Latvia, the official immunisation statistics were compared with data from three health surveys in which people were asked about the timing of their most recent vaccination ''jab'' against TBE: (1) the Finbalt (Finnish-Baltic) surveys in 1998, 2000, 2002 and 2004 [11—15]; (2) the Central Statistical Bureau of Latvia (CSB) survey in 2003 [16]; and (3) the Marketing and Public Opinion Research Centre SKDS survey in August 2001 at the request of the Latvian Ministry of Welfare [17]. For the present purposes, numbers of respondents who reported their last vaccination within the past year or 1—3 years previously were compared with those protected against TBE according to the official statistics.

Individual risk factors

The SKDS survey data, which refer specifically to Latvia, were also used to identify factors associated with differential individual risk of infection through entering tick-infested habitats and undertaking different activities there, and with the probability of being vaccinated against TBE. The statistical significance of differences between variables was tested using Pearson χ^2 test [18]. Crude odds ratios (OR) (not shown below) were calculated using binary logistic regression analysis in SPSS 14.0 (ordered logit regression was used in the case of an ordered dependent variable) to assess the association between each predictor variable and dependent variable [19]. Adjusted OR using multivariate binary logistic and ordered logit regressions were calculated to explore the independent impact of predictor variables while controlling for the most likely confounding factors. Of the many factors investigated (gender, age, nationality, education, employment, income, household size, size of settlement, place of residence and forest visit habits), only those revealed by analysis to be significant predictors are presented below (more details in Šumilo, 2007, DPhil. Thesis, Oxford University).

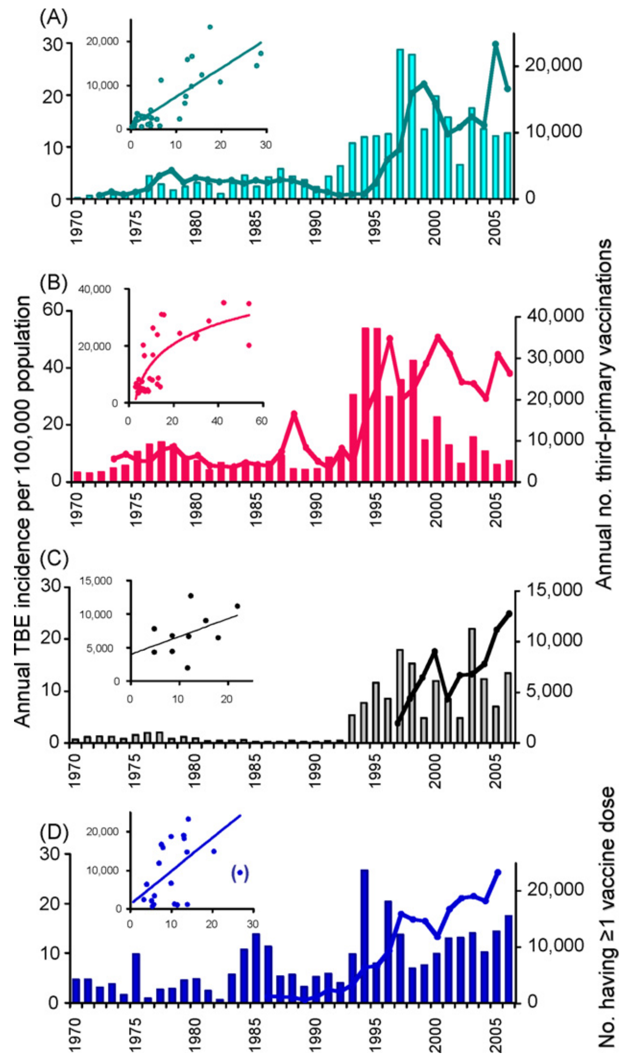

Figure 2 Changes in the annual incidence of TBE (bars) and third-primary vaccination doses (line) in Estonia (A), Latvia (B), and Lithuania (C), or at least one vaccination dose in Slovenia (D). Insets show correlations between TBE incidence in year *t* (*x*-axis) and vaccination doses in year $t+2$ (*y*-axis); R^2 values are 0.68, 0.59, 0.20 and 0.23 for Estonia, Latvia, Lithuania and Slovenia (omitting 1 outlier), respectively.

