M25 Junction 10/A3 Wisley Interchange

TR010030

9.84 Applicant's Comments on Regena Coult's Deadline 6 submission

Rule 8(1)(c)(i)

Planning Act 2008

Infrastructure Planning (Examination Procedure) Rules 2010

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The Infrastructure Planning (Examination Procedure) Rules 2010

M25 junction 10/A3 Wisley interchange

Development Consent Order 202[x]

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Chapter Pages

1. Introduction

1.1.1 This document sets out Highways England’s comments on the document submitted by Regena Coult at Deadline 6 (3 April 2020). It responds to the points made within the following document submitted to the Examination by Regena Coult:

- REP6-026 – Written summaries of intended oral statements

1.1.2 Where issues raised within the submission have been dealt with previously by Highways England, a cross reference to that response or document is provided to avoid unnecessary duplication. The information provided in this document should, therefore, be read in conjunction with the material to which cross references are provided.

1.1.3 In order to assist the Examining Authority, Highways England has not provided comments on every point made by Regena Coult, including for example statements which are matters of fact and those which it is unnecessary for Highways England to respond to. However, and for the avoidance of doubt, where Highways England has chosen not to comment on matters contained in the response, this should not be taken to be an indication that Highways England agrees with the point or comment raised or opinion expressed.

2. Highways England’s comments on Regena Coult’s Deadline 6 submission

2.1.1 As explained in reference number REP1-020-63 of the Applicant’s comments on Written Representations [REP2-014], the biodiversity chapter of the Environmental Statement [REP4-023] assessed the impacts of the Scheme on the Conservation Verges as identified in the Surrey Road Verge Habitat Action Plan (as part of the Surrey Biodiversity Action Plan (Surrey Biodiversity Partnership, 1999): NB this BAP is no longer active). The citation for the Bolder Mere Conservation Verge, which is located on Old Lane (refer to CV005 on Figure 7.4 of Biodiversity Figures [APP-068] for location), notes that its biodiversity interest lies in its population of common toad (which it states is of county importance) and that it is a registered toad crossing.

2.1.2 It should be noted that common toads are not a specially protected species, and the driver for the proposed mitigation as set out in Section 4 of the Report of proposed Scheme changes [REP4a-004] is to mitigate for the increased impacts that the Scheme, in combination with other plans and projects, will have on the overall common toad population at the Bolder Mere Conservation Verge as a result of increased traffic on Old Lane.

2.1.3 Surrey County Council originally raised concerns about the impact of increased traffic on common toads in their relevant representation [RR-004]:

“The County Council are concerned that more trips will be attracted to Old Lane (as stated in para 7.7.3 and 7.10.23 of Highways England’s Volume 7.4 Transport Assessment Report) particularly as this passes through the Site of Special Scientific Interest and Old Lane is a County registered Toad Crossing so the County Council would ask how ecology, public safety, noise and air quality impacts will be mitigated? The County Council has been working with Surrey Amphibian and Reptile Group to understand the impacts caused by the increase in traffic in Old Lane and the upgrade to Elm Lane. Mitigation measures have been submitted to Highways England for consideration e.g. toad tunnels and amphibian type fencing be provided.”

2.1.4 In addition Regena Coult raised concerns in a relevant representation [RR-036]:

“Since part of this project is to work on Old Lane, which is an existing toad crossing, could this be an opportunity to build a toad tunnel? Old Lane is a fast road and dangerous for toad wardens to patrol at night. Many toads get killed there every year. If an amphibian tunnel was built there, this would mean a net gain for biodiversity. If you could build something to save amphibians' lives on that road for the long term it would be wonderful. Many thanks.”

2.1.5 Highways England took account of these concerns, and reviewed the PowerPoint that Surrey County Council provided, as stated in the quote above, taken from RR-004. This PowerPoint has been provided as Appendix A.1 in this response. This PowerPoint set out information confirming that common toads breed within Bolder Mere and the smaller pond on the opposite side of Old Lane. The PowerPoint raised concerns about the existing impassable barrier that the A3 forms, the impact of increased traffic on Old Lane and the possible effects on the change of access for Elm Lane.

2.1.6 In an email forwarded by Surrey County Council on 4 December 2019, the study on mortality and traffic volumes undertaken by Hels and Buchwald (Hels, T. and Buchwald, E (2001) The effect of road kills on amphibian populations. Biological Conservation 99 (331-340)) was used to demonstrate the increases in mortality predicted as a result of the increased traffic on Old Lane as a result of the operational Scheme (in combination with other plans and projects). This study has been provided as Appendix A.2 in this response. This study considered five species of amphibian, including common toad, and assessed their movement patterns over five breeding seasons to answer two questions:

- What is the probability of an amphibian getting killed when it crosses the road?
- What fraction of the amphibian populations get killed by traffic?

2.1.7 Hels and Buchwald’s study quantified the mortality rates for different traffic volumes and was considered to be a relevant reference for determining the increased mortality predicted for Old Lane as a result of the Scheme, based on the expected increase in traffic. Based on this study, it is estimated that an increase of an AADT from 4,735 to 9,433 vehicles on Old Lane, as predicted in

2037, could result in an increase in common toad mortality from approximately 60% to over 70%.

2.1.8 Due to the predicted increases in traffic on Old Lane, two toad underpasses (tunnels) with 150 m of associated amphibian fencing were proposed in Change 2 of the Report on proposed Scheme changes [REP4a-004]. The total length of the potential dispersal route along Old Lane (as shown in the PowerPoint provided by Surrey County Council) is just under 800 m, with the key dispersal area being located between the two breeding ponds (where the proposed underpasses are located), due to toads dispersing in both directions along this section. Therefore, it is considered that the total protection of 150 m of Old Lane in this key location between the two breeding ponds will reduce the mortality along Old Lane to at, or below, pre-scheme levels.

2.1.9 The PowerPoint provided by Surrey County Council also raised concerns about Elm Lane, but concluded that it may not be feasible to provide tunnels and fencing for a road that services a small number of properties. This was the conclusion that Highways England also reached when considering the low levels of traffic anticipated.

2.1.10 It is not the responsibility of Highways England to remove all existing mortality for the toad population, but instead to mitigate for the impacts that the Scheme will cause. Highways England concluded that the proposed mitigation on Old Lane will be more than sufficient to mitigate the impact of the operational Scheme based on the predicted traffic models when considered in combination with other proposed plans and projects.

2.1.11 Highways England met with the lead ecologist from Surrey County Council (John Edwards) and two toad crossing volunteers (Regena Coult and Chris Campbell) on the 6 January 2020. The meeting minutes have been provided as Appendix A.3 in this response. During this meeting, the proposed toad underpasses where discussed. The feedback from the attendees suggested that although the proposed underpasses would provide some mitigation, it would be better for one to be moved to a natural depression on Old Lane (TQ 07892 58480) where the main migration occurs. The proposed location falls outside the red line boundary and would need to be implemented under a separate agreement with Surrey County Council. John Edwards confirmed that Surrey County Council would be willing to support this.

2.1.12 In the meeting, it was also stated by Regena Coult that the number of underpasses should be increased to three along Old Lane and one on Elm Lane. Chris Campbell emailed on the 27 February 2020 to confirm that should resources allow one additional underpass to the proposed two underpasses outlined in the Report on proposed Scheme changes [REP4a-004], then *‘the priority should be the crossings in Old Lane, simply due to the volumes of traffic being multiple levels greater than in Elm Lane and the long history of significant numbers of amphibians including toads crossing Old Lane’.*

2.1.13 Highways England is currently in discussions with Surrey County Council about the possibility of a separate agreement allowing one of the proposed underpasses on Old Lane (and associated fencing) to be moved to the location of the natural depression on Old Lane (outside the red line boundary) as specified in the meeting on the 6 January 2020, and also the possibility of providing a third underpass along Old Lane.

2.1.14 In addition to mitigating for the increased mortality to the population of common toads on the Bolder Mere Conservation Verge resulting from the operational Scheme in combination with other proposed plans and projects, there are large amounts of habitat creation and enhancement resulting from the Scheme. These include heathland creation, woodland enhancement and woodland planting within the SPA compensation land, SPA enhancement areas and replacement land. There are also habitat improvements proposed for the lake margins of Bolder Mere and a proposed green bridge (subject to designated funding) to link Ockham Common and Wisley Common. These measures will improve biodiversity and will be of benefit for amphibian and reptile populations throughout the wider Scheme.

2.1.15 In Ms Coult's written summary of intended oral statements [REP6-026], five pathways for impacts on the population of common toads are listed:

- The potential for toads to be destroyed during the ground investigation and construction phase;
- The widening of the A3 has three negative effects: a) habitat loss, b) road kill and c) as the road extends into the lake there is increased risk of run-off of contaminants into Bolder Mere;
- The increased traffic of Old Lane, resulting in increased road kill
- The effect of the new Elm Lane, resulting in a) habitat loss b) habitat fragmentation c) road kill;
- The effect of the new section of Wisley Lane, within the toad catchment area, resulting in a) habitat loss, b) habitat fragmentation c) road kill

2.2 The potential for toads to be destroyed during the ground investigation and construction phase

2.2.1 As committed to in paragraph 7.10.11 of the Biodiversity chapter of the Environmental Statement [REP4-023] Precautionary Measures of Working (PMW) will be put in place during construction to minimise risks to individual animals of protected species. Although common toads are not a protected species, they will also be protected by PMWs as stated in paragraphs 7.10.17 and 7.11.34 of the Biodiversity chapter of the Environmental Statement [REP4-023].

2.2.2 Further details of the specific mitigation for the common toad population of Bolder Mere Conservation Verge are outlined in Table G1 on page 74 of the Outline CEMP [REP4-033].

2.2.3 A PMW was also put in place for the ground investigation works, which were carried out from May 2019 to February 2020 outside the DCO process. Works within the Ockham and Wisley Commons Site of Special Scientific Interest (SSSI) were carried out under assent by Natural England.

2.3 The widening of the A3

2.3.1 The A3 is considered to be an existing barrier to toad movement due to the number of lanes, high speeds and large volumes of vehicles. The Scheme will not worsen the existing situation for amphibian dispersal across the A3 as it is already considered to be impassable.

2.3.2 The impacts of the Scheme, including the loss of habitats, is considered in the impact assessment in Section 7.11 of the Biodiversity chapter of the Environmental Statement [REP4-023] for a number of receptors, including Bolder Mere Conservation Verge, common reptiles, sand lizards and great crested newts. Large amounts of habitat creation and habitat enhancement are being undertaken as a result of the Scheme, and these will provide positive benefits to the reptiles and amphibians that occur within the footprint of the Scheme.

2.3.3 As outlined in Table G1 on page 78 of the Outline CEMP [REP4-033], there will also be beneficial habitats improvements to improve lake margins at Bolder Mere as part of the mitigation package and these will also benefit amphibians that breed within these margins.

2.3.4 As outlined in Table G1 on page 79 of the Outline CEMP [REP4-033], the mitigation in place will reduce the pollutant load in to Bolder Mere and is expected to improve lake water quality.

2.4 Increased traffic on Old Lane

2.4.1 This has been discussed above. The proposed mitigation measures will mitigate for the impacts resulting from the Scheme in combination with other proposed plans and projects but will not fully remove the existing levels of toad mortality resulting from the current road usage.

