The effect of rainfall upon the behaviour and use of under-road culverts in four amphibian species

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Research article

The effect of rainfall upon the behaviour and use of under-road culverts in four amphibian species

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Habitat fragmentation and road mortalities are major contributors towards declines in amphibian populations. This has seen the introduction of culverts, passages that run under roads and provide safe passage for amphibians. Research investigating the effects of rainfall upon amphibian culvert use is limited. This study, conducted at Frankfield Loch in Glasgow, assesses how time elapsed since rainfall influences migration behaviour and the use of culverts across four different species; common toads (*Bufo bufo*), common frogs (*Rana temporaria* and newts, a group composed of smooth newts (*Lissotriton vulgaris*) and palmate newts (*Lissotriton helveticus*). Analysis of images taken by a custom made, time lapse camera found that significantly fewer common toads ($r = 0.148$, $n = 468$, $p = 0.001$) and common frogs ($r = -0.175$, $n = 106$, $p = 0.037$) used the culvert as time since rainfall increased. This may have been caused by the culvert not maintaining wet enough conditions for amphibians. The study also found that more newts ($r = 0.272$, $n = 92$, $p = 0.004$) and common toads ($r = 0.531$, $n = 19$, $p = 0.010$) were using the culvert to move away from Frankfield Loch as time since rainfall increased. An increase in juvenile newts was also observed as time since rainfall increased ($r = 0.214$, $n = 92$, $p = 0.020$). This may have been caused by a decrease in barometric pressure, which follows a decrease in rainfall, acting as a cue for migration and juvenile dispersal. The study recommends careful consideration of the design of each culvert, incorporating species-specific preferences and the requirements of juveniles. The study also suggests that where possible the culvert should be designed to hold water for longer.

Key words: Bufo bufo, Rana temporaria, culverts, amphibian, migration behaviour, rainfall

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Introduction

Roads have been recognized as a major factor in the global population decline of amphibians (Glista, DeVault and DeWoody, 2008; Petrovan and Schmidt, 2016). Amphibians are strongly impacted by road mortalities and roads can further lead to the fragmentation of amphibian habitat and can intersect their migratory routes (Glista, DeVault and DeWoody, 2008). Semlitsch (2002) describes the seasonal cycles of amphibian migration; overwintering in terrestrial areas before moving to aquatic breeding sites in the spring. Breeding site fidelity is often maintained across the years and individuals generally follow the same migratory routes (Gamble, McGarigal and Compton, 2007; Santos *et al.*, 2007). As a result, intercepting these migration routes presents amphibians with a barrier that prevents them from accessing breeding sites and reproducing (Santos *et al.* 2007).

Road fragmentation can isolate populations. This reduces gene flow between populations and can lead to a reduction in genetic variability. This in turn can increase the population's vulnerability to extinction (Keller and Largiadèr, 2003; Cushman, 2006). Dispersal may also be reduced in fragmented landscapes meaning that immigrants cannot bolster struggling populations or recolonize and re-establish populations following a local extinction (Lehtinen, Galatowitsch and Tester, 1999; Cushman, 2006). It is, therefore, vital that connectivity between populations, breeding sites, overwintering sites and migration routes is maintained (Lehtinen, Galatowitsch and Tester, 1999; Semlitsch, 2002; Santos *et al.* 2007).

In response to this, ecological mitigation measures can be installed. The most promising measure for amphibians are road tunnels or culverts (Beebee, 2013). These are passages, varying from 0.3 to 2 m in diameter, that run under the road (Glista, DeVault and DeWoody, 2009). It has been shown that pipe culverts can reduce road mortality on a section of motorway in France from almost 100% down to 23% in common toads, *Bufo bufo* (Lode, 2000). Similarly, Dodd, Barichivich and Smith (2004) found that in the Paynes Prairie State Preserve in Florida the presence of culverts reduced road mortalities in the local wildlife, including southern toads, *Bufo terrestris*, and various other frog species, by 93.5%.

Rainfall has been shown to alter migration behaviour in amphibians and lead to earlier breeding (Beebee *et al.* 2002; Todd and Winne, 2006; Todd *et al.* 2010). Equally, for some species of amphibians, migration can be triggered by a decrease in barometric pressure caused by a decrease in rainfall (Elewa, 2005; Osbourn, 2012). However, the effect of precipitation upon amphibian movements is frequently ignored (Todd *et al.* 2010) and very little information exists on how rainfall patterns affect amphibian usage of road mitigation structures. Therefore, the aim of this study was to identify if and how rainfall affects the behaviour of amphibians using culverts. The study investigated how each of the following parameters correlated with time since rainfall: the total number of amphibians that entered the culvert; the number of amphibians that made a full crossing; the direction of amphibian travel and the numbers of juveniles and adults that were observed in the culvert.

Methods

Study site

Located in Seven Lochs Wetland Park in Glasgow, UK, the culvert used for this investigation is one of three that runs underneath Loch Road. Loch Road runs north-east of Frankfield Loch and separates the loch from a large area of woodland, grassland and wetlands. Both the loch and the area of woodland, grassland and reed beds accommodate amphibian populations of common frogs (*Rana temporaria*), common toads (*B. bufo*), smooth newts (*Lissotriton vulgaris*) and palmate newts (*Lissotriton helveticus*) (S. Petrovan, personal communication; glasgownaturalhistory.org.uk, 2016). As these species all exhibit seasonal migration between aquatic breeding sites (such as Frankfield Loch) and terrestrial habitat for overwintering and foraging (Semlitsch, 2002), then the recently constructed Loch Road is intersecting a key section of the migratory route for these populations.