Results and discussion

Vaccination rates: variation in time

Official statistics show an increase in the annual reported numbers of completed vaccination courses (third primary doses) from the mid 1990s that follows the increase in TBE incidence (Fig. 2). This is especially clear in Estonia and Latvia, where vaccination records over >30 years span the period of sharp increases in both TBE incidence and vaccination that coincided with political independence. During Soviet rule, when the state was responsible for immunisation against TBE, apart from some high-risk areas, generally only people in high-risk occupations (e.g. foresters) were vaccinated against TBE. After the collapse of the Soviet Union, as people slowly adapted to being responsible for their own health, uptake of privately funded vaccination remained low during the early 1990s, and then increased by an order of magnitude in Estonia and more than doubled in Latvia, after the increase in TBE. In Slovenia, vaccination also increased during the mid 1990s, and most sharply in 1997, at a time when TBE incidence became more consistently high.

The numbers of people who completed the primary vaccination course were most strongly correlated with TBE incidence 2 years previously in Estonia ($r=0.825$, $p<0.001$, $n=34$) and Latvia ($r=0.767$, $p<0.001$, $n=32$) (insets in Fig. 2). In Lithuania, where TBE infection and vaccination were rare until the early and late 1990s, respectively, a similar but statistically non-significant trend is seen ($r=0.450$, $n=10$). In Slovenia, the annual number of people who had received at least one vaccination dose (as recorded 1986—2000), equivalent to those who had received a second, third or booster dose (as recorded 2001—2005), was also related to TBE incidence 2 years previously, significantly so if the 1 year of exceptionally high TBE incidence is omitted ($r=0.484$, $p<0.05$, $n=19$).

These patterns indicate that people decide to seek vaccination in response to perceived risk due to notices of the variable annual number of TBE cases that are released in the media periodically during the tick season (calendar year *t*). Health professionals and vaccine distributors alert peo-

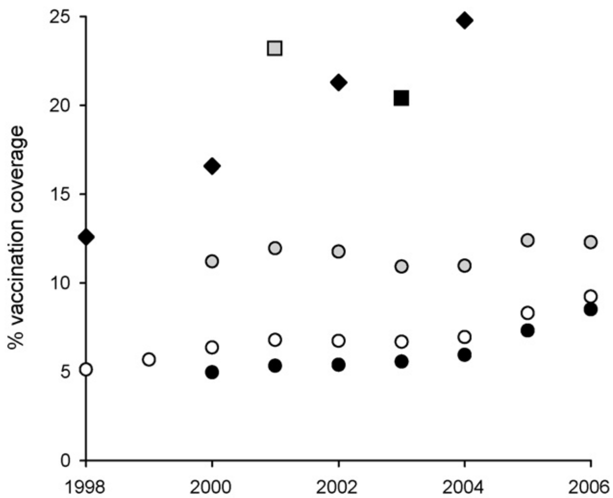

Figure 3 Percentage of adults in Latvia who had received at least one dose of vaccine against TBE in the previous 4 years according to the Finbalt (15—65 years) (diamonds), SKDS (18—74 years) (grey square) and CSB (15—74 years) (black square) health surveys; and adults (18 years and over) (black circles), children (grey circles) and total population (open circles) estimated to be fully protected by a course of vaccination according to official statistics.

ple to get vaccinated early in year $t+1$, before the start of the next tick season. Accordingly, demand for vaccination is highest in April, May and June [20] as seasonal tick activity increases. Anyone who starts the course then will receive the third vaccination in year $t+2$, approximately 1 year after the first 2 according to the recommended regime.