2.5 The effect of the new Elm Lane

2.5.1 Elm Lane will be a minor access road for 19 properties and will be subject to low levels of daily traffic movement, resulting in low levels of mortality predicted.

2.5.2 There will be no raised kerbs or other obstructing features on this single lane access road, and Elm Lane will not form a barrier for dispersal.

2.5.3 As the majority of traffic uses Old Lane, rather than Elm Lane, where the Bolder Mere Conservation Verge is located (refer to CV005 on Figure 7.4 of Biodiversity Figures [APP-068]), then the mitigation has appropriately been focused on Old Lane.

2.5.4 The proposals for Old Lane will mitigate for the impacts on the Bolder Mere Conservation Verge and its associated common toad population, and further mitigation on Elm Lane is not necessary.

2.6 The effect of the new section of Wisley Lane

2.6.1 As explained in 2.4.1 on page 19 of Highways England's response to the ExA's second written questions [REP5-014], mitigation measures are proposed to maintain the permeability of Wisley Lane. The mitigation measures will be refined during detailed design but are likely to include environmentally sensitive drainage systems (that are amphibian and reptile friendly), a wide-span bridge over Stratford Brook allowing continuous riparian habitat and wildlife passage (e.g. amphibians, reptiles and badgers) under Wisley Lane at Stratford Brook, and an additional wildlife passage under the Wisley Lane diversion in Elm Corner SNCI.

2.7 Summary

2.7.1 Highways England is confident that the proposed toad crossings and associated fencing on Old Lane will provide sufficient mitigation for the predicted increases in mortality on the common toad population of Bolder Mere Conservation Verge resulting from the Scheme in combination with other proposed plans and projects. However, Highways England accepts that the repositioning of one of these toad crossings could further reduce the toad mortality on Old Lane.

2.7.2 Highways England is currently in discussions with Surrey County Council about the possibility of moving one of the proposed underpasses on Old Lane to the location specified in the meeting on the 6 January 2020, and also the possibility of providing a third underpass along Old Lane. Highways England will include all attendees from the meeting on 6 January 2020 in consultation on the refinement of the details of these underpasses during detailed design.

2.7.3 Highways England will have sufficient measures in place to mitigate for the impacts of the operational Scheme on the Bolder Mere Conservation Verge and its associated common toad population. However, there are also large amounts of habitat creation and enhancement resulting from the Scheme. These include heathland creation, woodland enhancement and woodland planting within the areas of SPA compensation land, SPA enhancement land and replacement land. There are also habitat improvements proposed for Bolder Mere and a proposed green bridge (subject to designated funding) to link Ockham Common and Wisley Common. These measures will be of benefit for amphibian and reptile populations throughout the wider Scheme.

Appendix A.1. Surrey County Council PowerPoint

BOLDERMERE A3 / OLD LANE

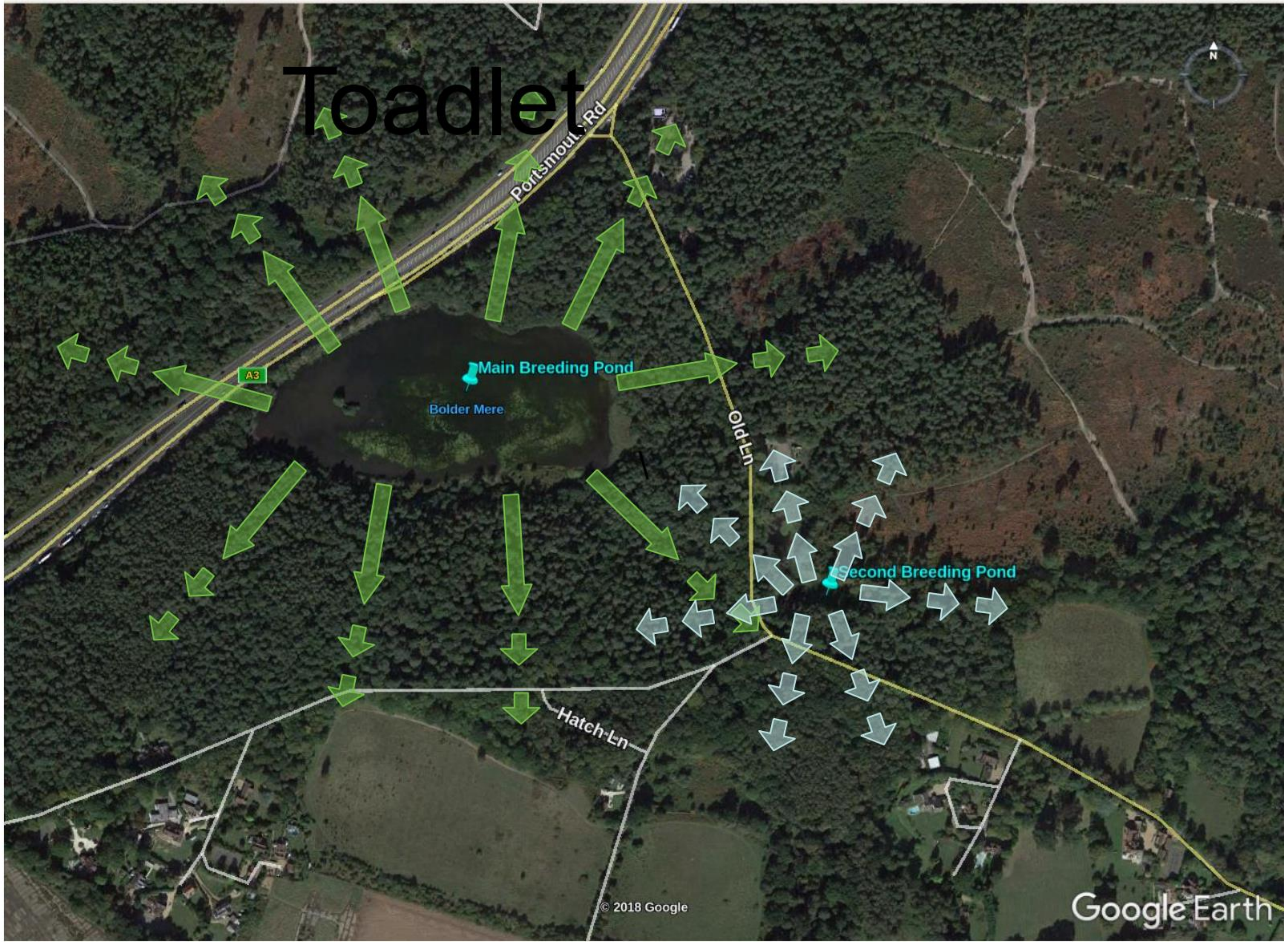
Breeding Ponds and Natural Toadlet Dispersion

There is a smaller breeding pond besides Boldermere, on the opposite side of Old Lane, as indicated

Toadlets disperse radially outward as shown by the larger arrows

If the habitat is good (i.e. wood, scrubland), toadlets will populate areas further afield, as shown by the smaller arrows - this can be up to two kilometres

Once established, toads will not only return to the same breeding ponds but also to the same summer / winter habitats, every year
There is therefore a crossover of routes as shown on the map



BOLDERMERE A3 / OLD LANE

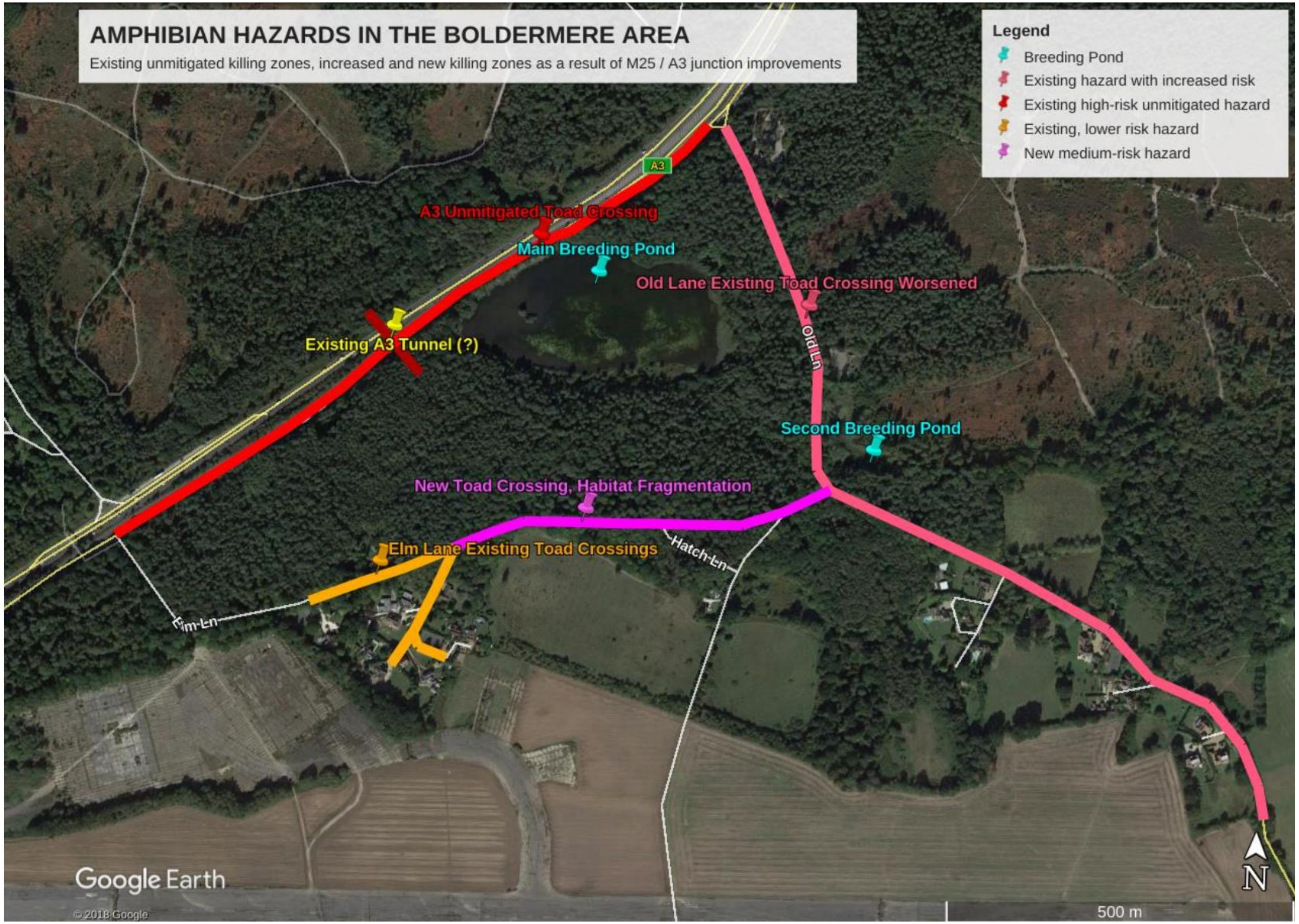
Danger zones old and new, explained

The A3 is a historic toad crossing. At present all toadlets dispersing in that direction are exterminated by the volume and speed of traffic, resulting in significant decimation.

The new part of Elm Lane dissects habitat.

Quieter roads present a different type of hazad. Amphibians move onto them on wet nights. Just one vehicle (for instance, a grocery delivery van) suffices to wipe out a very large number of them.