Seven Lochs Wetland Park seek to protect the heritage of the site and conserve local wildlife habitat (GCV Green Network, 2013). Following a series of planning applications, work was carried out to upgrade Loch Road (North Lanarkshire Council, 2003). The plans were designed so that the road would act as less of a barrier to wildlife and incorporated the construction of the three culverts that pass under the road (North Lanarkshire Council, 2006). The culvert is an amphibian road tunnel, built by ACO Germany, which has a gridded roof to allow rain and natural light into the culvert and is a widely used design type in Europe (Glista, DeVault and DeWoody, 2009; White, Mayes and Petrovan, 2017).

Method of observation

To observe the amphibians, a custom made, infra-red, time lapse camera was developed and set up inside the culvert by Froglife, a UK-based charity dedicated to amphibian and reptile conservation (Froglife, 2017). Rather than use standard motion detection, which has been shown to be largely ineffective for slow moving and very small species such as amphibians (Pagnucco, Paszkowski and Scrimgeour, 2011), these cameras record images every 10 s, 24 h/day during the monitoring period. Each image captured by the camera included the time and date that it was taken. The images are later analysed using a custom made software script that applies set levels of pixel change detection between consecutive frames and is shown as a green outline highlighting the affected area, indicating movement (Figure 1). Images from the camera were collected between the 11 September and the 30 September 2016. Froglife granted the ethical approval for the study.

Previous research supports the use of camera traps as the most effective method of observing amphibians inside a culvert, as unlike the alternative methods (sand beds, ink beds and pitfall traps), camera traps are not intrusive, can identify amphibians to a species level and can provide data about time, date, behaviour and age (Veenbaas and Brandjes, 1999; Hobbs and Brehme, 2017).

Figure 1. Image taken inside the culvert under Loch Road. Highlighted in green is a common frog. Recorded at the bottom of the image is information about which camera took the image, the date and the time.

Following automated analysis to select images with detected movement, the images were analysed individually and manually using the programme FastStone (FastStone soft, 2016). Upon identifying an amphibian, information about the image was recorded. This included the date and time of photo, the species of amphibian, the direction of travel, the age class of the amphibian, the behaviour being exhibited, the number of images the individual was recorded in and the position of the amphibian in the culvert. The position that an individual was in the culvert was recorded as either left, centre left, centre, centre right or right and was determined by dividing the image up equally into vertical bands, from left to right. The position of an individual could change as it moved through the culvert and this would be recorded as the range of positions the individual moved across. The direction was recorded as either moving 'in', towards the top of the image and towards the loch, or as 'out', towards the bottom of the image and away from the loch. If an individual was observed entering the image, turning around and leaving the way it came it in, then this was recorded as either 'in/out', if it was initially moving towards the top of the image, or if the opposite was true, 'out/in'. The age of each individual was subjectively determined by its size. Large individuals were recorded as 'adult' and smaller individuals were recorded as 'juvenile'. To classify the behaviour of an individual, an ethogram constructed by Froglife was used (Table 1). An individual may exhibit multiple behaviours in the culvert, all of which would be recorded.

Common frogs were identified as having webbed feet, travelling using a series of hops and having a pointed snout (Cooke, 2004; Halliday, 2012). Common toads were distinguished by their toes being separated rather than webbed, moving by walking and having a more rounded snout (Cooke, 2004; Halliday, 2012). Using the dorsal angle of view of the camera, juvenile and female smooth newts were indistinguishable from palmate newts, and as no great crested newts were recorded in this study, all observations of newts were grouped into a single 'newt' category.

Rainfall data was retrieved from www.timeanddate.com, an organization that monitors and records weather data (Time And Date, 2017). These data were collected from the weather station at Glasgow Airport, 11 miles away from Loch Road. These data were recorded twice every hour, at 30 min intervals. This meant that rainfall data for exact times was not available. Due to this all the data from the images were organized so that it was analysed per hour (Table 2). The amount of time elapsed since last rainfall, measured in hours, was then incorporated into the data. During rainfall, the amount of time since last rainfall was recorded as 0. For the hours where there was no rainfall, the amount of time since the last known rainfall was recorded. The rainfall data was recorded in 30 min intervals at either 20 min past the hour or 50 min past the hour.

Statistical analyses were carried out using IBM SPSS version 22.0 (IBM Corp., 2013). As the variable that was

Table 1. Ethogram for behaviour of amphibians using the culvert

Behaviour	Description
Moving	Direct movement through the culvert
Creeping	A combination of small movements and hesitations
Turns	180 degree change in direction heading either back into, or out of the tunnel
Hesitant	Stationary for 1 or 2 frames before moving on (10–20 s)
Waiting	Pausing for 3 or more frames (30 s or more), often seen to pivot on the spot
Freezes	Absolutely motionless—does not trigger motion detection until moving on again
Exploring	Strong lateral or stochastic movements across the tunnel, no clear heading

Table 2. Small section of database arranged to an hourly basis, spanning hours 66–69

Hour	Amphibian count	Common frog count	Newt count	Common toad count	Time elapsed since rainfall (h)
66	2	0	0	2	0.67
67	1	0	0	1	1.67
68	3	1	2	0	2.67
69	5	4	1	0	0

investigated sought to measure the strength of an association between two sets of non-parametric, scale data, a 1-tailed Spearman's rank correlation test was used to analyse each hypothesis. The Spearman's rank correlations conducted were 1-tailed tests as the hypotheses stated which direction the correlation would be. A Kolmogorov–Smirnov test for normality was conducted for each set of data and a histogram was produced. The following variables were tested for correlation with time since rainfall: the total number of amphibians that entered the culvert; the number of amphibians that moved through the culvert to make a full crossing; the direction of amphibian travel and the numbers of juveniles and adults that were observed in the culvert. Each parameter was studied considering all amphibian species collectively as well as considering each species individually.