In Latvia, the relationship between perceived risk and protection is linear until 1998 ($r = 0.883$, $p < 0.001$, $n = 26$), but then becomes non-linear (logarithmic) as data for the past 6 years are included, due to a continuing high level of vaccination despite a marked decrease in TBE incidence from 1999 (Fig. 2B). Furthermore, from 1998 onwards, completion of the full vaccination schedule once started averaged 79%, reaching 100% in 2005. This may reflect increased awareness and vaccine uptake by all age groups following a campaign, started in 1998, to vaccinate children against TBE free of charge in some rural areas of high risk in Latvia [20]. As a result, according to official statistics at least ca. 51—60,000 of the nation's children (ca. 11—12.4% of the sub-adult population) were fully protected year-on-year during 2000—2006 compared with ca. 92,000 rising to ca. 158,000 adults (5—8.5%) (Fig. 3); this increase was due largely to greater numbers of adults returning for boosters. Vaccination reportage is more complete and accurate for children, however, with considerable under-reporting in the official statistics for adults apparent from the health monitoring surveys. In the series of Finbalt surveys, the proportion of adults (15—64 years) who reported having had at least one vaccination in the previous 4 years increased from 12.5% in 1998 to 25% in 2004, in line with the SKDS survey in 2001 (23%) and the CSB survey in 2003 (20%) (Fig. 3). These figures are not strictly comparable to, but will be higher than, official statistics because they include different age ranges (see legend; Fig. 3), and refer to any one dose of vaccine. Nevertheless, the survey figures indicate the upper limit of the proportion of the population seeking vaccination, and all figures reveal a rising trend.

Vaccination rates and changing TBE incidence: variation in space

Spatial variation in the uptake of vaccination within the Baltic countries also indicates a response to perceived risk. Mean TBE incidence during 1993—1998, when it had first increased and was highest throughout the region, was taken as the benchmark. The mean percentage of the population protected by TBE vaccination in each county during 2002—2005 (when all the necessary county-specific data in both Latvia and Lithuania are first available) increased significantly and non-linearly with TBE incidence (Fig. 4A). Not surprisingly, many of the counties in Latvia with high uptake of vaccination across the population during 2002—2005 were those whose children had been targeted in 1998—2002.

In Latvia and Lithuania, the incidence during 2002—2005 was positively correlated with the incidence during 1993—1998 in each county, but with slopes significantly less than one (Latvia, $t = 5.337$, $p < 0.001$, $n = 26$; Lithuania, $t = 2.485$, $p < 0.01$, $n = 44$) (Fig. 4B). This indicates a differential change in TBE incidence per county between 1993—1998 and 2002—2005, with the sign and magnitude of the change dependent on the mean incidence in 1993—1998. In Latvia, 22 of the 26 counties showed a considerable decrease in incidence, consistent with the national average decrease, with greater proportional decreases significantly associated with higher previous incidence. In Lithuania, even though there was an increase in mean TBE incidence nationally over this period, 13 out of the 44 counties showed decreases also significantly associated with higher previous incidence. No such incidence-dependent relationships apply to Estonia; 10 out of the 15 counties showed decreases statistically independent of previous incidence, although nationally there was no overall trend separable from three exceptional years, 1997 and 1998 (high) and 2002 (low) (Fig. 2). Slovenia showed the least change in TBE incidence per county over these past 13 years.

The two sets of relationships shown in Fig. 4 for Latvia and Lithuania inevitably lead to a significant correlation between the percentage vaccination rate and the reduction in TBE incidence in each county [21]. The magnitude of these decreases, however, was far greater than can be accounted for by vaccination rates, even allowing for under-recording by official statistics. In Latvia, the national mean TBE incidence decreased by 74%, far in excess of even the absolute maximum of ca. 25% protection by vaccination indicated by health surveys (see above and Fig. 3). In 12 Latvian counties and 3 Lithuanian counties incidence decreased by >70%, in 7 others in Latvia by >50% and in 5 others in Lithuania by >20%, despite much lower vaccination rates (Fig. 4A). Only two counties in Latvia and one in Lithuania showed a decrease approximately in line with local rates of vaccination coverage rather than an order of magnitude greater. In Estonia, TBE incidence decreased by 22—77% in 9 of the 15 counties, also far in excess of the likely local vaccination rates (no county-specific vaccination data available), given a national average protection rate of ca. 5%.

