RESEARCH ARTICLES

Population declines of Common Toads (*Bufo bufo*): the contribution of road traffic and monitoring value of casualty counts

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ABSTRACT — Routine counts of Common Toads (*Bufo bufo*) killed by road traffic were used to demonstrate synchronous population declines since the late 1980s at three breeding sites in Cambridgeshire. All factors that might have contributed to the declines were considered in turn. It was concluded that road mortality of adult toads played a significant part at each site, although other factors were also implicated, especially habitat modifications. The level of local traffic flow was likely to have resulted in unsustainable losses, and counts decreased more rapidly on the busier roads. The use of counts of dead toads as a monitoring technique is discussed and suggestions made. A data-set of casualty counts needs careful interrogation, with analysis concentrating particularly on counts in the recent past.

SINCE Blaustein & Wake (1990) drew attention to the decline of many amphibian species in different parts of the world, this subject has generated considerable debate and concern. In Britain, we have been aware of amphibian population decreases for rather longer, the Common Toad (*Bufo bufo*) being one of the species for which regional declines occurred in the first half of the twentieth century. Declines of the toad began during the early 1940s when the war effort demanded more effective agricultural operations, and populations suddenly decreased in intensively farmed areas such as the East Anglian Fens (Cooke & Ferguson, 1976). After the Second World War, agricultural intensification continued and this, together with loss of habitat in and around towns, led to widespread population declines of the toad in the 1950s and 1960s (Cooke, 1972). These decreases slowed in the 1970s, with the continual erosion of suitable habitat being partially offset by the creation of garden ponds, particularly in England (Cooke & Scorgie, 1983). However, in the 1980s there were signs of further declines in parts of central and southern England (Hilton-Brown & Oldham, 1991). By this time, conservationists were showing increasing interest in toads, in particular by attempting to reduce mortality by carrying toads across roads (Langton, 1989). In the mid 1990s, a survey of these volunteer patrols revealed that a high proportion believed their local toad populations to be declining (Foster, 1996). Following on from this observation, Carrier & Beebee (2003) undertook a postal enquiry and found for the period 1985-2000 that there had been significant declines in Common Toad populations in central, eastern and south eastern England. Underlying reasons for these population decreases were unclear, but they occurred for populations outside gardens and parks, and the Common Frog (*Rana temporaria*) remained relatively unaffected (Carrier & Beebee, 2003).

This paper examines in detail one particular area in Cambridgeshire to determine whether recent declines occurred in Common Toad populations and, if they did, to attempt to unravel the factors responsible. While the situation may or may not be typical of those highlighted as of concern by Carrier & Beebee (2003), its recorded history up to 1980 broadly reflected that described

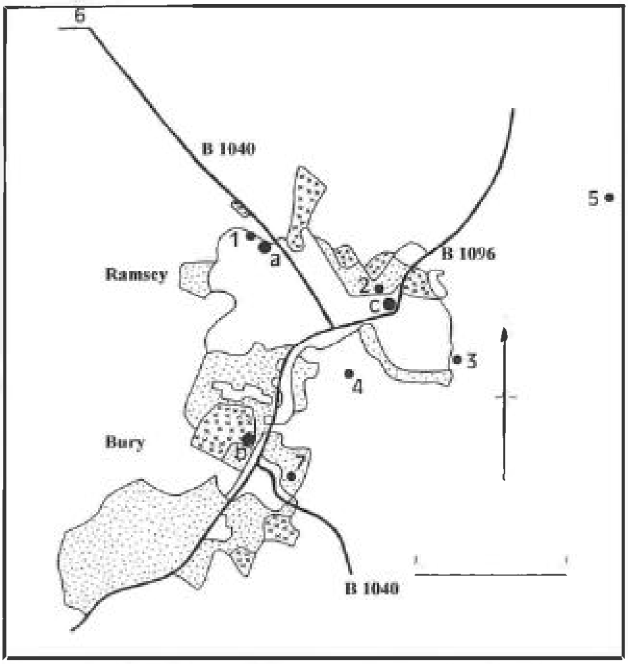

Figure 1. Sketch map of the area of Ramsey and Bury showing the main roads (thick lines) and the extent of development up to about 1950 (unshaded), 1975 (stippled) and 2000 (small crosses). The main toad breeding sites are marked by large black dots: (a) Field Road Pond, (b) Bury Pond and (c) Horse Pond. Other sites are numbered 1–7, as listed in Table 4; these are indicated by smaller dots, apart from no.6, which is a length of river beside the B 1040. The scale bar is 1 km.

above. Thus Common Toad populations decreased in this part of the country from the early 1940s through to the 1960s, before stabilising in the 1970s (Cooke & Ferguson, 1974, 1975; Cooke & Scorgie, 1983). This location is also in the centre of that part of the England where the recent declines have occurred (Carrier & Beebee, 2003).

The study utilises routine counting of road casualties as a method for monitoring population declines, so it is necessary to discuss what information such counting might provide.

WHAT CAN MONITORING NUMBERS OF ROAD CASUALTIES TELL US ABOUT POPULATION CHANGE?

In Britain, the recommended method for surveying populations of Common Toads is to count heads at night during the height of the breeding season (Griffiths & Inns, 1998). However, toads often breed in large, deep, turbid bodies of water that present logistical or safety problems for a surveyor, particularly at night. The possibility has been explored of utilising more readily achievable types of counts, including counts of road casualties (Cooke, 2000 and unpublished). At one of the sites examined in this paper, numbers of toad casualties counted on the roads over a period of 10 years or more were positively related to counts of live toads in the breeding site and to spawn production.