Results

After the automated selection from over 92 000 images, 7427 'positive' images were analysed manually, and 431 amphibians were recorded by the camera across twenty days. The majority were newts which were recorded on 205 occasions. The next most common species were common frogs, totalling 204 observations, whilst common toads were recorded on 26 occasions. 'Movement' was the most commonly recorded behaviour, being displayed in 404 instances and 338 amphibians were moving out (away from the loch), more than any other direction. There were 295 juveniles and 135 adults recorded. On the 18th day of the investigation, the lens became obscured by condensation due to a high level of mist in the tunnel and until the camera was serviced no data could be collected from the affected images. As the study was conducted during a rainy period, large amounts of the data are concentrated during rainfall or shortly after rainfall.

Hypothesis 1—The number of amphibians that moved through the culvert (in either direction) will increase as time since rainfall increases.

There was no significant correlation between the number of amphibians observed 'moving' through the culvert and the time since the last rainfall (r = −0.53, n = 157, p = 0.225). When splitting the data by species there was no significant correlation between time since rainfall and the number of 'moving' common frogs (r = −0.118, n = 106, p = 0.114) or common toads (r = −0.331, n = 19, p = 0.083). There was, however, a marginal significant correlation between the number of 'moving' newts and the time since rainfall (r = 0.173, n = 92, p = 0.049) (Figure 2). A large number of data points are concentrated during rainfall or shortly after rainfall but these data predominantly show few or no newts were observed during these hours whilst higher numbers of newts were seen per hour as time since rainfall increased.

Hypothesis 2—Fewer amphibians will be moving towards the body of water (in) as time since rainfall increases.

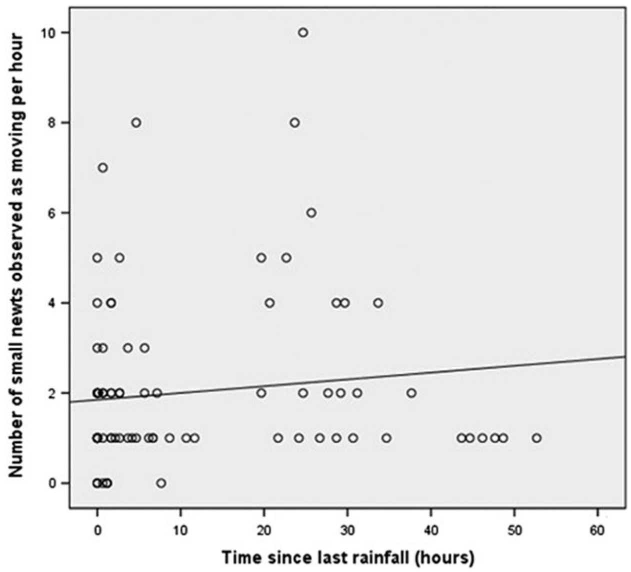


Figure 2. Scatter plot, with line of best fit, showing a marginally significant correlation between the number of 'moving' newts and the amount of time elapsed since rainfall (R^2 = 0.014). There were many hours during rainfall, or shortly after, where no newts were observed 'moving', however as time since rainfall increased more newts were 'moving' through the culvert each hour. Results of 1-tailed Spearman's rank correlation were r = 0.173, n = 92, p = 0.049. Circle thickness indicates frequency of data point.

A highly significant correlation was found between the number of amphibians moving in the 'in' direction, towards Frankfield Loch and the amount of time since rainfall (r = −0.213, n = 157, p = 0.004) (Figure 3). Splitting the data by species revealed that a highly significant correlation existed between common toads moving into the culvert and the amount of time since rainfall (r = −0.728, n = 19, p = <0.001) (Figure 4). No significant correlations were found for common frogs (r = −0.118, n = 106, p = 0.114) or for newts (r = −0.125, n = 92, p = 0.118).

Hypothesis 3—More amphibians will be moving away from the body of water (out) as time since rainfall increases.

There was no significant correlation between the number of amphibians moving in the 'out' direction, away from the Loch, with the amount of time elapsed since the last rainfall (r = 0.37, n = 157, p = 0.325). Splitting the data by species however found that highly significant correlations existed for common toads (r = 0.531, n = 19, p = 0.010) and newts (r = 0.272, n = 92, p = 0.004) (Figure 5). No significant correlation was found for common frogs (r = −0.099, n = 106, p = 0.156).

Hypothesis 4—Fewer amphibians will be observed using the culvert as time since rainfall increases.