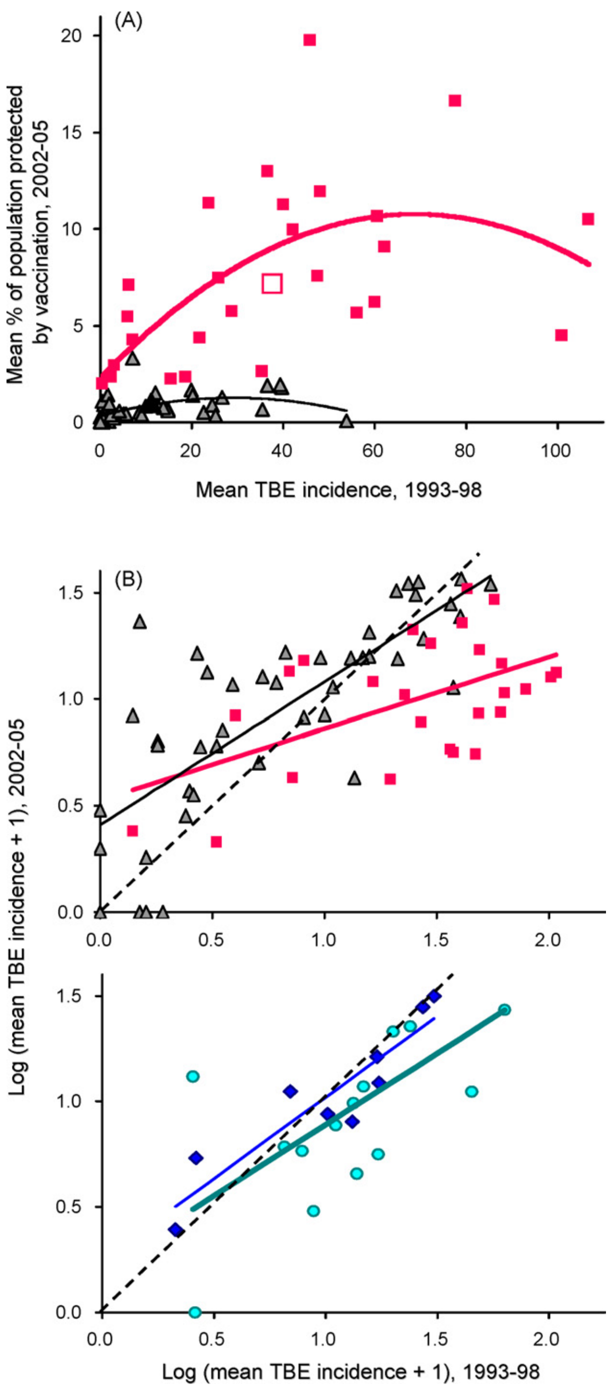

Figure 4 (A) The mean percentage of people officially reported as protected by vaccination during 2002—2005 (see text) in relation to the mean TBE incidence during 1993—1998 in each county in Latvia (squares, heavy line), Lithuania (triangles, light line), with national averages shown by large symbols. Latvia: $y = -0.0018x^2 + 0.247x + 2.286$, $R^2 = 0.362$, $p < 0.01$; Lithuania: $y = -0.0011x^2 + 0.064x + 0.338$, $R^2 = 0.250$, $p < 0.001$. (B) The relationship between mean TBE incidence in 1993—1998 and 2002—2005 in each county in (upper) Latvia and Lithuania (symbols as above), and (lower) Estonia (filled circles, heavy line) and Slovenia (diamonds, light line). Latvia: $b = 0.337$, $R^2 = 0.636$, $p < 0.001$; Lithuania, $b = 0.672$, $R^2 = 0.278$, $p < 0.001$; Estonia: $b = 0.679$, $R^2 = 0.363$, $p < 0.05$; Slovenia: $b = 0.770$, $R^2 = 0.850$, $p < 0.005$. Dashed line indicates slope of 1.