Hels & Buchwald (2001) modelled the probability of survival of an individual toad crossing a road, arguing that its chances depended on the number of vehicles passing per unit time, the killing width of the wheels, the velocity of the toad and its angle of crossing. Whether a casualty is recorded by an observer depends on how soon the count is made and on carcass persistence, which is related to the activity of scavengers and to weather conditions (Hels & Buchwald, 2001; Slater, 1994). A single count will detect only a (small) proportion of toads killed during migration, but systematic annual counts of casualties should reflect changes in the toad population if all the above factors remain unchanged. At most sites in this country, it is probable that frequency of road traffic has increased over time; and average tyre width is also likely to have increased. Therefore, if the number of adults breeding at a site does not change significantly from year to year, and neither do the other factors listed, then numbers killed by traffic should increase. If traffic levels continue to rise, toad losses may become unsustainable and the population will begin to decline. As a result, number of casualties recorded annually will level out, then progressively decrease.

This means that a situation where casualty counts increase over several years, although worrying for conservationists, indicates a stable or even an increasing toad population if the other factors apart from traffic remain constant. On the other hand, decreasing numbers of road casualties may indicate a declining population. While such a population reduction may have been caused by the road traffic, it may instead have occurred for other unrelated reasons, such as a reduced carrying capacity of the local environment, and simply be mirrored by the numbers killed on the roads.

SITE DESCRIPTIONS

Ramsey is a market town in Cambridgeshire at the south western edge of the Fens. The human population of the parish of Ramsey was 8080 in 2001, an increase of 37% over that of 1981 (Cambridgeshire County Council Research Group statistics). The nearby village of Bury was separate from Ramsey up to 1950, but expansion of both means there is no longer any clear separation (Figure 1). The human population of the parish of Bury was 1760 in 2001, an increase of 81% when compared with 1981. The large area developed to the south west of the centre of Bury during 1950–1975 (Figure 1) was primarily housing and other buildings constructed for the Royal Air Force.

Within the Ramsey/Bury area in recent decades, there have been three principal breeding sites for Common Toads (Figure 1a, b and c):

Field Road Pond. This pond (grid reference TL 283856) was created as a ballast pit in 1864 when Ramsey's northern railway station was built. The station and track were dismantled in the early 1970s. The pond is beside Field Road, one of the busier domestic roads of the town and is about 100 m from the B 1040, the main road out of Ramsey to the north west (Figure 1). The surface of the pond measures about 45 x 30 m, and it has a terrestrial margin of about 5 m, much of it covered by scrub and trees. Restricted access to the banks and the often turbid nature of the water has made systematic counting of breeding toads impossible.

Bury Pond. Washing lagoons were created behind a vegetable processing plant (TL 282843) in the 1950s. Toads evidently did not colonise immediately, but were common by the early 1980s. The site was progressively surrounded by housing during the 1970s and 1980s, and the plant itself was pulled down in 1988 to make way for new houses. One modified pond was retained specifically as a toad breeding site and is now managed by the Cambridgeshire Wildlife Trust. The dimensions of the pond are about 25 x 15 m, with a terrestrial margin of about 5 m. The pond is about 100 m from the main Ramsey-Huntingdon road, the B 1040. A traffic count on this road in 2002 was 6679 vehicles in 12 hours, an increase of 11% over 1992 (Cambridgeshire County Council, 2002). Because there has been ready access to most of the pond's edge and the water is usually clear, it has been possible to make regular counts of breeding toads and to monitor amounts of spawn by means of an index (Cooke, 2000). Bury Pond is 1.3 km in a straight line from Field Road Pond.

Horse Pond. Horse Pond is beside the B 1096 (at TL 292852). It has a hard sloping bottom, so that passing horses could be watered, and has been a feature of the town for centuries. It measures roughly 25 x 45 m with grassy margins varying between 1 and 6 m. Since the 1980s, a resident population of up to 40 semi-domesticated Mallards (*Anas platyrhynchos*) has made the pond very turbid, thereby precluding routine counting of breeding toads. Horse Pond is 1.3 km from Bury Pond and 0.9 km from Field Road Pond.

TOAD CASUALTY COUNTS

Each of these three sites has minimal terrestrial habitat in which toads might live, and animals evidently migrate over considerable distances to breed. Elsewhere toads often migrate >1 km (eg Sinsch, 1989). Because of the spacing of the breeding ponds in Ramsey and Bury, toads occur throughout the area depicted in Figure 1. In spring, dead toads may be found on roads anywhere in the area, but tend to be concentrated close to the three breeding sites. Casualties were counted on about 1.3 km of roads near Field Road Pond each year 1974–2003. Near Bury Pond, casualties were counted from 1990 to 2003 on a road circuit around the pond of 1.6 km (including