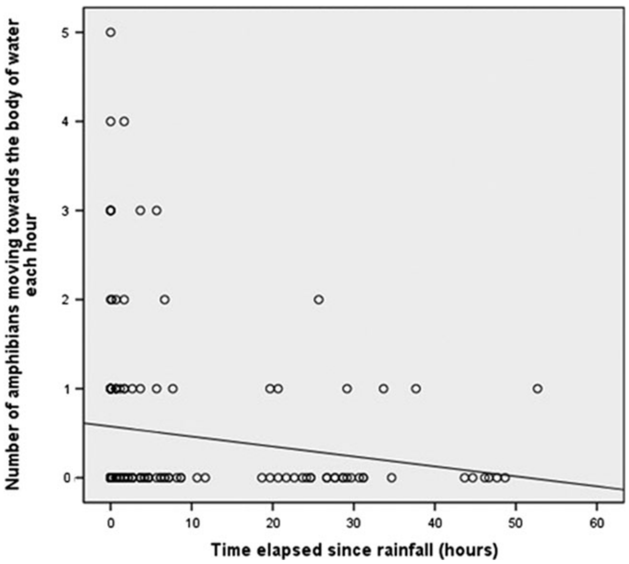


Figure 3. Scatter plot, with line of best fit, showing a significant correlation between the number of amphibians that moved into the culvert, towards Frankfield Loch and the amount of time since rainfall ($R^2 = 0.025$). Results of 1-tailed Spearman's rank correlation were as follows: $r = -0.213$, $n = 157$, $p = 0.004$. Circle thickness indicates frequency of data point.

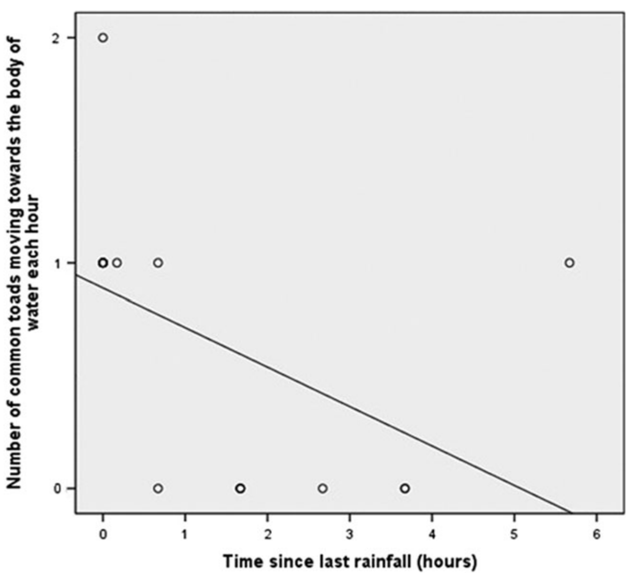


Figure 4. Scatter plot, with line of best fit, showing how fewer common toads moved into the culvert and towards Frankfield Loch in correlation with the amount of time elapsed since rainfall ($R^2 = 0.249$). Results of 1-tailed Spearman's rank correlation were as follows: $r = -0.728$, $n = 19$, $p = < 0.001$. Circle thickness indicates frequency of data point.

There was a highly significant correlation between the number of amphibians using the culvert with the amount of time elapsed since the last rainfall ($r = -0.158$, $n = 468$, $p = < 0.001$) (Figure 6). Splitting the data according to species found that highly significant correlations existed for common frogs ($r = -0.190$, $n = 468$, $p = <0.001$) and common toads ($r = 0.148$, $n = 468$, $p = 0.001$) (Figure 7).

Hypothesis 5—The number of juvenile amphibians using the culvert will decrease as time since rainfall increases.

There was a significant correlation between number of juveniles and the amount of time since the last rainfall ($r = -0.106$, $n = 468$, $p = 0.011$) (Figure 8). Dividing the data by species revealed that there was a significant correlation for newts ($r = 0.214$, $n = 92$, $p = 0.020$) (Figure 9) but not for common frogs ($r = 0.016$, $n = 106$, $p = 0.436$) and common toads ($r = 0.281$, $n = 19$, $p = 0.122$).

Hypothesis 6—The number of adult amphibians using the culvert will decrease as time since rainfall increases.

There was a highly significant correlation between the number of adults using the culvert each hour and the amount of time elapsed since rainfall ($r = -0.157$, $n = 168$, $p = < 0.001$) (Figure 10). Splitting the data by species revealed that significant correlations existed for both common frogs ($r = -0.175$, $n = 106$, $p = 0.037$) and common toads ($r = -0.445$, $n = 19$, $p = 0.028$) (Figures 11). No significant correlation was found for newts ($r = -0.087$, $n = 92$, $p = 0.204$).

Discussion

Culvert usage

A significant correlation was found when the number of amphibians using the culvert was compared with the amount of time elapsed since rainfall. As the time since rainfall increased, fewer common toads and common frogs were observed using the culvert. This correlation was not found to exist for newts. Glista, DeVault and DeWoody (2009) and Jackson (1996) report that many amphibians require wet conditions in culverts before they use them. The culvert under Loch Road is grated to allow in rain. However, the rainfall is unlikely to remain in the culvert for long as it was designed to maintain hydrological links between the loch and the surrounding environment (North Lanarkshire Council, 2006; GCV Green Network, 2013). Therefore, it is possible that the culvert not being wet enough could be a possible explanation for the negative correlation between common frogs and common toads using the culvert and the time elapsed since the last rainfall.