This discrepancy is even more marked considering that the vaccination campaign in Latvia was targeted at children [20]. Despite children (<18 years) making up approximately 23—19% of the population in 2000—2006, respectively [22], 44% of all recorded vaccinations in 2000 were given to children, declining steadily to 24% by 2006 as the campaign ended. Targeting was even more pronounced in rural communities, the comparable figures being 57% declining to 25% over the same period. Although it is a right and natural instinct to protect children from infection, these figures show that children were disproportionately protected, given that evidently they are not at disproportionately higher risk (Šumilo, 2007, DPhil. Thesis, University of Oxford). This will reduce the population impact of vaccination.

This analysis indicates that additional factors of much greater magnitude than vaccination are responsible for the recent decreases in TBE seen in many parts of the Baltic countries. No evidence exists to suggest that these factors involve the natural enzootic cycles of TBE virus. Sparse time series on tick populations in Latvia and Lithuania indicate increased tick abundance since the mid 1990s, possibly related to changing densities of important tick hosts (e.g. deer, wild boar) [23]. The mean infection prevalence of TBE in tick samples from Latvia was exceptionally and inexplicably high in 1995, but otherwise showed no variation from 1993 to 2002 consistent with TBE incidence [24]. Rather, as these putative factors appear to be responsive to TBE incidence, they are most likely to be of conscious human agency, such as awareness and avoidance through changing behaviour. Any effect of naturally acquired immunity does not alter this conclusion. Based on the ultra-conservative assumptions of (a) full protective immunity arising from any infection and (b) 99% of infections being asymptomatic and therefore unrecorded, and even ignoring the natural human death rate and recruitment of susceptibles into the population, TBE incidence in the estimated susceptible population in Latvia fell by 62% over the period being considered (Randolph, *unpublished analysis*).

Who is at greatest risk of TBE?

Identifying specific risk factors, and consequently the high-risk population groups, will improve explanations for changing TBE incidence and also allow more effective targeting of vaccination. Risk of exposure to TBE virus is associated with visits to forests as these are the primary habitat of *Ixodes ricinus* and *Ixodes persulcatus* ticks, which are the vectors and also the reservoir hosts of TBE virus [25]. Data for Latvia confirm that forest visitors are four to five times more likely to encounter ticks than those who do not enter forests (SKDS survey, analysed by Šumilo, 2007, DPhil. Thesis, Oxford University). Amongst respondents to the SKDS survey in Latvia, 69% (701/1022) of adults went to forests for leisure, food harvest or work during 2000 or 2001, and even though this was highest among rural dwellers (80%), a substantial percentage of town (71%) and even city (63%) dwellers had also visited forests. In general, younger adults were more likely than older people to visit forests, but age groups did not differ significantly in the frequency of their visits (Table 1). People more likely to make frequent visits

Table 1 Differences in likelihood of visiting a forest, visiting a forest at least once per month and being vaccinated against TBE, and main reasons for visiting forests, according to demographic and socio-economical groups in Latvia