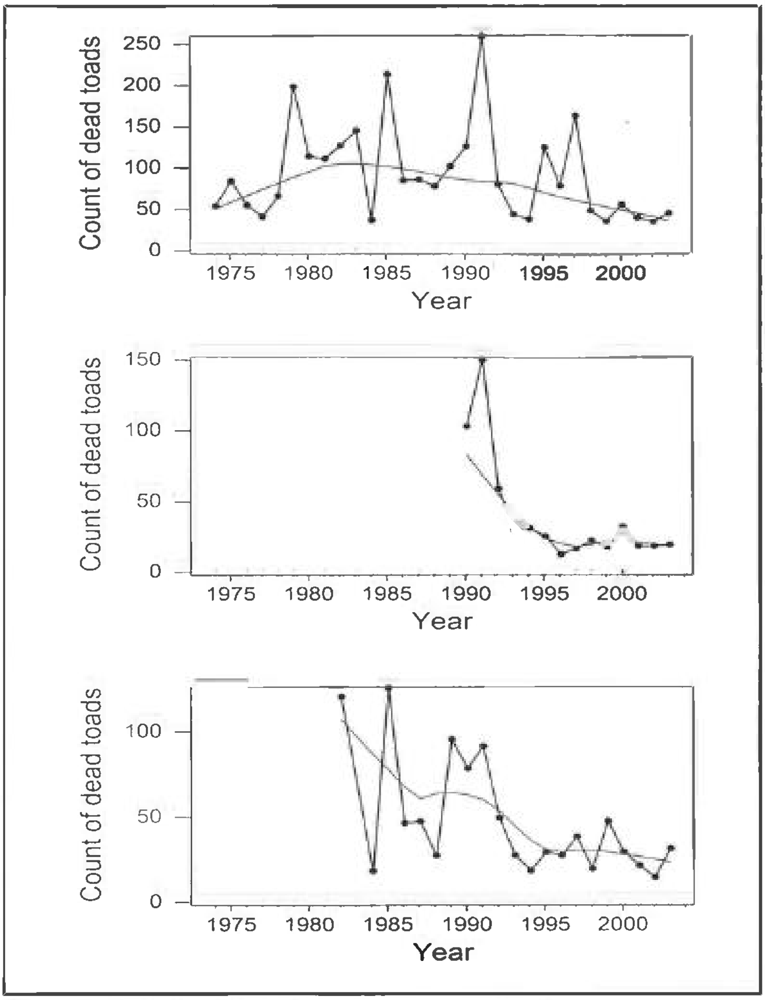

Figure 2. Annual peak casualty counts at the three toad breeding sites. A distance weighted (LOWESS) line indicates the underlying trends. a (top): Field Road; b (centre): Bury; c (bottom): Horse Pond. Note the different vertical scales.

a 500 m stretch of the B 1040). At Horse Pond, dead toads were counted along a 250 m length of the B 1096 in 1982 and from 1984 to 2003. During the toad breeding season, brief checks were made on most days to ascertain when peak numbers of casualties appeared to occur. When this happened, casualty counts were made on foot during daylight. If further appreciable mortality was noted in the same breeding season, counts were repeated as necessary and the highest figure used for that year. Earlier counts at Bury and Field Road Ponds are given in Cooke (1995 and 2000).

Casualty counts are shown for the three breeding sites in Figure 2. Regression coefficients are given in Appendices 1–3 for log_e(count + 1) against year for all periods of at least 10 years, with significant ones being emboldened. No adjustment was made for significance in the large number of comparisons in order to retain meaningful patterns in the significant coefficients. Focusing first on the Field Road data (Figure 2a and Appendix 1), the earlier coefficients for successive data-sets, 1974-year x, tended to be positive and the later ones negative. Only the earliest positive analysis, for 1974–1983, was statistically significant, whereas many of the later negative ones were significant. Thus, had only part of this 30 year period been recorded, any conclusion would have been dependent on the years covered. A distance weighted (LOWESS) line has been superimposed in Figure 2a to indicate the underlying trend; numbers increased to a peak in the early 1980s, then decreased to 2003. Data for Bury Pond showed negative coefficients for all periods of at least 10 years, with most being significant (Appendix 2). Smoothing the transformed data suggested a rapid decrease from 1990 to about 1997 (Figure 2b). At Horse Pond, a few early coefficients were positive, but the great majority were negative, with many of the later ones being significant (Appendix 3). Smoothing the transformed data indicated an overall decrease (Figure 2c).

Comparing transformed casualty counts between the three sites showed positive and significant relationships: Field Road Pond vs Horse Pond, Pearson correlation coefficient = 0.773 ($P < 0.001$); Field Road Pond vs Bury Pond, 0.540 ($P < 0.05$); Horse Pond vs Bury Pond, 0.689 ($P < 0.01$). This pointed to synchronous declines in counts at the three sites. By monitoring events in the Bury Pond, it is known that the breeding population has decreased significantly since 1990 (Cooke 2000 and unpublished), and the evidence based on casualty counts therefore indicated similar population changes at the other two sites. Examination of the regression relationships for count data during 1985-2003 and 1990–2003 suggested that the greatest rate of decline occurred at Bury Pond (Table 1). The start date of 1985 was selected because Carrier & Beebee (2003) chose the time period of 1985–2000 for their enquiry; and the start date of 1990 was the year that casualty counting began on the road circuit around Bury Pond. Regression coefficients were consistently more negative for 1990–2003 than for 1985–2003 (Table 1).

Site	1985–2003		1990-2003	
	Coefficient ±SE	Proportional annual loss	Coefficient ±SE	Proportional annual loss
Field Rd Pond				
All roads	-0.075 ± 0.023**	0.07	-0.105 ± 0.039*	0.10
Field Road	-0.125 ± 0.026***	0.12	-0.162 ± 0.044**	0.15
Star Lane	-0.037 ± 0.028	0.04	-0.069 ± 0.044	0.07
Bury Pond				
All roads	-	-	-0.145 ± 0.039**	0.13
B 1040	-	-	-0.215 ± 0.043***	0.19
Estate roads	-	-	-0.131 ± 0.052*	0.12
Horse Pond				
B1096	-0.077 ± 0.022**	0.07	-0.086 ± 0.033*	0.08

Table 1. Regression coefficients and proportional annual loss for log_e(casualty counts + 1) at the three sites, 1985–2003 and 1990–2003. *significant relationship $P < 0.05$, ** $P < 0.01$, *** $P < 0.001$

REASONS FOR POPULATION DECREASES

Potential reasons for changes in population size are listed in Table 2. It is also necessary to consider factors that might modify casualty counts (Table 3). While the main focus is on identification of reasons for population declines between 1985 or 1990 and 2003, it is recognised that factors responsible may have started to influence toad numbers prior to 1985. Potentially important factors, both for population decreases and for modifying counts, are italicised in the Tables and discussed below.

