Restoration of ponds in a landscape and changes in Common frog (*Rana temporaria*) populations, 1983–2005

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ABSTRACT – Monitoring of a population of the Common frog (*Rana temporaria*) was undertaken between 1983-2005 by annual counts of frogspawn during a pond restoration programme at the 103 ha Fryent Country Park, London, UK. Pond restoration, creation and management since 1983 resulted in a landscape with 31 water-bodies by 2005, though not all of these were suitable for breeding by frogs. Generally, smaller water-bodies were more prone to drying-up in dry seasons. Total annual frogspawn increased from 40 clumps in 1983 to a maximum of over 1,850 clumps. Populations of the Common frog appeared to respond to the pond restoration programme, though the quantity of frogspawn was also influenced by other, in particular, weather-related factors. There was a strong correlation between the size of ponds during the winter and the average spawn laid in available ponds. The quantity of frogspawn was strongly correlated with the number of ponds at the time of spawning and at the time of spawning in the previous year; and with the number of water holding ponds during the previous summer.

DECLINES in the populations of the Common frog from ponds and the countryside of lowland England as a result of habitat loss has been noted by e.g. Beebee (1983), Baker & Halliday (1999). Studies of the recovery of Common frog populations following the creation or restoration of ponds have included that of Baker & Halliday (1999); and of Cooke & Oldham (1995) who monitored a population of the Common frog for six years following the translocation of spawn to a new nature reserve.

Restoration and creation of ponds in the landscape at Fryent Country Park, in London, commenced in the early 1980s. This provided an opportunity to investigate how a population of the Common frog responded to increases of pond habitats.

Previous studies on the breeding of Common frogs in ponds on London Clay include that by Savage (as summarised in Frazer, 1983) at Totteridge, approximately 8 km north-east of Fryent Country Park. At Fryent Country Park studies have reported on changes in the Common frog population during the first ten years of the pond restoration programme (Williams & Green, 1993); a description of the flora of the ponds (Williams, 1990), the presence of the Meniscus midge *Dixella attica* in Honey Slough pond (Williams & Fowler, 1986) and a survey of dragonflies (Wilson, 1999).

METHODS

Study area

Fryent Country Park is a 103 ha Local Nature Reserve of lowland countryside, formerly in the parishes of Harrow and Kingsbury in the county of Middlesex; and now in the London Borough of Brent. The Park is surrounded by suburbia and bisected by a road, Fryent Way. The Park is approximately 15 km north-west of central London and 2 km from Wembley Stadium. Barn Hill, the highest point, rises to 86 m O.D. and is capped by Pebble Gravel, while Gotfords Hill, Beane Hill and the remainder of the Park are on London Clay. A tributary of the Gaderbrook flows through the north of the Park. Fryent Country Park is owned by Brent Council; and is managed for public recreation and wildlife conservation by the Council and the volunteers of Barn Hill Conservation Group. A Countryside Stewardship scheme was in operation from 1996 onwards. The Park is managed organically and produce has been certified to the Soil Association Organic Standard since 1998.

Over half of the Country Park area is of grassland, typically of meadows on neutral soils which are cut once annually, usually for hay. Other habitats include hedgerows, deciduous woodland, scrub, horse grazing, acid grassland, roadside mounds, ponds and an orchard (Williams & Cunnington (1985), Williams, Cunnington & Hewlett (1985), and Williams (1996)).

The first Ordnance Survey maps of the area, dating from the mid-nineteenth century, indicate that there were approximately 18 mapped ponds within the area corresponding to the current Country Park. Most of the ponds appeared to be farm ponds, presumably excavated rather than of natural origin, and distributed so that most fields had access to a pond. Some ponds were on hedgerow ditches and served two fields. London Clay holds water well during the winter months. During the summer, water levels can fall considerably and ponds can dry up due to reduced precipitation, increased evaporation and seepage as the level of the surrounding water table falls. One pond was constructed as part of a landscape scheme of Humphry Repton in about 1793 and is known locally as the 'Fishpond'. It is atypical of the other ponds in being the largest pond in the Country Park (at about 0.12 ha), located near to the summit of Barn Hill; and constructed in the Pebble Gravel capping the hill though the base of the pond was within the London Clay.

Monitoring

Records were maintained of the progress of the pond restoration programme including the date and a brief description of work undertaken, whether ponds held water in the winter and summer, and of annual counts of frogspawn at each pond.

Winter water: The presence or absence of water at each pond location was recorded at the time of spawning. This was generally the late winter between mid-February and mid-March, and thus the period of highest expected water level after ponds re-filled during the winter.

Summer water: The monitoring of summer water in ponds was more problematic than the winter survey, as the driest period of the year could fall anytime from late spring through to mid-autumn. Ponds could also dry up and then re-fill with water within this time. Generally the survey was undertaken in mid-late summer (late July to mid-September) supplemented by opportunistic records at other times. It was not practicable to measure the changing depths, areas and volumes of each pond. There were also borderline cases in which ponds were reduced to puddles.