Furthermore, it has been reported that amphibians prefer wet conditions for migration in general, which may also be a factor influencing the negative correlation (Jackson, 1996). To better understand the factors responsible for fewer common frogs and common toads using the culvert, further study, which contrasts both the numbers of amphibians moving outside the culvert and across the road with the numbers of

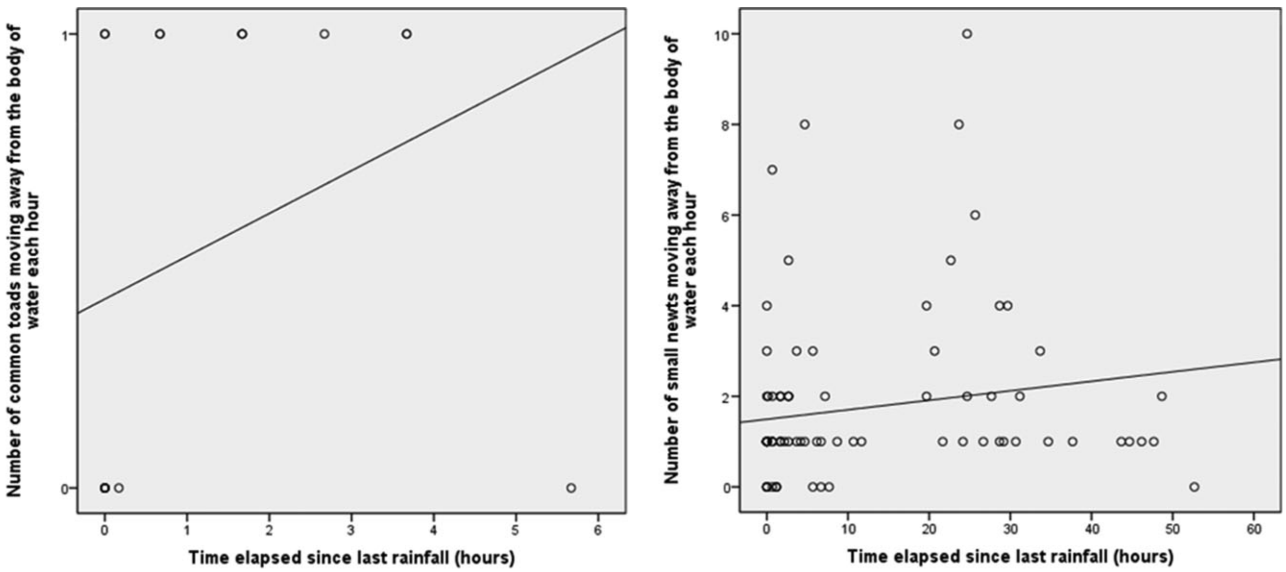


Figure 5. Scatter plots, with line of best fit, showing correlation between the amount of time since rainfall and (left) the number of common toads moving out of the culvert away and from Frankfield Loch ($R^2 = 0.093$) ($r = 0.531$, $n = 19$, $p = 0.010$) and (right) the number of newts moving out of the culvert ($R^2 = 0.028$) ($r = 0.272$, $n = 92$, $p = 0.004$). Circle thickness indicates frequency of data point.

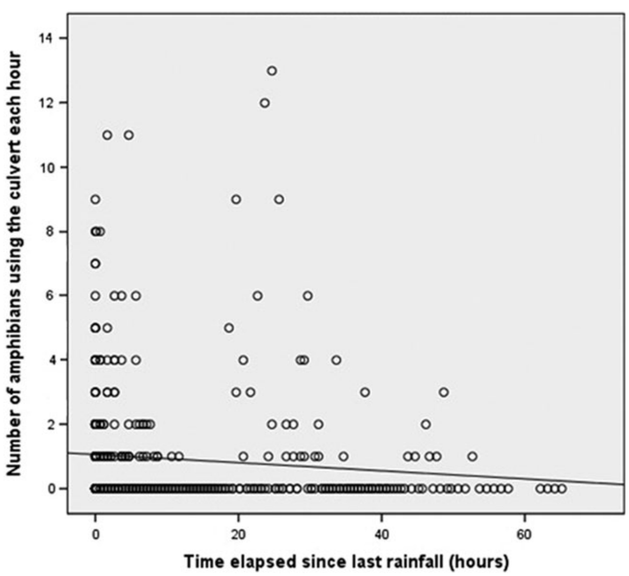


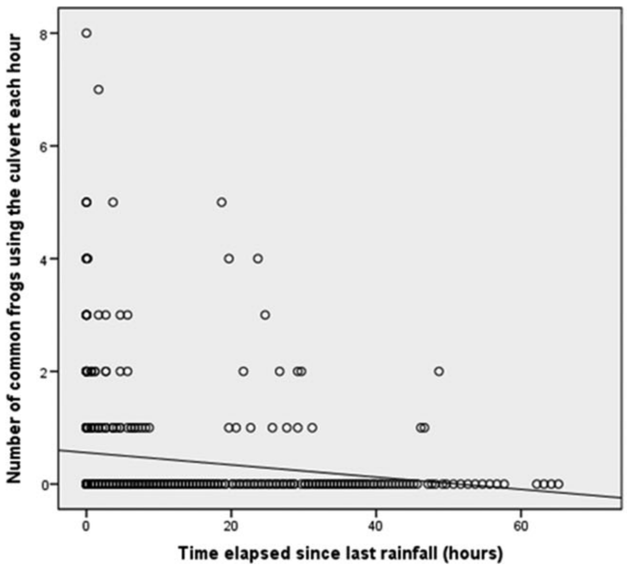
Figure 6. Scatter plot, with line of best fit, showing that fewer amphibians used the culvert in correlation with the amount of time elapsed since the rainfall ($R^2 = 0.010$). Results of 1-tailed Spearman's rank correlation were as follows: $r = -0.158$, $n = 468$, $p = < 0.000$. Circle thickness indicates frequency of data point.

amphibians using the culvert, in correlation with the time elapsed since last rainfall, would be required. In this study, only one culvert was used but it would be beneficial if future studies could involve more culverts. Being able to compare different culvert designs (such as ones that are not designed to maintain hydrological links) would help clarify the effect that the internal conditions of the culvert had on the results.