Reduction in the surface area of the breeding site. At Bury, the three ponds that existed up to 1988 were reduced to a single pond, with a decrease in surface area of about 75%. This may have limited recent reproductive potential.

Reduction in breeding site depth. In the autumn of 1992, Cambridgeshire Police drained the Field Road Pond when searching unsuccessfully for a missing person. The water surface never returned to its previous level and remained about 50 cm lower than before, perhaps affecting reproductive output.

Amount of vegetation. High densities of aquatic vegetation may may decrease tadpole survival, but little marginal vegetation may reduce toadlet survival (Young & Beebee, 2002). Since the 1980s, Horse Pond has had impoverished aquatic and marginal plant communities because of the presence of large numbers of ducks.

Failure to produce toadlets. At Bury, metamorphic success was visually assessed as poor, moderate or good each year from 1987 until 1998. During five of the first six years, 1987–1992, metamorphosis was good, whereas during 1993–1998 it was good in only one year. Areas of open water have persisted at this site, and increasing density of aquatic vegetation (Young & Beebee, 2002) seems unlikely to have reduced tadpole survival. Reading & Clarke (1999) suggested that when toads spawn earlier in warmer springs the resulting tadpoles might suffer higher

Factor	Bury Pond	Field Road Pond	Horse Pond
Breeding site			
Surface area	*Large reduction late 1980s*	No change	No change
Depth	No change	*Reduction in 1990s*	No change
Amounts of aquatic and marginal vegetation	Usually balanced amounts	Impoverished throughout study period	*Generally poor for aquatic higher plants and marginals since 1980s*
Point source pollution	No evidence of any pollution incidents	No evidence	No evidence
Breeding season			
Failure to spawn	No	Not studied	Not studied
Spawn loss	Nothing unusual seen	Not studied	Not studied
Failure to produce toadlets	*General failure 1993-8*	Not studied	Not studied
Waterfowl	Sporadic presence	Low numbers present	*Unusually high numbers since 1980s*
Competition from frogs	*Frogs increased greatly and mixed pairs seen*	No frogs seen	*Frogs increased*
Human predation or collection	No evidence	*Traditional site for collection by children*	No evidence
Terrestrial habitat			
Surrounding land developed	*Large change in recent decades*	*Some change*	*Some change*
Migration impeded	*Greatly impeded by fences and walls*	*Impeded to a more limited extent*	*As at Field Road*
Increase in traffic on existing roads	*Yes*	*Yes*	*Yes*
Extra roads	*Yes*	No	Not recently
Change in behaviour			
Move to garden ponds	*Some reports*	*Some reports*	*Some reports*
Move to other sites	No evidence	*Increases noted in 1990s*	*Increases noted in 1980s and 1990s*
Miscellaneous			
Disease	No evidence of incidents	No evidence	No evidence
Diffuse pollution	Not studied	Not studied	Not studied
Climate change	*Warmer springs may help to increase chance of frog/toad mixed pairs*	Unknown	As at Bury

Table 2. Evidence for factors that might have contributed to the recent observed declines in toad populations. Potentially important factors are in italics.

mortality, but no relationship was found at Bury Pond between the date of the casualty count and metamorphic success.

Presence of waterfowl. Since the 1980s, Horse Pond has had a large resident population of Mallard, and these have been regularly fed by local people. This has led to permanently turbid conditions with a reduced diversity of aquatic plants; and the ducks may also feed on spawn and tadpoles. However, in experiments with caged tadpoles elsewhere in this area, larval growth and development rate have been good in enriched sites (Cooke, 1981), and the waterfowl may not, on balance, be detrimental to toads.

Competition from frogs. Common Frogs increased in Ramsey and Bury during the study period, spawn production peaking at 283 clumps in 2002 in Bury Pond and 44 clumps in 2001 in Horse Pond. At Bury Pond, mixed pairs, consisting of a frog and a toad, have been occasionally seen since 1990. If a male frog mates with a female toad, the toad's reproductive output will be lost for that year. Inter-specific mating may have become progressively more serious for the survival of the Bury toads as they have become rarer and male frogs more abundant. However, this seems an unlikely mechanism to have caused the toad declines of the early 1990s. Another recent threat to the toad population in Bury Pond is that the hundreds of thousands of frog tadpoles that hatch each year may outcompete the toad tadpoles or inhibit their development.

Human predation or collection. Field Road Pond has always attracted children during the toad breeding season. Numbers of adults, spawn and tadpoles have been regularly removed from the site over the last 30 years. Such losses in the 1970s and early 1980s were apparently not associated with population decreases, but may be more significant now that the toads are rarer.

Changes in the surrounding land. Brown- and green-field land close to the breeding ponds has been developed in recent decades, mainly for housing (Figure 1). An exception to the trend was the dismantling of the station and track of the railway station beside Field Road Pond in the early 1970s. Approximately 40% of the land within 250 m of Bury Pond has been converted to relatively high density housing since 1975, while the figure for both Field Road Pond and Horse Pond is about 10%. Although gardens will provide terrestrial habitat for toads, the overall carrying capacity may not be as high as previously with roads and buildings now covering much of the land.

Barriers to migration. Another consequence of the building programmes may have been to render migration more difficult with the construction of walls, fences and the houses themselves. Dispersal may have been affected, resulting in

Table 3. Evidence for factors that might have affected the frequency with which casualties occurred and were counted in any particular year. Potentially important factors are in italics.