Old Lane is already responsible for many amphibian deaths and is set to become worse as traffic doubles.



Proposed Mitigation

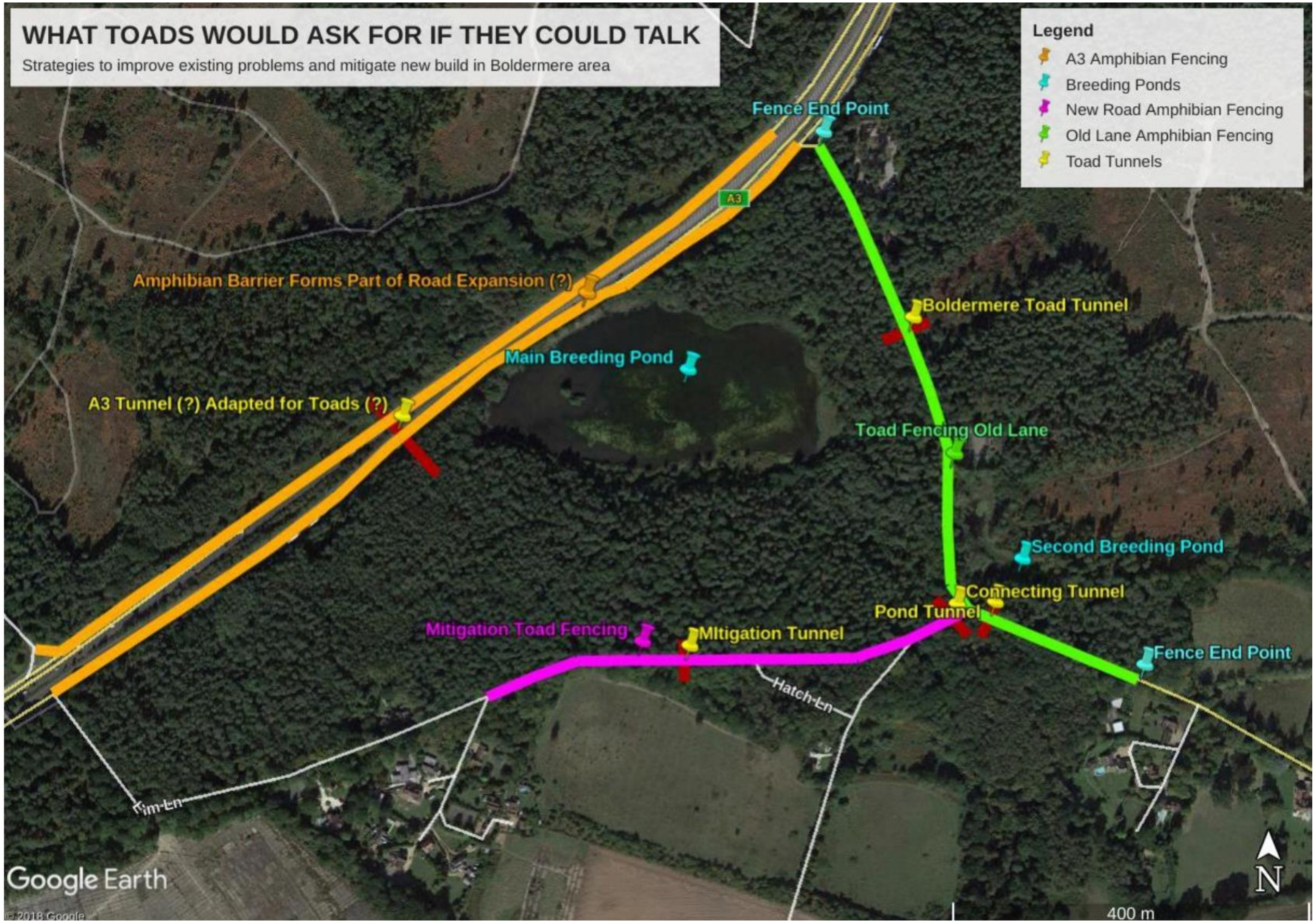
- Tries to incorporate the following:
- Address the neglected area of the A3 toad crossing
- Propose a solution for Old Lane
- Provide mitigation for the new road (Elm Lane) because:
  - What was previously the last safe direction of dispersion to the south of Boldermere will be intersected by a killing zone
  - The new road is very close to Boldermere and right next to the second breeding pond, and therefore in an area of high amphibian activity
  - The Elm Lane end stop cannot be considered as compensation as it is much further away from both ponds.
  - Amphibians will be hemmed in by dangereous roads on all sides especially considering that the Wisley by-pass is within the ponds' catchment area
- Implementation of proposal for Old Lane and A3 constitutes an improvement of the current solution and will result in a net gain for biodiversity
- The other measures in the new road could be classed as mitigation

BOLDERMERE A3 / OLD LANE

Strategies to reduce amphibian deaths

The existing A3 tunnel is not exactly known. Could it be adapted for amphibians? In combination with fencing along the A3 this would be an effective measure to prevent deaths.
In order to allow toads to move freely to their breeding ponds and summer habitat, there should be a system of two underpasses in Old Lane together with a connecting tunnel at the top of the new road.
An tunnel under the new road would mitigate for habitat dissection.

Fencing on both sides of the road would guide the amphibians to their tunnels



BOLDERMERE A3 / OLD LANE

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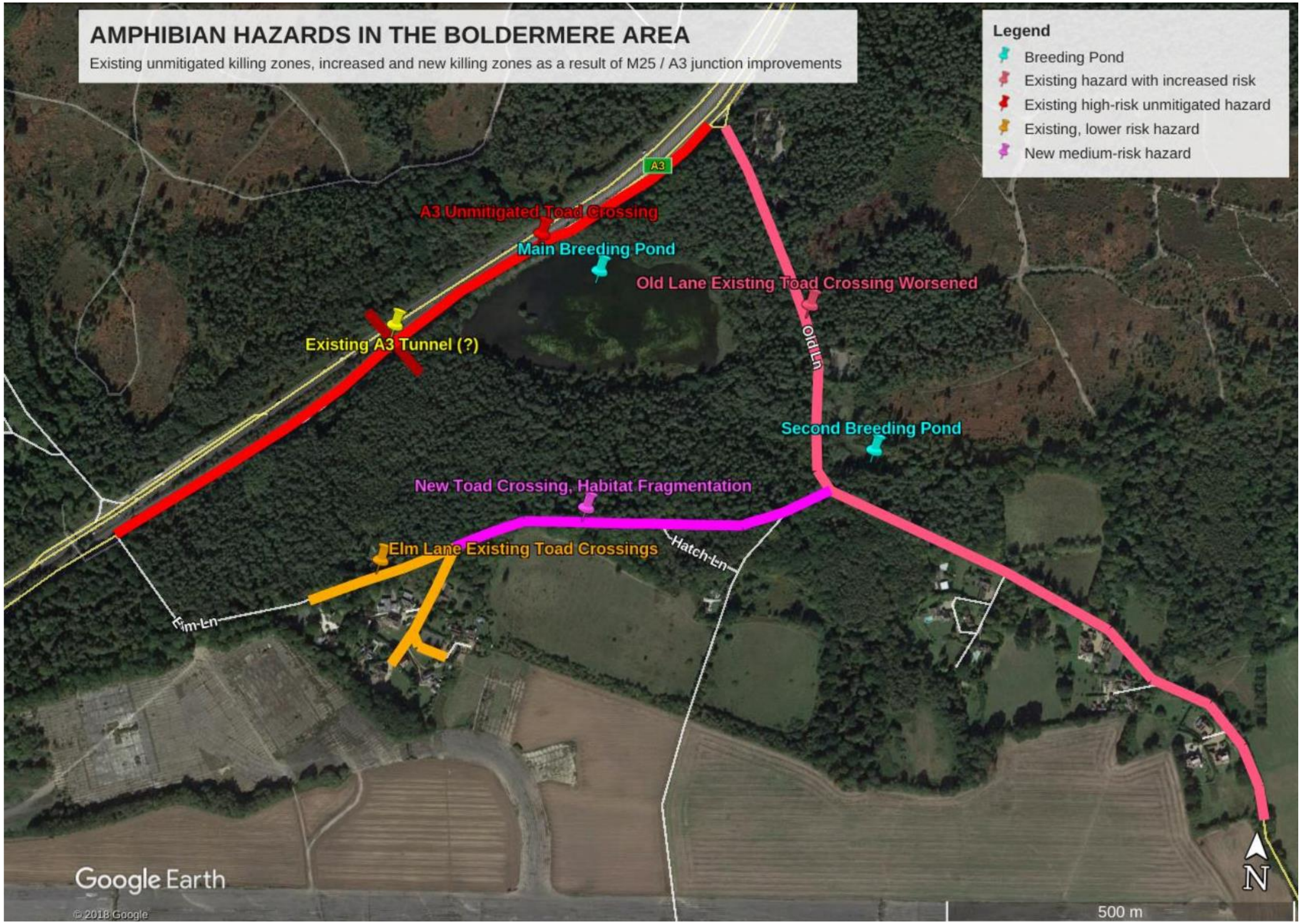

ECOLOGIST COMMENTS (EMAIL)

1. In addition to killing toads the A3 prevents dispersal between ponds on Wisley Common (500m north and west of Boldermere) and Boldermere, as well as reptiles!
2. For A3 I would suggest going for several tunnels, as large in diameter as possible (i.e. tunnels for pedestrians) and there should be space to incorporate permanent amphibian type fencing. This will also facilitate movement of the adder population (and possibly sand lizards) beneath A3, allowing dispersal between Chatley Heath and Wisley Common.
3. Fences and tunnels on A3 will need annual maintenance by highways to ensure sure the fence is not engulfed in vegetation and the tunnels cleaned-out after leaf fall.
4. Old Lane - Not sure how easy it will be to incorporate a fence along this small road - recall woodland goes right-up to the road side. Could we instead try to encourage more tunnels, could we incorporate tunnels within speed humps or (now I am probably sounding crazy) get them to raise the lane off the ground, i.e a mini-fly-over!?
5. Elm Lane - This looks like a cul-de-sac, do not fully understand what is being proposed here by Highways and not sure whether we could justify fencing and tunnels for a small number of properties. You would possibly need evidence of significant amphibian mortality for them to take this on.

Appendix A.2 Amphibian populations Biological Conservation study

ELSEVIER

Biological Conservation 99 (2001) 331–340

BIOLOGICAL CONSERVATION

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The effect of road kills on amphibian populations

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Abstract

The diurnal movement patterns of *Triturus vulgaris*, *Triturus cristatus*, *Pelobates fuscus*, *Bufo bufo*, *Rana temporaria*, and *Rana arvalis* were investigated during five breeding seasons (1994–1998). Two main questions were addressed: (1) What is the probability of an individual amphibian getting killed when crossing the road? and (2) What fraction of the amphibian populations gets killed by traffic? The rate of movement of 203 adult amphibians was recorded. Information on traffic loads was provided, and mortality risk was calculated depending on traffic loads and movement rate. The probability of getting killed ranged from 0.34 to 0.61 when crossing a road with a traffic load of 3207 vehicles/day, and from 0.89 to 0.98 when crossing a motorway. The number of amphibians killed on the road was estimated by systematic counts. Population sizes were estimated for all ponds within 250 m of the relevant highway stretch. Results indicate that about 10% of the adult population of *P. fuscus* and brown frogs (*R. temporaria* and *R. arvalis*) were killed annually by traffic at this site.