Group	Visited a forest[a]	Visited a forest frequently[b]	Vaccinated against TBE[a]	Percentage of people giving the following main reasons for visiting forests[b]				
	Adjusted OR[c] (95% CI)[b]	Adjusted OR[c] (95% CI)[c]	Adjusted OR[d] (95% CI)[d]	A[e]	B[e]	C[e]	D[e]	χ^2 value[f] (d.f.)
Gender								**64.8 (3)*** **
Male	1.2 (0.8–1.6)	**1.5 (1.1–2.1)***	1.1 (0.8–1.6)	27	29	23	22	
Female	1.0 Ref	1.0 Ref	1.0 Ref	22	39	36	4	
Age								**34.4 (6)*** **
18–34	**2.2 (1.5–3.3)*** **	0.8 (0.5–1.2)	1.5 (0.9–2.3)	34	26	30	11	
35–54	**1.6 (1.1–2.3)***	1.1 (0.7–1.7)	**1.6 (1.0–2.5)***	18	36	34	12	
55 and older	1.0 Ref	1.0 Ref	1.0 Ref	17	47	23	13	
Nationality								13.3 (3)
Latvian	1.0 (0.7–1.3)	1.0 (0.7–1.4)	**1.4 (1.0–2.0)***	23	35	30	12	
Other	1.0 Ref	1.0 Ref	1.0 Ref	27	33	29	11	
Education level								**30.8 (6)*** **
Primary	1.0 Ref	**3.3 (1.7–6.4)** **	1.0 Ref	15	41	22	22	
Secondary	**2.6 (1.6–4.1)*** **	**1.9 (1.3–2.8)** **	1.6 (0.8–2.9)	22	35	31	12	
Higher	**2.1 (1.2–3.7)** **	1.0 Ref	1.8 (0.9–3.6)	37	29	29	5	
Occupation								**55.0 (15)*** **
Manager, etc.	1.5 (0.8–2.7)	1.1 (0.5–2.0)	1.4 (0.7–2.8)	28	33	29	11	
Manual worker	1.3 (0.7–2.4)	1.0 (0.5–1.9)	1.1 (0.5–2.1)	21	32	36	11	
Student	1.3 (0.5–3.3)	1.6 (0.6–4.1)	2.4 (0.9–6.1)	50	8	29	14	
Housewife	1.1 (0.4–2.9)	1.2 (0.5–3.5)	1.0 (0.4–3.0)	25	38	34	3	
Unemployed	1.3 (0.5–3.0)	1.3 (0.5–3.4)	0.4 (0.1–1.5)	11	48	24	17	
Pensioner	1.0 Ref	1.0 Ref	1.0 Ref	14	52	24	10	
Monthly income per household member								**48.1 (9)*** **
<43 LVL	0.7 (0.4–1.4)	**2.4 (1.3–4.3)** **	1.0 Ref	11	48	29	13	
43–84 LVL	**0.5 (0.3–0.9)***	1.6 (1.0–2.6)	1.6 (1.0–2.6)	26	35	27	12	
85–126 LVL	**0.5 (0.2–0.8)***	0.9 (0.5–1.7)	**1.9 (1.0–3.5)***	44	26	25	4	
>126 LVL	1.0 Ref	1.0 Ref	**4.8 (2.6–8.9)*** **	33	18	43	7	
Place of residence								**59.6 (6)*** **
Rural parish	**2.1 (1.4–3.2)*** **	1.3 (0.9–2.0)	1.0 Ref	16	40	24	20	
Town	**1.6 (1.1–2.4)***	1.2 (0.8–1.7)	1.0 (0.6–1.6)	17	39	29	15	
City	1.0 Ref	1.0 Ref	1.2 (0.8–1.8)	33	28	34	4	
TBE vaccinated								**28.9 (3)*** **
Yes	1.0 Ref	1.0 Ref	n/a	29	20	36	15	
No	**2.2 (1.6–3.1)*** **	1.0 (0.7–1.4)	n/a	21	41	27	10	
Forest visit 2000–2001								–
No	n/a	n/a	1.0 Ref	n/a	n/a	n/a	n/a	
Yes	n/a	n/a	**2.0 (1.3–2.9)*** **	n/a	n/a	n/a	n/a	
Frequency of forest visits								**117.6 (6)*** **
<Once a month	n/a	n/a	–	44	32	21	2	
>Once a month	n/a	n/a	–	18	41	35	6	
≥Once a week	n/a	n/a	–	14	28	30	28	

Statistically significant adjusted odds ratios (OR) and χ^2 values ($p < 0.05$) are highlighted in bold.

[a] Baseline total number for analysis = 1022.

[b] Baseline total number for analysis = 701.

[c] OR controlled for gender, age, income, and place of residence, as appropriate.

[d] OR controlled for gender, age, income, place of residence, nationality and education, as appropriate.