Factor	Bury Pond	Field Road Pond	Horse Pond
Toad behaviour			
Direction of migration changed	*Some modification*	*Significant modification*	No obvious change
Distance migrated changed	No obvious change	No obvious change	No obvious change
Angle of crossing roads changed	Not directly studied but no obvious change in migration pattern	As for Bury Pond	As for Bury Pond
Velocity of crossing roads changed	Not studied	Not studied	Not studied
Miscellaneous			
Changes in weather	No clear changes in spring rainfall	As for Bury Pond	As for Bury Pond
Activity of scavengers	Bird scavengers rare throughout	As for Bury Pond	As for Bury Pond
Activity of conservationists	*Toad lifting primarily 1988-1994*	*Toad lifting 1987-1994*	*Toad lifting 1988-1989*

Site number and grid ref.	Description	Toad status
1. TL 282857	Pond in field by mill.	Good population in 1950s, but few bred by 1970s. Pond destroyed 1979/1980.
2. TL 291853	Overgrown pond in pasture.	Small population 1950s, declining to non-breeding refuge by late 1980s. Pond destroyed 1999.
3. TL 296848	Pond in school playing field.	Breeding site since 1970s at least, but numbers usually low.
4. TL 288847	Pond on golf course.	Breeding site since 1960s at least. Pond became silted and marshy but part dredged 2002/3.
5. TL 305860	Farm reservoir.	Site created 1950s. Built up to large population in 1995, but since declined. Sporadic presence in nearby farm ponds.
6. TL 271872	Fen river, extending 1.5 km to west.	In 1990s, significant numbers noticed for first time on adjacent road - maximum kill in 1995. Also seen beside river in late 1990s at TL 307881 and further east.
7. TL 284841	Field pond incorporated into garden.	Pond renovated 1990s. Small breeding population of toads, with many frogs.

Table 4. Other sites in the area where Common Toads have bred. Locations are indicated by the numbers in Figure 1.

toads being over-crowded in suboptimal habitat. Isolation of the colonies will have increased and genetic diversity reduced (Hitchings & Beebee, 1998).

Increase in road traffic on existing roads. As an example of the increase in traffic on existing roads: an increase of 11% in the number of vehicles using the B 1040 to the south of Bury was recorded between 1992 and 2002 (Cambridgeshire County Council, 2002). Greater traffic flow will increase mortality of toadlets, juveniles and adults, which may subsequently affect population size (Hels & Buchwald, 2001).

Construction of new roads. Near Bury Pond, a number of new roads were constructed during the late 1970s and the 1980s. Mortality of the terrestrial stages is likely to have been increased because of encountering traffic where none occurred before. Difficulty with migration, as mentioned above, may have resulted in adult toads walking along roads rather than across them. Not only will this have exacerbated road mortality, but there were instances of toads following curbs and falling into new drainage gulley pots.

Movement to garden ponds. Toads generally do not form large breeding aggregations in garden ponds (Cooke, 1975) and the vogue for creating garden ponds has benefited the Common Frog much more than the Common Toad (e.g. Cooke & Scorgie, 1983). Nevertheless, there have been increasing numbers of reports of toads in local garden ponds. This fact does not necessarily point to toads colonising garden ponds rather than their traditional sites, as it is often not clear whether the toads were breeding or simply using the ponds as refuges. Even those breeding in gardens may have been doing so because migration routes to their usual sites were blocked.

Movement to rivers, reservoirs and other sites. The occurrence of toads at other local sites is summarised in Table 4. During the 1990s, the toad population seemed more widely dispersed than formerly. Populations in several locations were high in 1995 (eg site 5). Dead toads seen on the B 1040 beside the old course of the River Nene (site 6, Figure 1) were at least 2 km from the breeding site at Field Road. As the casualty count was high at Field Road in 1995, it is possible that good emergence there in the early 1990s produced an exceptionally large cohort of young toads that dispersed unusually widely. Dead toads were also encountered along the B 1040 between site 6 and Ramsey. Wider dispersal, though, cannot account for the losses observed at the three traditional sites. In this context, it is worth mentioning a possible immigration event at Field Road, as opposed to emigration. Less than 200 m to the north west of Field Road Pond, there was another pond used by much smaller numbers of toads during the 1970s (site 1, Figure 1). This pond was destroyed during the winter of 1979/1980, so it is likely that toads that formerly bred there then swelled the numbers breeding at Field Road in the early 1980s. However, there were no roads between the two ponds, and any appreciable effect on numbers killed by traffic was unlikely.

Climate change. It is possible that warmer springs may decrease the interval between local spawning dates of Common Toads and Common Frogs, if toads show a greater response (Cooke, 2000, 2003), and render mixed pairs more likely (see above). The advantages and disadvantages of climate change were fully discussed by Reading & Clarke (1999).

Changes to direction of migration. To determine whether direction of migration had been modified over time at Field Road Pond, counts were compared between Field Road to the south east of the pond and Star Lane to the south west. Field Road is a busy suburban road, whereas Star Lane is a quiet side street which was a dead-end until the 1980s when it was modified, together with a neighbouring street, to form a crescent off Field Road. Field Road showed a steeper decline in casualty counts in recent years than Star Lane (Table 1), the difference in the slopes of the regression lines being significant ($P < 0.05$). At Bury, casualty counts were examined for 1990–2003 for the B 1040 to the east of the pond and for the two principal estate roads to the west, which were constructed in the late 1970s and 1980s. Counts showed a steeper decrease on the B 1040 where traffic was likely to be heavier (Table 1), although the slopes of the regression lines were not significantly different. Such comparisons were not possible at Horse Pond where toads were counted on a single road only. Observations around Bury and Field Road Ponds suggested that a progressively smaller proportion of toads migrated each year over the busier roads. Total annual casualty counts might have been rather higher in the 1990s had migration patterns not been modified.