Keywords: Frogs; Toads; Amphibians; Road mortality; Movement rate

1. Introduction

The decline of amphibian populations throughout the world is a well established fact that has received a lot of attention during the last 10 years (Blaustein and Wake, 1990; Wyman, 1990; Blaustein et al. 1994). Several factors have been proposed, but there seems to be a consensus about the fact that human activities are responsible for most of the declines. Road mortality is one factor which is potentially important but has received little attention (but see Fahrig et al., 1995). Traffic may be destructive to animal populations in two ways: directly, in the sense of actually killing individuals and indirectly, by fragmenting a population's habitat (Mader, 1984; Andrews, 1990; Mader et al., 1990; Groot Bruinderink and Hazebroek, 1996; Reed et al., 1996). Fragmentation in turn may lead to isolation of populations which again may result in a reduced population size and an increased stochastic risk of extinction (Bennett, 1990). As Fahrig et al. (1995) point out, traffic intensity throughout the world has increased in the last two decades and this goes for Denmark too (Anon., 1998). Thus, it is likely that the toll of animal lives taken by traffic has increased accordingly.

Several studies have quantified road kills of many different taxa, e.g. toads (van Gelder, 1973, Cooke, 1995), birds, mammals, amphibians, and reptiles (Hansen, 1982; Fuellhaas et al., 1989), butterflies (Munguira and Thomas, 1992), snakes (Rosen and Lowe, 1994), mammals, birds, and reptiles (Drews, 1995), deer and other ungulates (Romin and Bissonette, 1996, Groot Bruinderink and Hazebroek, 1996). Due to their activity pattern, population structure, and preferred habitats, aquatic breeding amphibians are more vulnerable to traffic mortality than most other species. If they have to cross a road to get from their hibernation site to the breeding pond, or if a road runs through their terrestrial habitat, it may pose a serious threat to the population. Few studies, however, have related the number of road-killed individuals to the size of the total population, and as Huijser and Bergers (1997) mention, and Mallick et al. (1998) infer, a species often found killed on roads may simply reflect the presence of large thriving populations.

It is even more uncommon in the literature to relate road kills to the spatial organisation of the population. Vos and Chardon (1998), however, demonstrated a significant negative effect of road density on the occupation probability of ponds by moor frogs (*Rana arvalis*) in the Netherlands.

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Most studies regularly count road kills from slow moving vehicles, e.g. Hansen (1982), Rosen and Lowe (1994), Drews (1995), Mallick et al. (1998) or by foot, e.g Fuellhaas et al. (1989), Munguira and Thomas (1992). These assume that every victim is observed, which may be true for large conspicuous mammals, but is certainly not true for small animals. If an estimate of the total number of animals killed on a road in a given period of time is needed, one must quantitatively compensate for the number of animals that disappear from the road between censuses. Although often noted in the above mentioned studies, only Munguira and Thomas (1992) attempt to make this compensation.

The present study aimed at quantifying road kills in populations of six amphibian species: common newt (*Triturus vulgaris*), crested newt (*Triturus cristatus*), spadefoot toad (*Pelobates fuscus*), common toad (*Bufo bufo*), moor frog (*Rana arvalis*) and common frog (*Rana temporaria*). During a period of 5 years (1994–1998) the population sizes were estimated and road kills quantified (including corrections for animals not observed). The problem of quantifying road kills was approached from two different angles:

(1) by establishing a relationship between the probability of getting killed by crossing the road and (a) velocity of the animal, (b) diurnal activity pattern, (c) traffic intensity;
(2) by identifying the proportion of the populations killed on the road, and assessing the importance to the probability of population persistence.

2. Methods

2.1. Study site

The study site is located on the peninsula of Djursland, northern Denmark (56°26′N, 10°34′E). It is situated next to a two-lane road connecting two towns. The road is about 8 m wide, with a traffic intensity of ca. 3200 vehicles per 24 h. The speed limit is 80 km/h but the usual vehicle speed is 10–20 km/h higher. The landscape is dominated by intensively cultivated fields (mostly barley), with small woods and farms here and there. Ponds are quite numerous in the area; most of them are of natural origin (glacial formations), although some are artificially dug (peat bogs, gravel pits).

2.2. Population size estimates

Population sizes of *P. fuscus*, *R. temporaria* and *R. arvalis* were estimated in 1996 and 1997 for all ponds within a distance of 1000 m from the relevant road stretch ($n=14$ ponds). Five of the ponds were completely encircled by drift fences in both years. Estimates for the two *Rana* species were based on egg-clumps counted in 1996 and 1997, which corresponded very well with the number of females and males known to have entered the ponds by the pitfall traps. Moreover, the number of calling males was found to correspond well with the number of males known to be present in the pond. The number of egg clumps and the number of calling males were then used as a basis for an estimate of the population size in the ponds that were not fenced, assuming one egg clump per female and a sex ratio of unity. Population sizes of *T. vulgaris*, *T. cristatus* and *B. bufo* were estimated in the five fenced ponds only. Here, all adults of *P. fuscus* were caught by the fence in pitfall traps and were individually marked in both years. In the nine unfenced ponds, *P. fuscus* was assumed to be absent because there were no males calling either year. For *B. bufo*, the number of calling and/or visible males was assessed at the peak of the calling season and used as a basis of a population estimate.

2.3. Velocities and activity patterns of amphibians crossing roads

In order to establish a relationship between the probability for an amphibian of getting killed by crossing the road, data on velocity and diurnal activity pattern of the amphibians, and vehicle intensity, and diurnal variation, were needed. The velocity of adults of the six naturally occurring amphibian species was recorded during their spring migration to the breeding ponds (i.e. before spawning), as well as during their summer movements (in August) in 1996–1998. Some of the animals were spontaneous migrators, i.e. they were discovered on their way to the breeding pond (and their movement speed recorded directly), whereas some of the animals were caught in pitfall traps by the drift fences. They were then taken to a nearby paved area and released. Time spent and distance moved were then recorded from the time the animal started moving until it left the paved area. Pitfall traps were used to describe the amphibian diurnal activity pattern by emptying the traps at regular intervals during each 24 h period (April–May 1996 and 1997).

Traffic intensity (number of vehicles per 24 h, and frequency distribution during 24 h), and the number and frequency of different vehicle types occurring were provided by the Danish Road Directorate. Traffic intensity was recorded as the mean number of vehicles on the road in each 1-h interval in the months of April, May, June, and August 1996 (where amphibian activity and road kills were recorded).

2.4. Monitoring of road kills

A 600-m stretch of the road was monitored for road-killed adult amphibians every morning at dawn, in order to minimise the number of corpses removed by day time scavengers (routine monitorings). Both sides of the road were carefully examined (one side at a time) by foot. All road victims were removed after recording in order to avoid double counts. This took place during the breeding period, and in late summer: 1995, 30 March–31 May and 27 July–1 September; 1996, 11 April–2 June and 1 August–2 September; 1997, 25 March–2 June and 29 July–1 September.

In addition to the routine monitoring, 19 control monitorings were conducted during peak spring migration (20–27 April, 1996 and 31 March–28 April, 1997), to assess the efficiency of our method of monitoring by foot. The control monitorings were spread evenly around the clock. Each road victim was recorded and the site carefully but invisibly marked, so as not to influence the probability of its recording during the routine monitoring. During control monitorings, victims were not removed from the road, so victims not recorded by the following routine monitoring must have disappeared or been missed. A few control monitorings were undertaken as direct continuations of the routine monitoring to check the number of extant victims missed.

The efficiency of monitoring was calculated using basic mark-recapture theory (Lincoln index, e.g. Begon, 1979). Let:

R = number of victims recorded by routine monitorings only, C = number of victims recorded by control monitorings only, B = number of victims recorded by routine *and* control monitorings, N = total number of victims.

Assuming that we are dealing with the same population of road kills for both routine and control monitoring and that the probability of missing an amphibian during routine monitoring is independent of the probability of missing it during control monitoring, then

$$\frac{B}{B+R}=\frac{B+C}{N} \quad (1)$$

and by rearranging (1), we get an estimate of the total number of victims ($\hat{N}$):

$$\hat{N}=\frac{(B+C)(B+R)}{B} \quad (2)$$

We define efficiency of routine monitorings (E) as the fraction of all victims found by routine monitorings:

$$E=\frac{R+B}{N} \quad (3)$$

Replacing N with the expression in (2), we get:

$$E=\frac{(R+B)B}{(B+C)(B+R)}=\frac{B}{B+C} \quad (4)$$

Substituting the expression for E in (3) into (4) yields:

$$\hat{N}=\frac{1}{E}(R+B)$$

Consequently, $F=1/E$ is the factor to be multiplied by the number of road victims found by routine monitorings to get the estimated total number of road victims.

2.5. Model for probability of getting killed when crossing the road

The probability of surviving one road crossing [P(surv)] is:

$$P(\text{surv})=\frac{1}{\pi}\int_{\alpha=-\pi/2}^{\alpha=\pi/2} e^{-\frac{Na}{v\cos\alpha}}d\alpha$$

(cf. Eq. (10), Appendix)

where N = number of cars passing per time unit, a = killing width of car, v = velocity of animal and α = angle of road crossing.

This expression averages the survival probability for all possible crossing angles. Note that according to the expression, survival probability decreases exponentially with increasing traffic intensity (N), and increases exponentially with velocity of the animal. $\alpha=0$ corresponds to perpendicular road crossing; in this case survival probability is at its maximum value. As the crossing angle deviates from perpendicular, cosα — and thereby survival probability — decreases.

Our calculation is based on the fact that amphibians get killed if they are hit, even if only partly, by a wheel but usually not if they remain still under a passing vehicle (pers. obs.). Therefore, we calculated the killing width of vehicles (α) as twice the width of a tyre plus twice the body length of the species in question, assuming that the front and rear wheels traverse exactly the same part of the road. α was calculated as a weighted average of all vehicles occurring on this particular road: 72% cars (<2 t), 18% vans (between 2 and 3.5 t) and 10% trucks >3.5 t, 2% with single wheels and 8% with twin wheels) (Møller, pers. commun.). Tyre widths for cars, vans and trucks were 0.22 m, 0.24 m and 0.38 m/0.64 m (single wheels/twin wheels), respectively (Møller, pers. commun.). Anurans usually jump when passed by heavy vehicles (>3.5 t; pers. obs.), so for such traffic twice the length of a jump was added to the width of the wheels instead of twice the length of the body. Finally, for all vehicles, α was increased by 5% which is an assessed fraction of vehicles that kill by their wind speed alone rather than by hitting the animals. α is thus proportional to the body length of the amphibians and ranges from 0.71 m (*P. fuscus*) to 0.77 m (*Triturus* spp.).

3. Results

3.1. Velocities, activity patterns and probability of getting killed by road crossing

We recorded velocities of 203 adult amphibians (Table 1): 185 were recorded during their spring migration (31 March–10 June) and 18 during their summer movements (30 July–24 August). All velocities were recorded between 2000 and 0230, reflecting the peak activity period. There was no significant difference between velocities of spontaneously and non-spontaneously moving individuals (Table 1). Because of this non-significant difference, we did not distinguish between spontaneous and non-spontaneous movers in the following analyses. Also, despite the low number of amphibians moving in summer, there was no significant difference between movement rates of adult amphibian individuals moving in spring and summer.