No significant correlation was found to exist between the number of newts using the culvert and the time elapsed since rainfall. One of the limitations of the study was that the camera was unable to distinguish between smooth newts and palmate newts. The newt category therefore was a combination of both smooth and palmate newts and this may well have influenced the results. To better understand how time elapsed since rainfall influences smooth and palmate newt usage of culverts, further investigation will be required. An alternative method to the infra-red camera, potentially pitfall traps, would be needed so as to distinguish the two newt species but this has substantial bias implications in terms of influencing the behaviour of the newts.

Another limitation of the study is that the rainfall was not recorded at the study site but at the weather station at Glasgow Airport which may result in slight disparities between the recorded rainfall and the actual rainfall. These differences, however, would be minimal and unlikely to impact the results. It would be preferable if in future studies rainfall could be recorded at the study site.

The study took place over a 20-day period in September which is a relatively short timeframe. Although previous research has shown that amphibian migration away from breeding sites does occur during this timeframe (Sinsch, 1988; Miaud, Guyétant and Elmberg,1999; Matos *et al.* 2017), further research would benefit from extending the duration of the study.



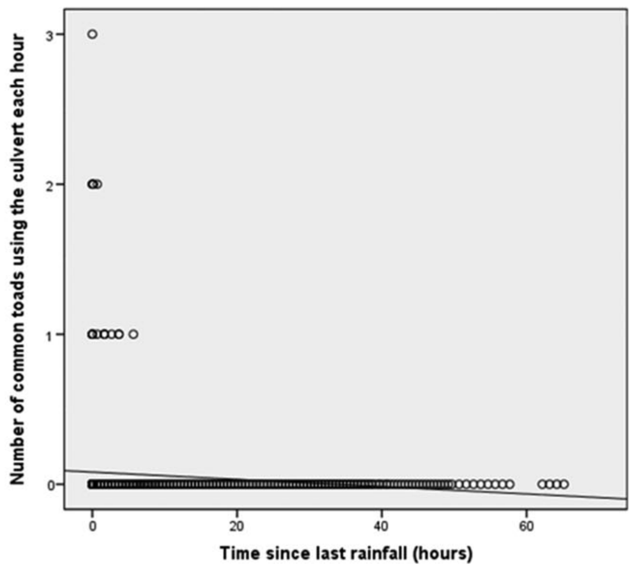


Figure 7. Scatter plots, with line of best fit, showing correlation between the amount of time elapsed since rainfall and (left) the number of common frogs that used the culvert ($R^2 = 0.026$) ($r = -0.190$, $n = 468$, $p = <0.001$) and (right) between the number of common toads that used the culvert ($R^2 = 0.017$) ($r = 0.148$, $n = 468$, $p = 0.001$). Circle thickness indicates frequency of data point.

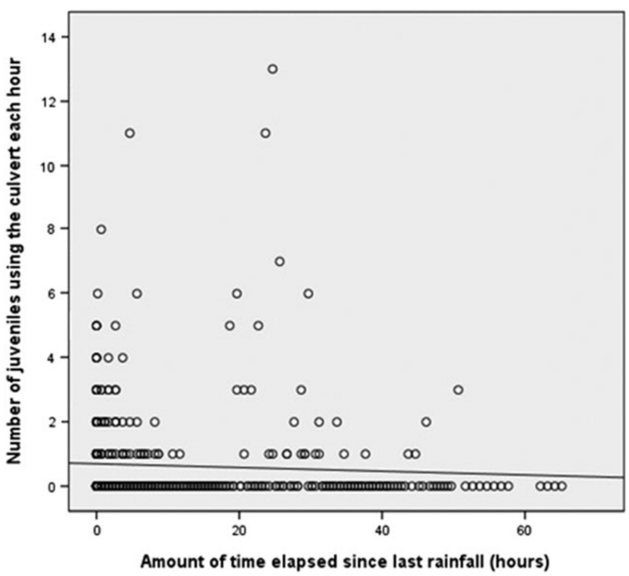


Figure 8. Scatter plot, with line of best fit, showing correlation between the number of juveniles that used the culvert and the amount of time since rainfall ($R^2 = 0.003$). Results of 1-tailed Spearman's rank correlation were as follows: $r = -0.106$, $n = 468$, $p = 0.011$. Circle thickness indicates frequency of data point.