Activity of conservationists. The local Wildlife Trust first organised conservationists to help toads across roads in 1987. Prior to that date, little effort had been made to reduce numbers of toads killed. The years of 1988 and 1989 witnessed the most activity, and Trust helpers and other individuals reported moving totals of >700 and >600 respectively. Official toad warning signs were erected in 1993 at Field Road and close to Horse Pond. However, numbers of toads found in the early 1990s declined and interest waned, and by the mid 1990s, only one or two individuals bothered to look for toads. The impact of helping toads is difficult to estimate quantitatively: a proportion of the toads carried across the roads would otherwise have been killed. Therefore, without such conservation action, numbers killed would have been higher, especially in 1988 and 1989. The trend at all three sites for casualty counts to show a significant decline from the late 1980s occurred despite this bias. Had the conservation action not happened, these trends would probably have been even more marked, especially at Field Road where helpers were most active.

Assessment of contributing factors. It is worthwhile considering Horse Pond first because fewer reasons for change were identified there (Table 2). The presence of frogs and waterfowl were probably relatively unimportant, which left: a certain amount of habitat change, an increase in traffic and some movement to other sites. All of these factors were also identified at Bury and Field Road. At Bury Pond, movement to other sites was rated as comparatively unimportant, but the major landscape changes of recent decades could help explain the more dramatic reduction in the toad population. These changes included a reduction in pond area, a probable reduction in carrying capacity of the terrestrial environment, impeded migration and higher mortality on the roads. The general failure to produce toadlets at Bury Pond during 1993–1998 remained unexplained. Casualties have been counted for longest at Field Road, where the pattern over the last 30 years of an increase followed by a decline was consistent with increasing road traffic having a progressive impact which eventually became unsustainable. While this pattern might instead reflect changes caused by other factors, the observation that declines in casualty counts in recent years were steeper on the busier roads lends support to traffic mortality being the main reason for the observed decline. Individual toads have a propensity to migrate in a certain direction (eg Oldham, 1999), which could explain why the pattern of direction of migration was modified to favour the less lethal routes. In the equation of Hels & Buchwald (2001), survival probability decreased exponentially with increasing road traffic, so a situation might quickly change from traffic deaths being sustainable to being unsustainable. In 2002, during a 12 hour daytime period observing traffic use, 6679 vehicles were counted on the B 1040 south of Ramsey and Bury (Cambridgeshire County Council, 2002). A toad crossing a road with this amount of traffic during a whole day would have a probability of being killed of 0.67, when taking into account the diurnal variations in traffic intensity and toad activity in the Danish study of Hels & Buchwald (2001).

DISCUSSION

Casualty counts showed synchronised declines at the three sites, 1990–2003. At Bury Pond, the population declined during this period with casualty counts being significantly related to counts of toads in the breeding site and to a spawn string index (Cooke, 2000 and unpublished). It is reasonable to conclude that (1) toad populations have decreased at all three sites and (2) these declines may have common causes. While other factors will have contributed (particularly various habitat modifications at Bury), road traffic mortality appears to be implicated. At a site in the Netherlands, the mortality of female toads was estimated at 29% during a single breeding season on a road carrying less than one twentieth of the traffic on the B 1040 at Bury in 2002 (van Gelder, 1973). Using the model and data of Hels & Buchwald (2001), the amount of traffic on the B 1040 was sufficient to kill at least 67% of toads trying to cross. While it is not possible to state what the threshold of sustainability might be, such a level is surely unsustainable (see Langton, 2002). The pattern of counts around the Field Road site, 1974–2003, was consistent with road mortality becoming unsustainable in the 1980s. Although only circumstantial evidence, this is supported by counts on Field Road itself showing a greater decrease than on a much quieter side road. Fahrig et al. (1995) reported from Canada that locations with high traffic intensity had smaller toad populations and fewer road casualties per km of road. Results from this study in Ramsey and Bury appear to show the progress of this effect from year to year.

It is not clear how typical these sites might be with regard to those sites with declining populations reported by Carrier & Beebee (2003). In Britain, toad populations face many other types of threat. Factors listed in Table 2 might provide a convenient framework for considering reasons for toad declines elsewhere, perhaps with other local factors being incorporated. There is nothing particularly remarkable about Ramsey or Bury. Each of the three main breeding sites is not more than 100 m from a B class road. The same is true of three of the seven sites listed in Table 4; the remaining four populations would be expected to have lower mortality because of traffic. Carrier & Beebee (2003) ruled out road mortality as a significant cause of the reported population decreases because replies from road patrol volunteers about changes in status did not differ from those of other rural correspondents. However, toads at the non-patrol sites may still cross roads and the patrols' actions may exert a compensatory effect. Young & Beebee (2002) followed up a sub-set of replies from the correspondents of Carrier & Beebee (2003) and reported widespread concern about increasing road traffic. In an earlier enquiry by Froglife, patrol volunteers considered that an increase in traffic was the main reason for the population declines they reported (Foster, 1996).

If road mortality is implicated in toad declines more widely, this could help to explain the lack of a similar impact on frog populations (Carrier & Beebee, 2003). Common Frogs are far less prone to be killed on the road, presumably because they neither migrate so far as toads nor tend to cross such relatively open and dry habitats. Also frogs are faster when crossing roads (Hels & Buchwald, 2001). In recent years, casualty counts of frogs near to Bury Pond or Horse Pond have always been <10. Frogs in this area are increasing by colonising garden ponds (eg Cooke, 2003) and other sites such as Bury Pond (Cooke, 2000).