In the period of investigation, the sun set between 2000 and 2130 and rose between 0530 and 0700 and the activity patterns of the investigated amphibian species were concentrated at night (Fig. 1). It is clear, however, that the time of peak activity differed between species: most *R. temporaria* and *R. arvalis* were active soon after sunset whereas most *B. bufo* were active between 2200 and 2300. The two *Triturus* species and *P. fuscus* were later still, the latter with a distinct activity peak around midnight to 0200. There was a small rush-hour peak of traffic intensity around 0700 and a large peak around 1500. From 1500 to 0200, traffic intensity decreased steadily, reaching a minimum value of nine vehicles per hour in the middle of the night.

According to Eq. (12), the probability of getting killed increases to a maximum value with increasing traffic intensity. We investigated this for different velocities of amphibians, representative of the species in the study area, assuming perpendicular road crossing (Fig. 2) and for perpendicular road crossing in contrast to road crossing with all possible angles (Fig. 3). In order to investigate the significance of velocity only, α was set to 0.74 (mean of α) in both Fig. 2 and Fig. 3. Up to a traffic intensity of 625 vehicles/h (15 000 vehicles/day), corresponding to a busy road, the velocity of the animals has a large influence on the probability of getting killed. Above this traffic intensity, the probability of getting killed during a road crossing is very close to 1 for all amphibian species investigated, whatever their velocity (within the range investigated).

We also calculated the probability of getting killed at different traffic intensities for velocities representative for hedgehog (*Erinaceus europaeus*, 45 m/min) and hare (*Lepus europaeus*, 120 m/min)(pers. obs.). For these two species, α was set to 2.0 m (total vehicle width), since, because of their size, they are killed by any part of a vehicle, not just the tyres. At these velocities, the probability of getting killed is far lower than for any of the amphibians considered (Fig. 2).

The angle of crossing clearly has an effect on the probability of getting killed (Fig. 3). The difference in probability of getting killed by perpendicular and random road crossing is most pronounced at medium

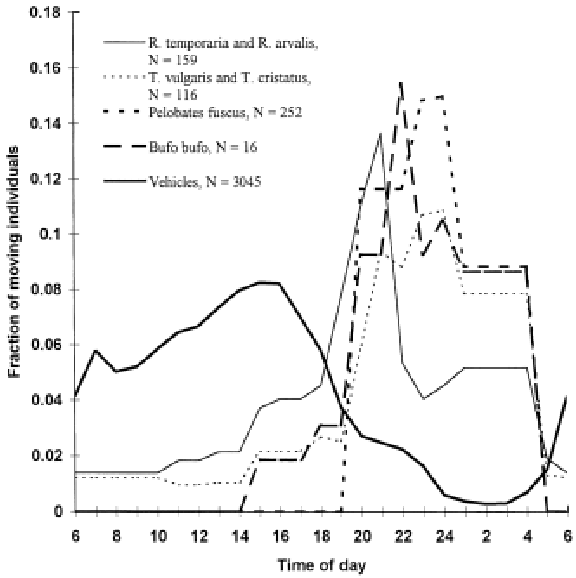

Fig. 1. Diurnal activity patterns of the six species of amphibians investigated and diurnal variation in vehicle intensity. Traffic data for April and May 1996.

Table 1
Mean speed and distance moved for the six naturally occurring amphibian species in the study area[a]

Species	Number of records		P	Mean distance moved (m ±S.D.)			Mean speed (m/min ±S.D.)		
	Sp	Non-sp		Sp	Non-sp	All	Sp	Non-sp	All
Triturus vulgaris	6	19	0.52	1.37(0.39)	1.28(0.65)	1.30(0.59)	0.69(0.49)	0.51(0.25)	0.55(0.32)
Triturus cristatus	0	7	–	–	1.66(0.81)	1.66(0.81)	–	0.99(1.01)	0.99(1.01)
Pelobates fuscus	8	40	0.18	2.81(3.04)	2.33(1.01)	2.41(1.50)	0.97(0.84)	1.50(0.99)	1.41(0.98)
Bufo bufo	38	0	–	3.63(2.67)	–	3.63(2.67)	0.93(0.82)	–	0.93(0.82)
Rana temporaria	11	19	0.06	2.77(2.03)	3.41(1.03)	3.18(1.48)	1.51(2.39)	2.39(1.94)	2.07(2.12)
Rana arvalis	20	35	0.59	5.29(3.05)	2.60(1.77)	3.58(2.64)	2.51(3.06)	1.76(2.18)	2.03(2.54)
Total	83	120	–	3.67(2.81)	2.37(1.38)	2.90(2.17)	1.37(1.93)	1.53(1.62)	1.46(1.75)

[a] Sp, undisturbed, spontaneous movement across pavement; Non-sp, movement after relocation to metalled road; P, P-value for H_0: movement speeds equal for spontaneous and non-spontaneous moving amphibians (Kruskal–Wallis test).

probabilities of getting killed — for slow movers this corresponds to a traffic intensity of about 1500 to 3000 vehicles per 24 h.

3.2. Diurnal variation in probability of death from crossing the road

In order to estimate diurnal variation in the probability of getting killed, species were grouped taxonomically, i.e. *Triturus* species, *Rana* species, *B. bufo*, *P. fuscus*. For any taxonomic group (k) at any time interval (j), the probability of getting killed ($P_{j,k}$(death)) was calculated as the mean probability of getting killed for all individuals in that particular group. Assuming perpendicular road crossing, Eq. (9) (cf. Appendix) reduces to:

$$P_{j,k}(\text{death}) = \frac{\sum_{i=1}^{n(k)}\left(1 - e^{-\frac{aN_j}{v_{i(k)}}}\right)}{n(k)}, \qquad (13)$$

where $n(k)$ is the total number of individuals in the taxonomic group in question (k), $v_{i(k)}$ denotes the velocity of one individual in group (k), and α is species specific. P(death) was then multiplied by the fraction of amphibians in this taxonomic group that are known from the recordings of diurnal activity pattern to be active in this particular time interval. Diurnal variation in the actual probability of getting killed was thus calculated, given the particular activity pattern and velocities of amphibians recorded, and the traffic intensity pattern. Diurnal variation in the probability of getting killed by a single road crossing not only reflects diurnal variation in traffic intensity (Fig. 4) but more particularly, the diurnal movement pattern of the species, and to a lesser extent the velocity of the species. The probability of getting killed is very small in the day time with a small increase before dawn, reflecting the early rush-hour peak in traffic intensity late at night when the amphibians are still

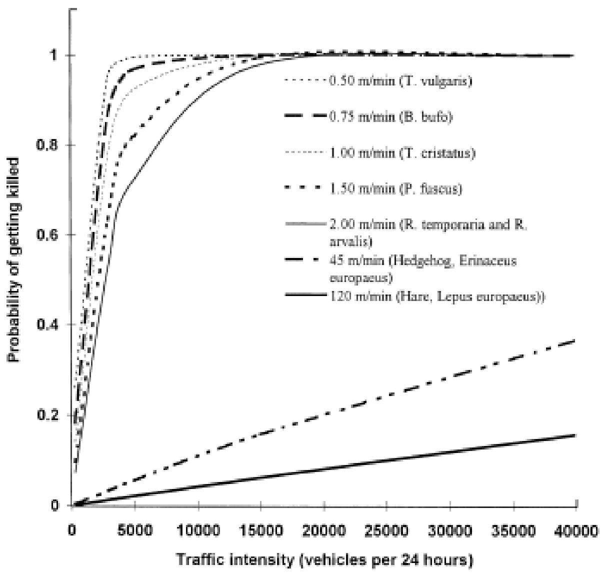

Fig. 2. Probability of getting killed for one individual of different species on the road, as a function of its velocity and traffic intensity, following the model: $P_{(\text{death})} = 1 - \frac{1}{\pi}\int_{\alpha=-\pi/2}^{\alpha=\pi/2} \frac{-Na}{e^{v\cos\alpha}} d\alpha$, and assuming perpendicular road ($\alpha = 0$). Velocities representative for different amphibian species are shown, together with velocities representative for hedgehog and hare. A traffic intensity of 3200 vehicles per 24 hours corresponds to the road investigated.

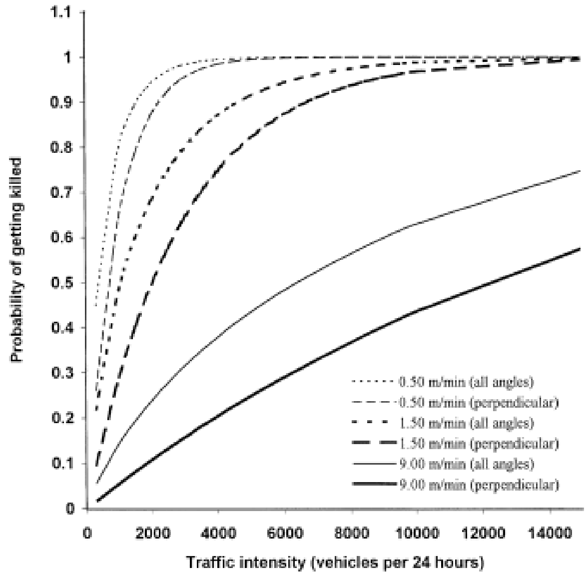

Fig. 3. The effect on probability of getting killed by crossing the road randomly (*all angles*) compared to perpendicular road crossing (*perpendicular*) for three representative velocities of amphibians; 0.50 m/min corresponds to slow moving amphibians (mainly *Triturus* species), 1.50 m/min corresponds to *Pelobates fuscus*, and 9.00 m/min is the velocity of the fastest moving *Rana temporaria* and *Rana arvalis*.

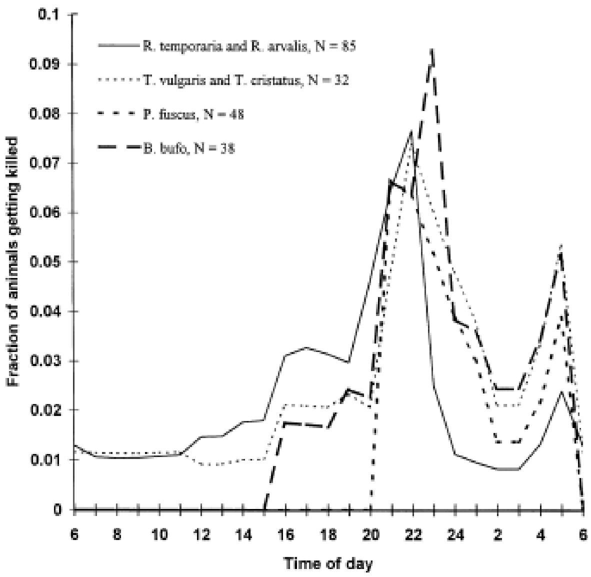

Fig. 4. Diurnal variation in probability of getting killed for the six amphibians species investigated. Probability of getting killed has been weighted by the movement pattern of the species.