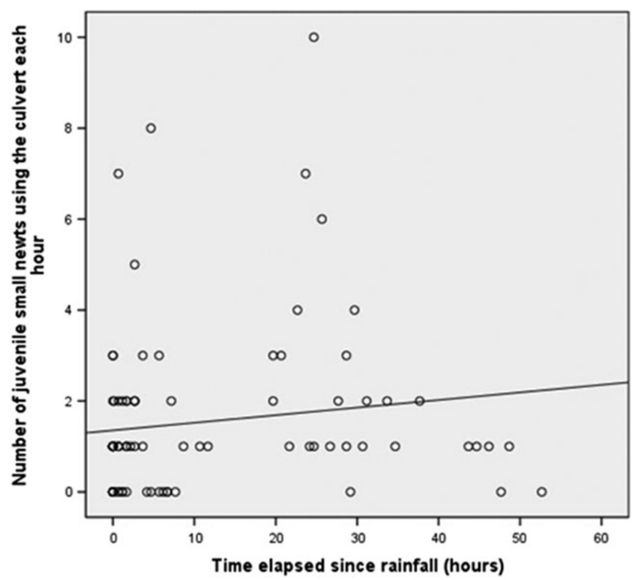


Figure 9. Scatter plot, with line of best fit, showing correlation between the number of juvenile newts that used the culvert and the amount of time elapsed since the last rainfall ($R^2 = 0.018$). Results of 1-tailed Spearman's rank correlation were as follows: $r = 0.214$, $n = 92$, $p = 0.020$. Circle thickness indicates frequency of data point.

Direction of travel

As time since rainfall increased, significantly fewer common toads were travelling in the 'in' direction, towards Frankfield Loch. Alongside this, as time since rainfall increased, significantly more common toads and newts were observed moving in the 'out' direction, away from Frankfield Loch. No correlation, in either direction of travel, was found to exist when common frogs were compared with time since rainfall. The results would suggest that an increasing absence of rainfall encourages common toads and newts to move away from the loch, in the 'out' direction.

As common toads and newts migrate away from breeding sites and towards terrestrial areas, the correlations that exist between direction of travel and time since rainfall may suggest that an increasing absence of rainfall encourages migration towards terrestrial sites. This, however, contradicts previous research that states that common toads and other amphibians typically prefer wet conditions for migration (Sinsch, 1988; Jackson, 1996; Glista, DeVault and DeWoody, 2009).

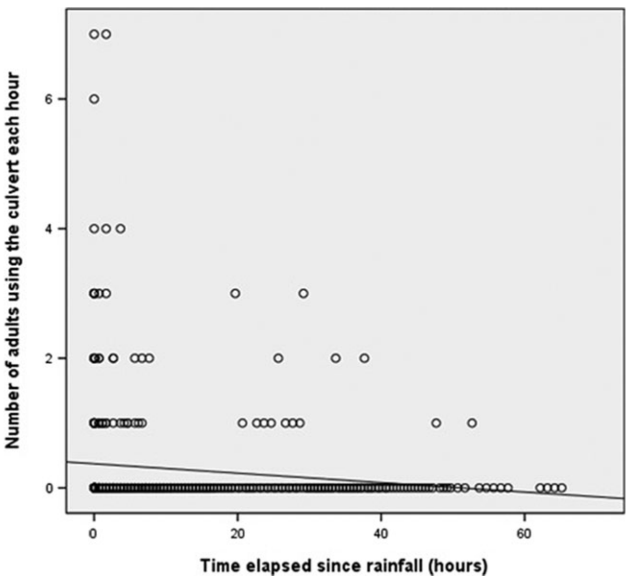


Figure 10. Scatter plot, with line of best fit, showing correlation between the number of adults that used the culvert and the amount of time since rainfall ($R^2 = 0.017$). Results of 1-tailed Spearman's rank correlation were as follows: $r = -0.157$, $n = 168$, $p = < 0.001$. Circle thickness indicates frequency of data point.

Significantly more juvenile newts and common frogs were observed in the culvert as time since rainfall increased whilst significantly fewer adult common toads were found using the culvert as time since rainfall increased. This, combined with more amphibians moving away from Frankfield Loch, would indicate that an increasing absence of rainfall may result in an increase in juvenile dispersal (Rothermel, 2004; Cushman, 2006; Matos *et al.* 2017). This too, however, would contradict what previous research has found as juveniles also favour wet conditions for dispersal (Rothermel, 2004; Cushman, 2006).

The habitat surrounding Frankfield Loch is a wetland and the culverts that run under Loch Road are designed to establish a hydrological link between the loch and the surrounding wetlands (North Lanarkshire Council, 2006; GCV Green Network, 2013). It may, therefore, be possible that the surrounding area remains wet enough to still favour dispersal, even after extended periods of no rainfall (Lesbarrères, Lodé and Merilä, 2004).

As discussed by Elewa (2005), a decrease in barometric pressure, which is brought about by a decrease in rainfall, may encourage amphibians to initiate migration (Tao *et al.* 2011). Juvenile dispersal may also be prompted by a decrease in barometric pressure (Osbourn, 2012). It may therefore be possible that as the culvert maintained hydrological links between the loch and the surrounding environment, the conditions remained wet and juvenile newts instead used a decrease in barometric pressure as a cue to begin migrating