[e] A, Walk or recreation; B, collect mushrooms or berries; C, walk or recreation and collect mushrooms or berries; D, work or work and collect mushrooms or berries.

[f] Calculated using Pearson's χ^2 test. Significance level: $^{*}p < 0.05$; $^{**}p < 0.01$; $^{***}p < 0.001$.

include males (1.5 × females), those with lower educational achievements (3 × those with higher education), and those on the lowest incomes (2.4 × highest earners), controlled for gender, age and place of residence (Table 1).

The main reasons for entering forest habitats in Latvia are to collect berries or mushrooms (33% of 701 respondents); to combine collecting berries or mushrooms with walking or recreation (29%); simply for walking or recreation (23%); and either to work or both to work and collect berries or mushrooms (11%). These reasons vary amongst different demographic and socio-economic groups (Table 1). Mushroom and berry collecting is given as the principal reason by women, by older people, the less well educated, the unemployed and pensioners, people on lower incomes, those living in both rural parishes and towns (but not cities), those who are not vaccinated against TBE, and those who visit forests more frequently. Overall, of those people who visit forests frequently (see above), 73% of males and 85—89% of people with primary education and lowest incomes included food harvest in their activities. In contrast, the young, the well educated, the better paid and the less frequent visitors go to forests principally for walking and recreation. Overall, work is the least common purpose of going to forests, but was most common amongst men, the less well educated, rural residents and the most frequent visitors. While none of this is surprising, it does indicate that with falling socio-economic conditions, more people are likely to go to forests to gather wild food and to work, and *vice versa*.

Furthermore, people who went to forests to collect mushrooms or berries were significantly more likely to have suffered a tick bite in the year prior to the SKDS survey than those going to forests only for walking or recreation (OR adjusted for gender, age income, place of residence and frequency of forest visits = 2.3, $p < 0.01$), while those who worked in the forests were at greatest risk (adjusted OR = 2.8, $p < 0.05$). Since mushroom and berry yields vary between years depending on meteorological conditions [26,27], the frequency of human visits to forests and associated exposure to ticks may also vary depending on the abundance of these natural resources. Mushrooms are thought to be most abundant after rainfall followed by warm weather. The number of weekends with dry weather and maximum air temperature above 15 °C following a rainy week differed between 2002 and 2003. During 2002, there was only one such weekend in the first week of July before a particularly dry and hot August, compared with six during 2003, and all seven weekends coincided with dekads when peak numbers of ticks were brought to the State Public Health Agency (Fig. 5A). The weather on three other weekends in August or September 2003 when >100 ticks were removed from humans did not match these conditions exactly, but September was warmer in 2003 than in 2002, which may have encouraged continuing outdoor activity. Although these data are not conclusive, they are highly suggestive that the risk of tick bite between April and October depends on varying human activities in tick habitats, independent of the seasonal patterns of tick activity (Fig. 5B).

Such behaviour can change through time and may even be purposefully modified in response to perceived risk. Indeed, 35% of SKDS respondents reported going to forests less frequently during 2000—2001 than 5 years previously, with only 15% going more often. This was true of all demographic and socio-economic groups apart from those who were unemployed in 2000—2001, 35% of whom went more often, and those who worked in forests or visited once or more per week, 32—39% of whom went more often and only 15—19% less often. Thus, the majority of the population, albeit not the groups at highest risk, changed their behaviour in ways consistent with the decreased TBE incidence in Latvia from 1999 onwards. Any such trend, however, may be relaxed or