Table 2
The efficiency of monitoring road victims by foot[a]

	Triturus vulgaris and *Triturus cristatus*	*Pelobates fuscus*	*Bufo bufo*	*Rana temporaria* and *Rana arvalis*
R	5	2	4	29
C	14	2	7	73
B	1	4	8	34
Total = $R+C+B$	20	8	19	136
$\hat{N}$	90.0	9.0	22.5	198.3
E^*	0.067	0.667	0.533	0.318
SE	0.065	0.192	0.129	0.045
$F = 1/E^*$	15.00	1.50	1.88	3.15

[a] The efficiency (E^*) with standard error is given as a fraction of road victims discovered out of the total (unknown) number (N). $R=$ number of victims recorded by routine monitorings only; $C=$ number of victims recorded by control monitorings only; $B=$ number of victims recorded by routine *and* control monitorings. The numbers are sums of 16 routine monitorings and 19 control monitorings, all by foot; F is the factor that converts, by multiplication, the number of victims found by routine monitorings ($R+B$) into the estimated total number of victims ($\hat{N}$).

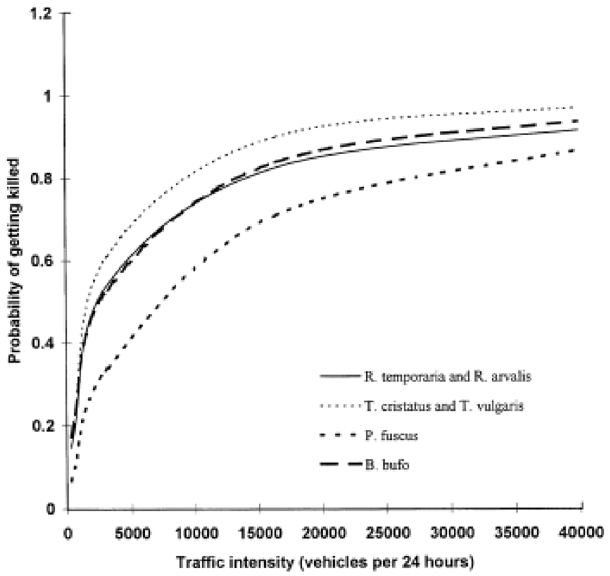

Fig. 5. Probability of getting killed for one individual of different amphibian species on the road, as a function of traffic intensity. Probability of getting killed has been weighted by movement pattern of the amphibian species and diurnal variation in traffic intensity.

active. However, the probability of getting killed reaches a peak just after sunset, owing to the activity pattern of the amphibians (Fig. 1).

Finally, the overall probability of getting killed by a single road crossing was found by summing up probabilities of getting killed for each of the 24 h-long intervals. This probability was also extrapolated to other traffic intensities (Fig. 5). Again, the difference in levels of probability of getting killed reflects the velocity and the diurnal activity pattern of the species. The slow moving salamanders face the highest probability of getting killed and the fast moving *Rana* species face a somewhat lower risk. The diurnal activity pattern for *P. fuscus* is complementary to that of vehicles and lowers the probability of getting killed considerably.

3.3. The efficiency of recording road deaths

The efficiency of monitoring of road victims by foot was estimated with the expression derived in the Section 2 (Table 2). The two *Rana* species were pooled since they are hard to distinguish as road kills. *Triturus vulgaris* and *T. cristatus* were pooled because of low numbers and taxonomic similarity.

Monitoring road victims by foot was surprisingly inefficient, ranging from about 7 to 67% of the road victims discovered (Table 2). The efficiency of foot monitoring was highest for *P. fuscus* and *B. bufo* — species that are believed to stay on the road for some time after getting killed due to their relatively tough skin and unpalatability, while only about one third of the brown frogs (*R. temporaria* and *R. arvalis*), and about 7% of the salamanders were discovered by foot.

3.4. Impact of road deaths on populations

In 1996, anuran adult population sizes in the area were estimated to be 1075 *Rana temporaria*, 3309 *Rana arvalis*, and 265 *Pelobates fuscus*. In 1997, the figures were 425 *R. temporaria*, 1,680 *R. arvalis*, and 439 *P. fuscus*.

The estimated total number of adult amphibians killed was found by extrapolating the results from the period of road kill monitoring (April, May, and August) to the assumed whole active season (1 April–15 October), assuming that the 3 months of monitoring are representative (Table 3). Finally, the estimated fraction of road-killed adults in 1996 and 1997 was calculated.

4. Discussion

4.1. Probability of getting killed on the road

Formally expressing the probability for an animal to get killed by a single road crossing has been attempted before (Heine, 1987). However, Heine's equation suffers from the logic shortcoming that high vehicle intensities and/or slow moving animals result in negative values of survival probability- values that are then truncated at zero. van Langevelde and Jaarsma (1997) overcome this by turning the equation (very similar to that of Heine (1987)), into an exponential expression, allowing the probability of getting killed by road crossing to approach 1 asymptotically for high traffic intensities and/or slow moving animals. Their equation is very similar to ours, except that van Langevelde and Jaarsma consider the entire paved width to be effective in killing

Table 3
The number of road victims and the estimated fraction of the adult populations killed on the road, found by foot-monitoring in 1996 (85 days) and 1997 (102 days), extrapolated to whole active seasons (1 April–15 October)[a]

	T. vulgaris and *T. cristatus*	*P. fuscus*	*B. bufo*	*R. temporaria* and *R. arvalis*
1996				
Observed victims	17	8	20	91
Estimated victims[b]	86.29	7.61–28.27	25.28–72.73	223.04–399.13
Total estimate for active season	201.02	17.73–65.85	58.90–169.42	519.55–929.73
Fraction of adult population	–	0.07–0.25	–	0.11–0.21
1997				
Observed victims	11	13	14	30
Estimated victims[b]	55.88	12.37–45.94	17.70–50.91	73.53–131.58
Total estimate for active season	108.47	24.01–89.17	34.36–98.82	142.73–255.42
Fraction of adult population	–	0.05–0.20	–	0.07–0.12

[a] The ranges of the total number killed are calculated from estimates of monitoring efficiency (E^*) ± 2 times S.E. (cf. Table 2). As $E^* - 2 \times$ S.E. for *Tritutus vulgaris* and *T. cristatus* is below zero, only minimum values of total number killed are given. Population estimates for *T. vulgaris* and *T.cristatus* and for *Bufo bufo* are incomplete, and therefore the fraction of adult populations killed is not estimated for these three species.
[b] $\frac{1}{E^* \pm 2 \mathrm{S.E.}} \times$ number of victims found.

whereas we operate with a narrower killing width of vehicles (α). Since van Langevelde and Jaarsma mainly consider large animals (roe deer (*Capreolus capreolus*), foxes (*Vulpes vulpes*), mustelids) their assumption is a realistic approximation, but this does not apply to small animals which may remain still under a passing vehicle without getting hurt. It is also clear from our study that the actual distribution of crossing angles at a site has a large effect on the probability of getting killed; the effect is most pronounced for fast moving animals, and for intermediate values of probabilities of getting killed. The actual distribution of crossing angles at a site is expected to vary considerably between sites, and in this work, we did not record crossing angles in a systematic way. Therefore, we mainly considered perpendicular road crossing, and consequently it needs to be stressed that our calculations of probabilities of getting killed by road crossing must be considered minimum values. Where amphibians have a fixed route to and from spawning sites they may be undeterred by low to medium traffic intensity (i.e. below 12000 vehicles per 24 h). Mortality on this type of road may therefore be higher than predicted from traffic intensity alone. However, this is only speculative, and we recommend investigations on actual crossing angles.

The width (a) of vehicles that kill, was calculated as a weighted average of the vehicles on this particular road. The proportion of vehicles is likely to vary somewhat diurnally, seasonally, and with the day of the week. Because there is no existing data on this variation, we did not include it in our model. We did, however, tentatively increase and decrease the proportion of trucks by 5% and changed the proportion of cars accordingly. The resulting probability of getting killed was increased and decreased by up to 5%, respectively. The change in probability was largest on roads with low traffic intensity, and for species with low overall probability of getting killed. Thus, it seems that in situations where traffic is intense, the results of the model are most reliable; for busy roads (15000+ vehicles per 24 h), with a 5% change in proportion of vehicles as described above, the change in model results for *T. vulgaris*, *T. cristatus*, *B. bufo*, *R. temporaria*, and *R. arvalis* was 1% or less.

Clearly, the three most important factors determining species vulnerability to road mortality are velocity of the species and diurnal movement pattern of the species and the vehicles. As a logical consequence of this, the most vulnerable species are day-active, slow-moving species. Velocity as an important factor has been stressed by several authors (e.g. Heine, 1987; Rosen and Lowe, 1994; Schlupp and Podloucky, 1994; van Langevelde and Jaarsma, 1997), but none considers the diurnal movement pattern of the animals and the vehicles (movement patterns are discussed by Rosen and Lowe (1994), but on a seasonal basis only).

The road investigated has a large diurnal variation in traffic intensity (high traffic intensity in the daytime dropping to almost zero at night), and this pattern reduces the vulnerability of nocturnal amphibians considerably. Other types of roads (e.g. motorways) may have diurnal variation in traffic intensity quite different from this one. In assessing the overall vulnerability of a species to traffic, the frequency of road crossing has to be included as well. *P. fuscus* may have a low frequency of road crossing whereas the badger (*Meles meles*), for example, is vulnerable to traffic mortality because of its frequent road crossings (Verboom, pers. commun.).

4.2. Assessing the number of road kills

Despite earlier attempts to quantify road killed amphibians and reptiles, none of the authors have quantified the efficiency of their estimated number of road kills. Göransson et al. (1978) developed an expression to calculate the efficiency of foot monitoring. Their equation calibrates the efficiency of routine and control monitorings against all victims found. In contrast with our approach, Göransson et al. do not consider the unknown total number of victims killed on the road, i.e. the ones found plus the ones missed, and they thereby tend to overestimate monitoring efficiency by underestimating the total number of animals killed on the road.

Road-killed amphibians do not remain on the road for long; they are eaten by scavengers or are, especially in rainy weather, obliterated by being repeatedly run over by cars. They presumably have a shorter duration than mammals, for example, whose size and furry skin make them visible for a longer time. Our calculations confirm that many amphibians are missed even when patrolling the road by foot once every 24 h: only 7% (*Triturus vulgaris* and *T. cristatus*) to 67% (*Pelobates fuscus*) of the total number of road victims are found. Patrolling by car, which is done by most authors, is far less efficient. Thus, uncorrected road kill estimates are highly unreliable.

One basic assumption of estimating the size of a population using a Lincoln index is that the population is closed. This assumption is clearly violated in the case of estimating the total number of road-killed amphibians. On the road, new victims are continuously added to the 'population', and others are removed by scavengers. Violation of this assumption tends to underestimate the victims found both at the routine and the control monitoring, and thereby overestimate the total number of amphibians killed. Another basic assumption is the one of independence in observing/missing a road victim during routine and control monitorings, respectively. There may be a slight bias in that very obvious roadkills are more likely to be recorded, but to all intents and purposes, the assumption is met.