Long term decreases in casualty counts have proved of value in this study by indicating population declines for the local toad colonies. It should be stressed again that if counts increase in a typical situation of increasing traffic flow, then it is likely to be impossible to interpret this as a population change without much more detailed knowledge. The question then arises as to how useful shorter term monitoring might be, especially as inter-year counts may vary by up to an order of magnitude (Figure 2)? Regression analysis is not the answer. Based on the counts at Field Road from 1974 to 1994, there was no evidence of any major long term trend (Cooke, 1995); at this point in time, the regression coefficient was +0.006 (Appendix 1), but there had been decreases for three successive years (Figure 2a). Although counts temporarily increased again in the mid 1990s, this conclusion was reached at a time when the long term decrease had already begun. A data-smoothing technique may help to understand trends. The LOWESS line for Field Road revealed a slow decline in counts from the early 1980s, but this was distance weighted and based on the whole data-set. Calculating a three year moving mean would have raised a minor concern in 1993 and then a permanent concern from 1999. Even looking out for decreases over three consecutive years could prove of value. One further word of caution about casualty counts – Slater (1994) concluded that daytime counts of toads might grossly underestimate true mortality or completely fail to detect it because of the scavenging activity of corvids. In Ramsey and Bury, corvids were rare around the breeding sites, and were never seen feeding on dead toads. However, in other locations, Carrion Crows (*Corvus corone*) and Magpies (*Pica pica*) will be common, and their potential impact should be considered.

It is not the purpose of this paper to discuss in detail what might be done when a population decline is suggested because of road traffic. There has been concern about toad mortality on roads since the 1980s and many techniques are available involving carrying toads across roads; installing warning signs, constructing tunnels, using barriers to steer them away from danger or to render them easier to collect and carry to the pond; or even moving the colony to a safer location (eg Langton, 1989, 2002; Schlupp & Podloucky, 1994; Highways Agency, 2001). Translocation or installation of barriers or tunnels are probably impractical in the majority of situations. Although carrying toads across the roads failed in Ramsey and Bury to prevent or arrest population declines, it remains the most practical and popular method. If more conservationists appreciate that road mortality is a real, rather than a hypothetical, risk to their local toads, then even more people may participate. It would be far better to use casualty monitoring as a device for checking the success of conservation action, rather than waiting until a population decline was indicated and then attempting to rectify the problem. Knowing that you are preventing population declines that would otherwise occur should provide more of a stimulus for continuing. If toad numbers start to decline, conservation effort should be intensified, not allowed to slacken, as in Ramsey and Bury. Once we have a greater ability to understand and quantify risk, it should be possible to target volunteer effort more effectively, as well as provide objective input to local planning issues.

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Appendix 1. Regression coefficients for log transformed casualty counts at Field Road Pond for runs of ten or more years. Start years are given along the top of the table and end years down the side. Positive coefficients are in italics, and significant relationships are emboldened.

	1974	1975	1976	1977	1978	1979	1980	1981	1982	1983	1984	1985	1986	1987	1988	1989	1990	1991	1992	1993	1994
1983	*0.131*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*
1984	*0.052*	*0.039*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*
1985	*0.080*	*0.074*	*0.092*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*
1986	*0.062*	*0.054*	*0.065*	*0.048*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*
1987	*0.049*	*0.040*	*0.047*	*0.031*	-0.024	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*
1988	*0.037*	*0.027*	*0.032*	*0.015*	-0.033	-0.076	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*
1989	*0.034*	*0.026*	*0.029*	*0.015*	-0.025	-0.059	-0.034	*	*	*	*	*	*	*	*	*	*	*	*	*	*
1990	*0.036*	*0.029*	*0.033*	*0.021*	-0.012	-0.038	-0.014	-0.011	*	*	*	*	*	*	*	*	*	*	*	*	*
1991	*0.050*	*0.046*	*0.051*	*0.043*	*0.018*	*0.001*	*0.027*	*0.037*	*0.051*	*	*	*	*	*	*	*	*	*	*	*	*
1992	*0.040*	*0.035*	*0.038*	*0.029*	*0.006*	-0.011	*0.010*	*0.015*	*0.022*	*0.043*	*	*	*	*	*	*	*	*	*	*	*
1993	*0.022*	*0.015*	*0.016*	*0.006*	-0.018	-0.035	-0.021	-0.021	-0.021	-0.013	*0.013*	*	*	*	*	*	*	*	*	*	*
1994	*0.006*	-0.002	-0.003	-0.014	-0.037	-0.055	-0.045	-0.049	-0.053	-0.051	-0.038	-0.115	*	*	*	*	*	*	*	*	*
1995	*0.010*	*0.003*	*0.003*	-0.007	-0.026	-0.041	-0.030	-0.031	-0.033	-0.028	-0.013	-0.071	-0.038	*	*	*	*	*	*	*	*
1996	*0.007*	*0.001*	*0.000*	-0.008	-0.026	-0.039	-0.029	-0.030	-0.031	-0.027	-0.014	-0.063	-0.034	-0.047	*	*	*	*	*	*	*
1997	*0.013*	*0.008*	*0.008*	*0.001*	-0.014	-0.024	-0.014	-0.013	-0.012	-0.006	*0.008*	-0.030	*0.000*	-0.005	-0.012	*	*	*	*	*	*
1998	*0.005*	*0.000*	-0.001	-0.008	-0.022	-0.032	-0.025	-0.025	-0.025	-0.021	-0.011	-0.046	-0.024	-0.031	-0.042	-0.064	*	*	*	*	*
1999	-0.004	-0.010	-0.011	-0.019	-0.033	-0.043	-0.037	-0.038	-0.040	-0.038	-0.032	-0.065	-0.049	-0.059	-0.072	-0.096	-0.111	*	*	*	*
2000	-0.007	-0.013	-0.014	-0.022	-0.035	**-0.044**	-0.039	-0.040	-0.042	-0.041	-0.035	-0.065	-0.050	-0.059	-0.071	-0.090	-0.102	-0.100	*	*	*
2001	-0.013	-0.018	-0.020	-0.027	**-0.040**	-0.049	**-0.044**	**-0.046**	-0.048	-0.048	-0.044	-0.071	-0.059	**-0.068**	-0.079	-0.097	-0.108	-0.107	-0.048	*	*
2002	-0.018	-0.024	-0.026	-0.033	**-0.045**	**-0.054**	**-0.050**	**-0.052**	**-0.055**	**-0.055**	-0.052	**-0.077**	**-0.067**	**-0.076**	**-0.087**	**-0.103**	**-0.113**	-0.114	-0.067	-0.065	*
2003	-0.021	-0.026	-0.028	**-0.035**	**-0.046**	**-0.054**	**-0.051**	**-0.053**	**-0.055**	**-0.055**	**-0.053**	**-0.075**	**-0.066**	**-0.074**	**-0.083**	**-0.097**	**-0.105**	**-0.104**	-0.063	-0.061	-0.099