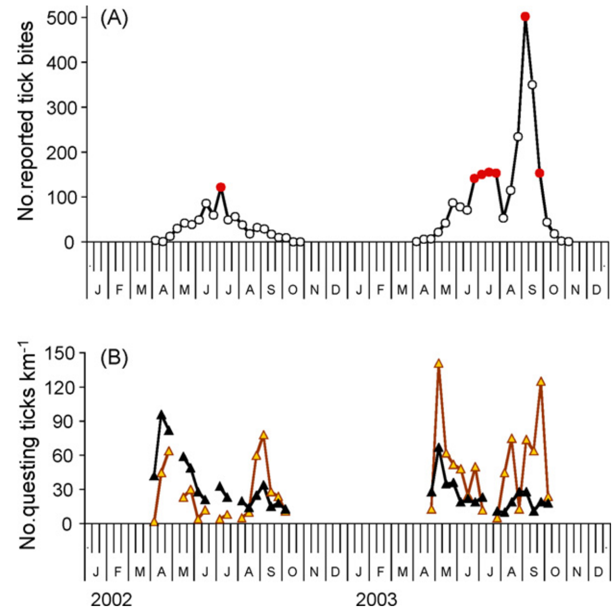

Figure 5 (A) The number of tick bites reported to the State Public Health Agency in Riga, Latvia in each dekad from January 2002 to December 2003. Filled dots mark the dekads that included rain-free weekends with mean maximum air temperatures above 15 °C and heavy rainfall in the preceding week. (B) Corresponding dekadal numbers of ticks (nymphs, open triangles; adults, closed triangles) collected at the Tireli monitoring site, Riga county, Latvia.

suddenly reversed in response to other factors, for example an exceptional and prolonged mushroom season such as occurred in the Czech Republic in 2006.

Who is most likely to seek vaccination against TBE?

The only sure means of protection in the face of fluctuating conditions is vaccination. This requires that constraints on individuals wishing to be vaccinated be recognised and alleviated. In general, people who visit forests are more likely to be vaccinated against TBE than those who do not (Table 1), which suggests, not surprisingly, that they are aware of ticks and recognise the risk of TBE. Interestingly, native Latvians were more likely than other nationals to be vaccinated; a higher percentage of other nationals thought that vaccination could cause health problems or was not effective [17]. Males and females did not differ, but vaccination was significantly less likely among people on lowest incomes (associated with lowest levels of education), even though these socio-economic groups were the most likely to visit forests frequently and to engage in the higher risk activity of mushroom or berry collecting (see above).

Conclusions

TBE epidemiology is a highly dynamic system, with increases and decreases due to an increasingly understood and quantified proposed nexus of biological and socio-economic factors [28]. In the Baltic States and Slovenia, both the number of TBE cases and the number of vaccinations increased during the 1990s, the latter apparently in response to the former, presumably due to increasing perceived risk. In Latvia, however, after the peak in the 1990s, TBE incidence decreased markedly in almost all counties (although nationally it is still amongst the highest in Europe at 10 cases per 100,000 over the past 4 years). In Lithuania, where national incidence increased, and Estonia, where there was no trend, incidence nevertheless also decreased markedly in some counties while increasing in others. These reductions are too great to be due to improved vaccination rates or naturally acquired immunity alone. The fact that the observed changes were incidence-dependent in Latvia and Lithuania suggests strongly that other human behavioural responses were the cause. It is as yet impossible to say why this pattern is not seen in Estonia or Slovenia. In these two countries, the much more modest increase in TBE incidence from 1993, related to the lesser socio-economic crisis that accompanied political transition [23], possibly indicates less potential for a reversal of high risk behaviour. The influence of human behaviour in determining, and thereby potentially avoiding, the risk of infection, adds complexity and instability to the spatio-temporal dynamics of this disease system.

The evidence from Latvia of the importance of socio-economic conditions in determining contact with tick-infested habitats, and the patterns of existing vaccination practices, emphasize the need for targeting to improve vaccination campaigns. Furthermore, those whose activities put them at greatest risk are also apparently deterred from vaccination by low incomes, suggesting that TBE vaccine needs to be made more accessible to people who are constrained by their socio-economic circumstances from reducing their exposure to ticks. Under a wide range of economic conditions, however, inadequate, static and even declining vaccination coverage in the face of increased risk of TBE infection is common throughout Europe, e.g. Switzerland, Sweden, the Czech Republic and parts of Russia [2,5,6,29].

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