4.3. Population size estimates

Our estimates of the population size of *P. fuscus* in the five fenced ponds are fairly accurate since they are based on marked individuals. The estimate of the population size of the two *Rana* species is not as accurate as the one for *P. fuscus*; partly because the brown frogs were not individually marked and partly because a larger fraction of the population bred in the ponds that were not fenced, compared to the *P. fuscus* population. The population estimates of *B. bufo* are very inaccurate, since the main part of the population bred in other ponds than the five fenced ones. They are therefore omitted from the following calculations together with *Triturus vulgaris* and *T. cristatus* and all data from 1995, where population sizes were estimated in the five fenced ponds only and thus do not form a basis of a total population estimate.

Our calculation of the fraction of adult amphibians killed on the road is based on the assumption that we have monitored the entire (meta)populations affected by the highway. We chose 1000 m from the highway to be the upper limit of movement (in the sense that all populations within 1000 m from the highway are believed to be affected by its presence. In the literature, exact data on amphibian movement range are scarce). This assumption is in reasonable accordance with existing data, as *P. fuscus* is recorded to move a maximum of 1200 m between hibernation site and breeding pond (Nöllert, 1990). Moreover, *P. fuscus* seems to be philopatric to its native pond with few adults changing breeding pond from year to year, which makes it reasonable to assume that we have monitored the entire metapopulation affected by road mortality. The two *Rana* species were pooled when estimating the fraction of adults killed on the road, partly because they are difficult to distinguish as road victims and their eggclumps cannot be distinguished with certainty (Fog et al., 1997). Haapanen (1970) found that the maximum distance moved between years by *R. arvalis* and *R. temporaria* was 350 and 600 m, respectively. Despite the accordance between our assumptions and existing data on amphibian movement range, it is clear that more data on the subject are needed until a firm fraction of amphibians killed can be established. Results should therefore be regarded as preliminary, although within the right range.

4.4. The impact of road kills on the populations

The road mortality estimates from this study cannot be extrapolated to other populations, but the equation, relating probability of getting killed for one individual on the road to the crossing angle, the velocity of the animal and the traffic intensity, is directly applicable to other populations, other geographical areas, and even to other species. The use of the equation is restricted, however, to species that do not behave intelligently towards traffic (e.g. stay on the side of the road until no vehicles are present). It is still useful to consider whether an annual mortality of up to 25 and 21% of the reproductively active adult population of *P. fuscus* and *R. temporaria*/*R. arvalis*, respectively, would have a significant effect on the population size (note that the annual mortality range is underestimated since it does not take into account the standard errors of the population estimates). That is, does road mortality constitute an additive or a compensatory mortality effect? For anuran adults in general, density independent mortality factors seem to be most important whereas for larvae, both density dependent and density independent mortality factors seem to be important (Duellman and Trueb, 1994, and references therein). If the population in question is mainly regulated by density-independent mechanisms, such as climatic variability, road mortality will be an additive effect and is thus important as a population regulating factor. If, however, the population is regulated by density dependent factors (mainly intraspecific competition among the larvae, cf. e.g. Wilbur (1972,1977)), road mortality will be compensated for by higher larval survival and the impact on the population will not be very large. This particular *P. fuscus* population is probably regulated in the larval state by density-dependent mechanisms (Hels, unpublished), and the road mortality is therefore expected to have no large regulating effect. If traffic intensity continues to increase, however, increased road mortality may eventually reduce the population to a level where its reproductive output is too small to reach the carrying capacities of the breeding ponds. This in turn may drive the population down to a level where demographic stochastic processes become important for the survival of the population. Finally, it should be noted that road mortality may be even more serious to the juveniles in the population since they are slow movers. This is a field where more investigations are needed, since very little is known about the movement ranges of juvenile amphibians.

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Appendix A

The probability of an amphibian surviving t time units on the road is denoted p. The change in p during one time step ($\mathrm{d}t$) becomes:

$$\mathrm{d}p = -\lambda p \mathrm{d}t, \qquad (6)$$

where λ is a positive constant depending on: N: mean number of vehicles passing per time unit (the actual number is assumed to be Poisson distributed with mean N), $\frac{a}{L}$: the probability of getting hit, where a is the width of vehicles that actually kills, and L = width of the road. The change in p thus becomes:

$$\mathrm{d}p = -\frac{Na}{L} p \mathrm{d}t \qquad (7)$$

Integration of Eq. (6) yields:

$$p = \mathrm{e}^{-\lambda t}. \qquad (8)$$

Since $t = \frac{s}{v}$, where s = distance moved to cross the road and v = velocity of the animal in question, Eq. (8) can be rewritten as:

$$p = \mathrm{e}^{-\frac{\lambda}{v}s} = \mathrm{e}^{-\frac{Na}{Lv}s}. \qquad (9)$$

s depends on the angle of crossing the road. Crossing angle is denoted α, $\alpha = 0$ corresponds to perpendicular road crossing, which implies that the following condition must be satisfied for the animal to cross the road: $-\frac{\pi}{2} < \alpha < \frac{\pi}{2}$. Consequently, the distance moved by crossing the road becomes $s = \frac{L}{\cos\alpha}$ (note that for perpendicular road crossing: $s = L$). Mean probability of surviving one road crossing (P(surv)), including all possible crossing angles, becomes:

$$P(\mathrm{surv}) = \frac{1}{\pi}\int_{\alpha=-\pi/2}^{\alpha=\pi/2} \mathrm{e}^{-\frac{Na}{v\cos\alpha}} \mathrm{d}\alpha \qquad (10)$$

and the mean probability of getting killed (P(death)) consequently becomes:

$$P(\mathrm{death}) = 1 - \frac{1}{\pi}\int_{\alpha=-\pi/2}^{\alpha=\pi/2} \mathrm{e}^{-\frac{Na}{v\cos\alpha}} \mathrm{d}\alpha, \qquad (11)$$

which can be extended to include variation in animal velocity by weighting Eq. (11) with the density function of velocities ($p(v)$), i.e.

$$P_{(\mathrm{death})} = 1 - \frac{1}{\pi}\int_{v=0}^{\infty} p(v) \int_{\alpha=-\pi/2}^{\pi/2} \mathrm{e}^{-\frac{Na}{v\cos\alpha}} \mathrm{d}\alpha \mathrm{d}v. \qquad (12)$$

References

Andrews, A., 1990. Fragmentation of habitat by roads and utility corridors: A review. Australian Zoologist 26 (3&4), 130–141.
Anonymous (1998) Trafikrapport 1996 (Traffic Report 1996, in Danish). The Road Directorate, Copenhagen, Denmark. pp. 1–48.
Begon, M., 1979. Investigating Animal Abundance. Edward Arnold Publishers Ltd, London.
Bennett, A.F., 1990. Habitat Corridors: Their Role in Wildlife Management and Conservation. Department of Conservation and Environment, Melbourne, Australia.
Blaustein, A.R., Wake, D.B., 1990. Declining amphibian populations: A global phenomenon? Trends in Ecology and Evolution 5 (7), 203–204.
Blaustein, A.R., Wake, D.B., Sousa, W.P., 1994. Amphibian declines: judging stability, persistence, and susceptibility of populations to local and global extinctions. Conservation Biology 8 (1), 60–71.
Cooke, A.S., 1995. Road mortality of common toads (*Bufo bufo*) near a breeding site, 1974–1994. Amphibia-Reptilia 16, 87–90.
Drews, C., 1995. Road kills of animals by public traffic in Mikumi National Park, Tanzania, with notes on baboon mortality. African Journal of Ecology 33, 89–100.
Duellman, W.E., Trueb, L., 1994. Biology of Amphibians. The Johns Hopkins Press Ltd, London.

Fahrig, L., Pedlar, J.H., Pope, S.E., Taylor, P.D., Wegner, J.F., 1995. Effect of road traffic on amphibian density. Biological Conservation 73, 177–182.

Fog, K., Schmedes, A., Rosenørn de Lasson, D., 1997. Nordens padder og krybdyr (Amphibians and Reptiles of the Nordic Countries, in Danish). GAD, Copenhagen.

Fuellhaas, U., Klemp, C., Kordes, A., Ottersberg, H., Pirmann, M., Thiessen, A., Tschoetschel, C., Zucchi, H., 1989. Untersuchungen zum strassentod von vöglen, säugetieren, amphibien und reptilien. Beiträge zur Naturkunde Niedersachsens 42, 129–147.

Groot Bruinderink, G.W.T.A., Hazebroek, E., 1996. Ungulate traffic collisions in Europe. Conservation Biology 10 (4), 1059–1067.

Göransson, G., Karlson, J., Lindgren, A., 1978. Vägers inverkan på omgivande natur II. Fauna (Influence of roads on the surrounding nature II. Fauna, in Swedish). Statens Naturvårdsverk, Lund, Sweden.

Haapanen, A., 1970. Site tenacity of the common frog (*Rana temporaria* L.) and the moor frog (*R. arvalis* Nilss.) Ann. Zool. Fennici 7, 61–66.

Hansen, L., 1982. Trafikdræbte dyr i Danmark (Road kills in Denmark, in Danish). Dansk Ornitologisk Forenings Tidsskrift 76, 97–110.

Heine, G., 1987. Einfache Mess und Rechenmetode zur Ermittlung der Überlebenschance wandernder Amphibien beim Überqueren von Strassen. Beih. Veröff. Naturschutz Landschaftspflege Bad.-Württ. 41, 473–479.

Huijser, M.P., Bergers, P.J.M., 1997. The mortality rate in a hedgehog population: The relative importance of road kills. In: Canters, K. (Ed.), Habitat Fragmentation & Infrastructure, Proceedings of the International Conference on Habitat Fragmentation, Infrastructure and the Role of Ecological Engineering, September 1995, The Netherlands. Ministry of Transport, Public Works and Water Management, The Netherlands, pp. 98–104.

Mader, H.-J., 1984. Animal habitat isolation by roads and agricultural fields. Biological Conservation 29, 81–96.

Mader, H.-J., Schell, C., Kornacker, P., 1990. Linear barriers to arthropod movements in the landscape. Biological Conservation 54, 209–222.

Mallick, S.A., Hocking, G.J., Driessen, M.M., 1998. Road-kills of the eastern barred bandicoot (*Perameles gunnii*) in Tasmania: an index of abundance. Wildlife Research 25, 139–145.

Munguira, M.L., Thomas, J.A., 1992. Use of road verges by butterfly and burnet populations, and the effect of roads on adult dispersal and mortality. Journal of Applied Ecology 29, 316–329.

Nöllert, A., 1990. Die Knoblauchkröte, 2nd Edition. A. Ziemsen Verlag, Wittenberg Lutherstadt.

Reed, R.A., Johnson-Barnard, J., Baker, W.L., 1996. Contribution of roads to forest fragmentation in the Rocky Mountains. Conservation Biology 10 (4), 1098–1106.

Romin, L.A., Bissonette, J.A., 1996. Deer-vehicle collisions: status of state monitoring activities and mitigation efforts. Wildlife Society Bulletin 24 (2), 276–283.

Rosen, P.C., Lowe, C.H., 1994. Highway mortality of snakes in the Sonoran Desert of Southern Arizona. Biological Conservation 68, 143–148.