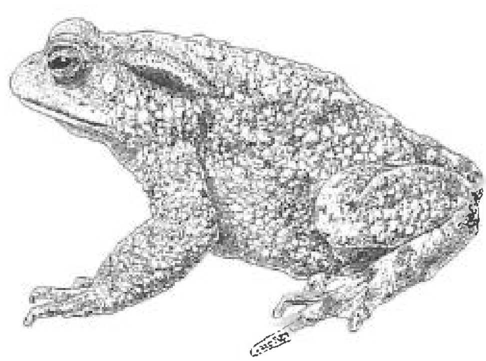
	1986	1987	1988	1989	1990	1991	1992	1993	1994
1995	-0.107	*	*	*	*	*	*	*	*
1996	**-0.182**	**-0.188**	*	*	*	*	*	*	*
1997	**-0.202**	**-0.211**	**-0.251**	*	*	*	*	*	*
1998	**-0.221**	**-0.232**	**-0.268**	**-0.364**	*	*	*	*	*
1999	**-0.200**	**-0.206**	**-0.233**	**-0.304**	**-0.295**	*	*	*	*
2000	**-0.174**	**-0.175**	**-0.192**	**-0.245**	**-0.227**	**-0.220**	*	*	*
2001	**-0.195**	**-0.199**	**-0.217**	**-0.266**	**-0.254**	**-0.253**	**-0.235**	*	*
2002	**-0.205**	**-0.210**	**-0.228**	**-0.271**	**-0.262**	**-0.263**	**-0.250**	**-0.215**	*
2003	**-0.190**	**-0.192**	**-0.205**	**-0.240**	**-0.228**	**-0.223**	**-0.206**	**-0.170**	-0.158

Appendix 2

Regression coefficients for log transformed casualty counts at Bury Pond for runs of ten or more years. Start years are given along the top of the table and end years down the side. Positive coefficients are in italics, and significant relationships are emboldened.

Appendix 3. Regression coefficients for log transformed casualty counts at Horse Pond for runs of ten or more years. Start years are given along the top of the table and end years down the side. Positive coefficients are in italics, and significant relationships are emboldened.

	1982	1983	1984	1985	1986	1987	1988	1989	1990	1991	1992	1993	1994
1991	*0.026*	*	*	*	*	*	*	*	*	*	*	*	*
1992	*0.009*	*0.089*	*	*	*	*	*	*	*	*	*	*	*
1993	-0.028	*0.024*	*0.024*	*	*	*	*	*	*	*	*	*	*
1994	-0.066	-0.034	-0.034	-0.115	*	*	*	*	*	*	*	*	*
1995	-0.071	-0.045	-0.045	-0.114	-0.085	*	*	*	*	*	*	*	*
1996	-0.074	-0.053	-0.053	**-0.111**	-0.087	-0.109	*	*	*	*	*	*	*
1997	-0.065	-0.046	-0.046	**-0.094**	-0.071	-0.086	-0.105	*	*	*	*	*	*
1998	**-0.074**	-0.059	-0.059	**-0.103**	-0.085	-0.099	-0.117	**-0.180**	*	*	*	*	*
1999	-0.060	-0.045	-0.045	**-0.080**	-0.062	-0.071	-0.081	**-0.126**	-0.106	*	*	*	*
2000	-0.058	-0.044	-0.044	**-0.075**	-0.059	-0.066	-0.073	**-0.110**	-0.091	-0.066	*	*	*
2001	**-0.061**	-0.050	-0.050	**-0.078**	**-0.063**	**-0.070**	**-0.077**	**-0.109**	**-0.093**	-0.072	-0.022	*	*
2002	**-0.070**	**-0.061**	**-0.061**	**-0.087**	**-0.075**	**-0.082**	**-0.090**	**-0.119**	**-0.107**	**-0.093**	-0.055	-0.029	*
2003	**-0.063**	**-0.054**	**-0.054**	**-0.077**	**-0.065**	**-0.071**	**-0.076**	**-0.099**	**-0.086**	-0.071	-0.036	-0.011	-0.010



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