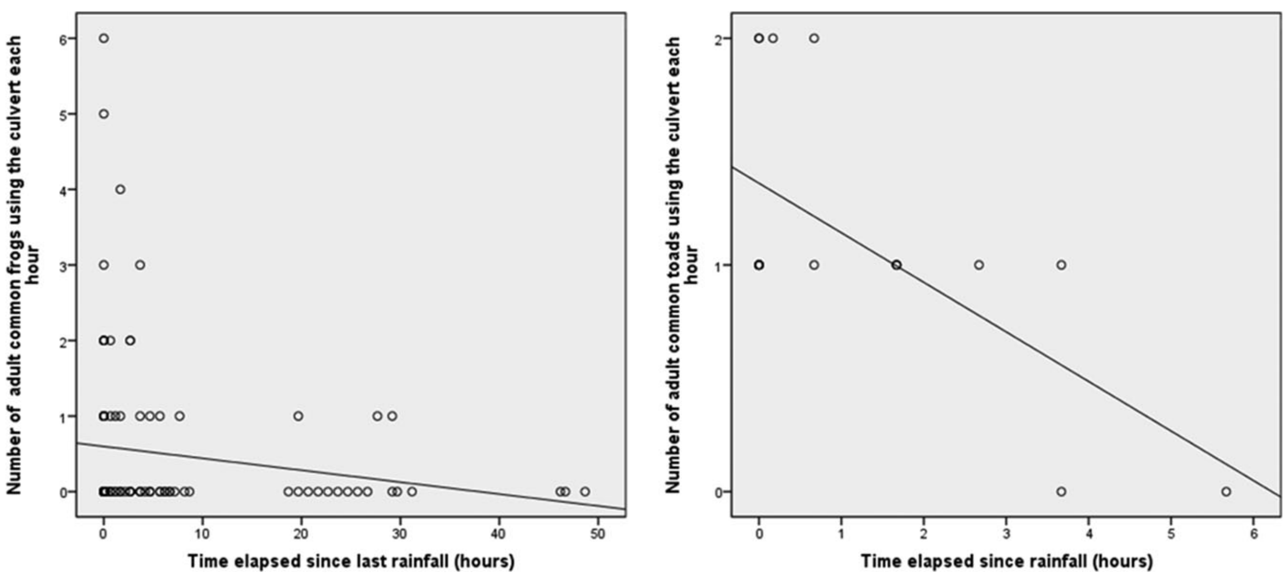


Figure 11. Scatter plots, with line of best fit, showing correlation between the amount of time elapsed since the last rainfall and (left) the number of adult common frogs that used the culvert ($R^2 = 0.028$) ($r = -0.175$, $n = 106$, $p = 0.037$) and (right) between the number of adult common toads that used the culvert ($R^2 = 0.409$) ($r = -0.445$, $n = 19$, $p = 0.028$). Circle thickness indicates frequency of data point.

and dispersing. In order to better understand this, further research is required that focuses on comparing barometric pressure with dispersal away from breeding sites.

Implications for culvert design and amphibian conservation

Our study found that a lack of rainfall saw more juveniles moving through the culvert. Schmidt and Zumbach (2008) suggest that imperfections in culvert design are more pronounced for juveniles and are likely to be less effective for them, compared to adults. This would imply that an increasing lack of rainfall may see more juveniles avoiding or failing to use mitigation measures. It is, therefore, recommended that culverts in locations which experience extensive periods of no rainfall during times of juvenile dispersal, should pay careful attention to the specific preferences in culvert design exhibited by the target species and particularly juveniles.

One of the factors that may have been responsible for contradictions between the results of this study and previous studies is that the culvert was designed to provide a hydrological link between the loch and the surrounding habitat (North Lanarkshire Council, 2006; GCV Green Network, 2013). Although this may have maintained wet conditions in the surrounding habitat, it may have caused water not to remain in the culvert for long, leaving the culvert too dry for amphibians. Amphibians require wet conditions to prevent desiccation of their skin (Lesbarrères, Lodé and Merilä, 2004) and may, therefore, have avoided using the culvert if it was not wet enough. Therefore, the ideal design would hold water in the culvert for longer, as is also reported by Glista, DeVault and DeWoody (2009) but without being flooded (Schmidt and Zumbach, 2008). This may be difficult to achieve in practice as water levels are likely to vary substantially at most sites. The design feature with the slotted top surface as in the studied tunnel is likely to have substantial advantages by allowing free temperature and humidity exchange between the tunnel and the outside environment but there are potentially problematic inflows of heavily polluted water from the road surface (White, Mayes and Petrovan, 2017). This design feature, however, should be considered in the development of other culverts to maximize their effectiveness but might require additional measures, such as annual cleaning in early spring to remove road salt and other pollutants that might accumulate over winter.

Conclusion

This study found that as time since rainfall increased, fewer common toads and common frogs would use the culvert under Loch Road. The results of the investigation also suggest that more newts and common toads would move away from Frankfield Loch and more juvenile newts would use the culvert, as time since rainfall increased. This contradicts previous research and may have been a result of a decrease in barometric pressure that is associated with a decrease in rainfall. The study recommends careful consideration of the design of each culvert, particularly with regards to juveniles, and that where possible the culvert should hold water for longer. This study provides insight into how rainfall affects the behaviour and culvert use of common frogs, common toads and newts.

Author's biography

Tim Gleeson studied Animal Behaviour at the University of Chester and this research is part of his undergraduate dissertation. His fields of interest include conservation and animal welfare.

Silviu Petrovan was Conservation Coordinator at Froglife where he remains a trustee and is a Research Associate at University of Cambridge. He set up the monitoring work, contributed to designing the equipment and automated analysis and provided the camera trap images.

Anna Muir is a lecturer in Conservation Biology at the University of Chester and supervised the research.

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