Schlupp, I., Podloucky, R., 1994. Changes in breeding site fidelity: A combined study of conservation and behaviour in the Common toad *Bufo bufo*. Biological Conservation 69, 285–291.

van Gelder, J.J., 1973. A quantitative approach to the mortality resulting from traffic in a population of *Bufo bufo* L. Oecologia (Berlin) 13, 93–95.

van Langevelde, F., Jaarsma, C.F., 1997. Habitat fragmentation, the role of minor rural roads and their traversability. In: Canters, K. (Ed.), Habitat Fragmentation & Infrastructure, Proceedings of the International Conference on Habitat Fragmentation, Infrastructure and the Role of Ecological Engineering, September 1995, The Netherlands. Ministry of Transport, Public Works and Water Management, The Netherlands, pp. 171–182.

Vos, C.C., Chardon, J.P., 1998. Effects of habitat fragmentation and road density on the distribution pattern of the moor frog, *Rana arvalis*. Journal of Applied Ecology 35, 44–56.

Wilbur, H.M., 1972. Competition, predation, and the structure of the *Ambystoma-Rana sylvatica* community. Ecology 53, 3–21.

Wilbur, H.M., 1977. Density-dependent aspects of growth and metamorphosis in *Bufo americanus*. Ecology 58, 196–200.

Wyman, R.L., 1990. What's happening to the amphibians? Conservation Biology 4 (4), 350–352.

Appendix A.3 Minutes from meeting with Surrey County Council ([redacted]) and two toad crossing volunteers ([redacted] and [redacted]) on the 6 January 2020.

ATKINS
Member of the SNC-Lavalin Group

Meeting Notes

Project:	M25 J10/A3 Interchange		
Subject:	Toad Crossing		
Meeting place:	Ockham Common, Surrey	Meeting no:	1
Date and time:	06 January 2020 at 10:00	Minutes by:	[redacted]
Present:	[redacted]	Representing:	Atkins Atkins Surrey County Council Toad crossing volunteer Toad crossing volunteer Atkins

ITEM	DESCRIPTION AND ACTION	DEADLINE	RESPONSIBLE
1.	PW provided an update to the DCO process: proposed non-material DCO changes was submitted in time for the 18th December (Deadline 2), see the Highways England (HE) Targeted non-statutory consultation brochure[1]. 1. With regards to Old Lane (see Change 2), HE has asked the Planning Inspectorate for an extension of the Red Line Boundary to allow for the provision of 2x ACO toad crossings with associated fencing and toad crossing signage[1]; 2. Along Elm Lane, a request has been made to reduce the speed limit to 20 mph along Byway 525 (see Change 5).	N/A	N/A

[1] Highways England. January – February 2020. M25 junction 10/A3 Wisley interchange improvement scheme. Targeted non-statutory consultation 2020 Brochure.

Next meeting:	N/A		
Distribution:	[redacted]		
Date issued:	13 February 2020	File Ref:	

NOTE TO RECIPIENTS:
These meeting notes record Atkins understanding of the meeting and intended actions arising therefrom.
Your agreement that the notes form a true record of the discussion will be assumed unless adverse comments are received in writing within five days of receipt.

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Toad crossing meeting minutes_final 1

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Member of the SNC-Lavalin Group

ITEM	DESCRIPTION AND ACTION	DEADLINE	RESPONSIBLE
	[redacted] will find out in early March 2020 if these changes have been accepted. Aim of meeting was to discuss the relevant changes and get [redacted]s', [redacted]s and [redacted]s thoughts on the matter.		
3.	**<u>Toad crossing:</u>** [redacted] welcomed proposed changes. However, they stated that the proposed changes only mitigate for the population using the smaller pond by the car park, with the main toad migration being located closer to Bolder Mere. By moving at least one of the tunnels, to the location of the natural depression in Old Lane ([redacted] 07892 58480 – location 1) which sees the bulk of the migration and using slightly more fencing, a larger proportion of the population could benefit from the mitigation measures. Ideally one tunnel would be located at location 1 and the other would be located at location 2 ([redacted] 07953 58252)[2]. [redacted] highlighted that from his personal experience of acting as a warden along Old Lane, approx. 5x the population of toads cross at location 1, as opposed to the suggested tunnel locations. [redacted] – if the locations of the tunnels are to remain as per Change 2, wardens will still need to go out to Old Lane at night to check for toads at location 1 during the migration period. This poses road safety and health and safety implications, especially in light of the predicted increases in traffic. [redacted] highlighted that the in-combination effects of the Scheme and Wisley Airfield development, sees an increase in traffic movements along Old Lane in 2030 from Approx. 5,000 to 9,000. According to the modelling undertaken in Hels et al[3]. this results in a 10% increase in mortality from 0.6 to 0.7. The proposed changes therefore aim to mitigate this 10% increase in mortality. The driver for the mitigation is the Toad Crossing Conservation Verge. [redacted] explained that the proposed changes will make a difference to the population, particularly at the smaller pond and would mitigate for the 10% increase in mortality that is expected to occur as a result of the in-combination effects of the Scheme. [redacted] acknowledged that the relocation of the toad crossings could potentially further reduce the expected mortality of toads crossing Old Lane. However, unfortunately due to the delay in being able to arrange a meeting it was not possible to accommodate the proposed relocation in the proposed non-material changes that were submitted to PINS in December.	N/A	N/A

[2] Ordnance Survey National Grid References of toad crossing tunnels collected during a walkover undertaken as part of this meeting.

[3] Hels, T. & Buchwald, E. (2001) *The effect of road kills on amphibian populations*. Biological Conservation 99 (331-340)

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ITEM	DESCRIPTION AND ACTION	DEADLINE	RESPONSIBLE
	[redacted] – ideally at least 4x toad tunnels with the associated fencing would be provided along Old Lane. [redacted]– SCC have no issue with regards to land owner consent if the tunnel locations were to be moved. SCC would not have any objections to a change of tunnel location. [redacted]- raised that there will be a second opportunity to request for further mitigation from the developers of Wisley Airfield. [redacted]- aspiration would be to eliminate the need for Wardens/volunteers at all. [redacted]- would be beneficial to leaflet local residents to inform them of toad crossing and what you can do to help toads. [redacted]encouraged [redacted] to provide a written submission with regards to the proposed changes to highlight that although the changes are welcome, different tunnel locations would be preferred. [redacted]– will keep [redacted]informed of success in getting changes put through. **Update** [redacted]sent an email to all attendees of the meeting on 7th January 2020 explaining the consultation process and providing links and inviting the attendees to submit their feedback on the proposed toad crossings via this process.		
4.	**Toad crossing - fencing:** [redacted]- if having gaps between fencing (as a result of the existing car park), [redacted]would prefer one-way fencing or a mix (preferably one-way) to allow any toads trapped within the road to escape. [redacted]– commented that on another Scheme where there is a mixture of one-way and standard fencing, sometimes the panels can move resulting in gaps between these. [redacted]– requested the use of more fencing. Ideally 100 m of fencing would be installed per tunnel. [redacted]- Guidance that [redacted]have found recommends 50 m of fencing either side of a crossing is effective. If there is evidence that longer fencing is effective, then we would be happy to receive this evidence.	N/A	N/A
5.	**Toad crossing – tunnel maintenance:** [redacted]– maintenance would be low key and involve a clean/flush out of the tunnels once a year, outside of migration period. This would be SCC responsibility. [redacted] - does not consider it to be a big issue.	N/A	N/A
6.	**Elm Lane:** [redacted] - considers a toad crossing tunnel along Elm Lane is needed as it is a new road. Could tunnels be incorporated into speed bumps?	N/A	N/A

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ITEM	DESCRIPTION AND ACTION	DEADLINE	RESPONSIBLE
	[redacted] – Taking into consideration the volume of traffic on the road (servicing 19 properties), mitigation is not required as this is not considered a severance to movement as the road will be level with the surrounding ground with no kerbs. Also, the reduced speed limit of 40 to 20 mph (Change 5) on Elm Lane will be of benefit for toads. Increase chances of users seeing if it's a wet night for toad crossing. There is potential to put up signs for peak time of year for toad crossing. Furthermore, it would be more effective to provide two toad tunnels on Old Lane rather than Elm Lane. [redacted] stated that she feels that two additional underpasses (a third on Old Lane and one on Elm Lane) are essential for the conservation of toads at Bolder Mere. If further discussion is needed on Elm Lane, [redacted] encourages [redacted] to provide a written response. **Update** [redacted] sent an email to all attendees of the meeting on 7th January 2020 explaining the consultation process and providing links, and inviting the attendees to submit their feedback on the toad crossings via this process. [redacted] emailed on the 27th February 2020: *"I should like to confirm that I did express a view that should it be the case that the circumstances unfortunately be such that the number of toad crossing would be limited for various reasons, resources likely being the main reason, the priority should be the crossings in Old Lane, simply due to the volumes of traffic being multiple levels greater than in Elm lane and the long history of significant numbers of amphibians including toads crossing Old lane."*		
7.	**A3 underpasses:** [redacted] suggested that mitigation is needed along the A3 to address the migration of juveniles in that direction. [redacted] - this is an existing barrier that has not been caused by the Scheme. Inputting new tunnels under the A3 is therefore not considered appropriate mitigation for the Scheme. [redacted] also highlighted that there is an existing underpass located along the A3 which will be retained. The scheme will therefore not worsen the issue and it will remain the same as it is. Therefore, no mitigation is required as there will be no change. Therefore, [redacted] have focussed their efforts on Old Lane.	N/A	N/A
8.	**Green bridge:** [redacted]– would like 4x green bridges to connect the four sections of the SSSI. [redacted]- The Scheme is not causing any severance as a result of the A3 and M25.	N/A	N/A

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ITEM	DESCRIPTION AND ACTION	DEADLINE	RESPONSIBLE
	Throughout the consultation process, Surrey Wildlife Trust have expressed a strong desire for a green bridge linking Ockham Common and Wisley Common. [redacted] made it clear that a green bridge would not mitigate the scheme and therefore this would need to come under [redacted] designated funds. An application to the designated funds has been made for 1x green bridge at Cockcrow as this is the most effective location. Due to the large costs involved it was agreed that one large green bridge would be most effective. The non-material changes include the proposal for Cockcrow bridge to contain a 25m wide green element subject to approval of the non-material change and a successful application for designated funds for detailed design and construction.		
9.	**Wisley bypass:** [redacted] - Is there anything we can do to keep connectivity? [redacted] – Along the new Wisley Lane where it is raised there will be a culvert to go between the woodland areas within Elm Corner Woods Site of Nature Conservation Interest (SNCI) and the woodland to the north of the existing Elm Lane. [redacted] have committed to investigate the potential for a culverted underpass within the embankment on the new section of Wisley Lane during detailed design to facilitate the passage of wildlife. This was detailed in response to Elm Corner Residents in the Applicants comments on relevant representations [REP1-009]. [redacted] - consider Wisley Lane to be a major wildlife barrier. [redacted] – there will be enhancement works within Elm Corner Wood SNCI and along Stratford Brook. During detailed design ecologists will be engaged to ensure that the design of the culvert is such that it is effective. [redacted] - preferred option would have been Wis-10.	N/A	N/A
10.	**HE Designated Funds:** [redacted] highlighted that if there are any enhancement measures that [redacted] would like to see provided at this location which are not considered necessary mitigation for the current Scheme, then there is a process for individuals or organisations, such as SARG, to apply to the [redacted] designated funds to apply for enhancement measures[4]. **Update** The designated funds application process is understood to be likely to change in the near future.	N/A	N/A

[4] https://highwaysengland.co.uk/designated-funds/

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