Spawn counts: One frog species, the Common frog (*Rana temporaria*) occurred at Fryent Country Park. Spawning usually took place between mid-February and mid-March. The method for counting the frog spawn followed that in Griffiths & Raper (1994) and involved visits to each pond during the breeding season to count the clumps of frogspawn. As each mature female lays one clump of spawn per year, the count provided an estimate of the number of breeding females. The Common frog is generally considered to have a sex ration of 1:1, so the total breeding population would be approximately twice the number of females.

It was assumed that there could have been movements of Common frogs between the Country Park and the surrounding suburban areas. Similarly, whilst it is considered that all, or almost all of the spawn included in the results was laid by local frogs, the extent of translocations of spawn, tadpoles or frogs by human activity to and from the Country Park, or between ponds, was not known. For this purpose, a search was undertaken of any records associated with the pond restoration programme.

The data is presented using basic statistical summaries, Spearman Rank Correlation Analysis (using StatView software) and graphs.

RESULTS

By the early 1980s many of the farm ponds had fallen into disuse and presumably held less water than previously due to the accumulation of alluvium and vegetation growth. At least two ponds had been filled-in. The initial emphasis was on the removal of accumulated material from the ponds. Though most of this early work was undertaken manually, machinery was increasingly employed. Some of the original farm ponds were also enlarged and new ponds created. An artificial liner was used on one pond, that in the orchard, but had to be replaced once, due to theft.

Table 1 provides some information and location details for each of the ponds that were included in the monitoring. Ponds were named on the basis of the field in which they were located or by reference to other features. Of the 31 ponds or water bodies, one was the landscape-era Fishpond, 11 were farm ponds marked on the mid-19th century maps, while 19 ponds or water bodies were created during the pond restoration programme. Note that though spawn was laid in a small scrape at 'Hedge 74' and that that spawn has been included in the spawn totals used in this paper, the winter and summer water levels at this location were not monitored and therefore have been excluded from the totals and analysis involving the numbers of ponds.

Figure 1 indicates the trend of the pond restoration and creation work by reference to the number of ponds that held water in the winter (February / March); and throughout the summer of each year. At the start of the restoration programme in 1982/83, 10 ponds held water during the winter. The number of ponds holding water in the winter rose to 28 in 1991 and to 30 in 1998; and did not fall below 22 since 1989 with the exception of the dry winter of 1991/92 when 16 ponds held water.

The number of ponds retaining water throughout the summers was highly variable; and was indicative of factors including the pond restoration programme, the quantity of rain and of water loss during the summer and early autumn. The Fishpond was the only pond that held water continuously throughout this investigation and the only pond that held water during the dry summer of 1983, before

Table 1. Summary information on the ponds at Fryent Country Park. Farm ponds are ponds that were marked on the mid-19th Century Ordnance Survey maps. The Fishpond was created as part of a landscape scheme in about 1793.

	Grid reference (TQ)	Pond origin	Cumulative spawn, 1983-2005.	Size of ponds (square metres)	No. of years winter water, 1983-2005.	No. of years summer water, 1983-2004.
Fishpond	1931, 8741	Landscape	8879	1200	23	22
Upper Hydes	1929, 8779	Farm pond	2834	195	21	13
Oldefield mid	2006, 8830	1980s	1528	80	17	9
Great Hydes	1934, 8782	1980s	1290	800	20	17
Robert Southwell	2005, 8840	1980s	1236	90	21	13
Gotfords	1969, 8828	Farm pond	1128	196	23	11
Lower Hydes	1936, 8807	Farm pond	595	250	23	13
Oldefield south	2005, 8828	Farm pond	555	80	22	9
Oldefield north	2005, 8833	1980s	290	30	17	9
Little Hillcroach	1999, 8777	1980s	287	100	21	16
Richards	1947, 8796	Farm pond	278	450	23	14
Long Down	1986, 8732	Farm pond	230	90	23	17
Robert Southwell north	2004 8840	1990s	218	60	8	6
Warrens	1970, 8780	1980s	155	100	21	10
Coneyvale Glade	1929, 8750	1980s	145	90	18	1
Orchard (with liner)	2006, 8813	1990s	111	4	13	12
Gotfords ditch	1968, 8829	1980s	96	20	19	8
Hedge 7 pond	1916, 8786	1990s	82	10	11	0
Meade	1969, 8787	Farm pond	79	10	22	6
Dormers Meade	1978, 8773	Farm pond	67	50	18	10
Goldringe	1962, 8796	Farm pond	16	6	20	0
Honey Slough	1946, 8801	Farm pond	13	75	23	21
Great Cowlays	1987, 8734	Farm pond	12	50	19	0
Hedge 74 ditch	1992, 8836	1980s	11	1		
Little Cowlays east	1986, 8744	1980s	8	2	8	0
Little Cowlays west	1982, 8745	1980s	2	3	18	2
Clump	1919, 8751	1980s	1	2	11	0
Hedge 3 pond	1939, 8783	1980s	0	5	17	0
Great Cowlays south	1988, 8730	1980s	0	2	13	0
Great Cowlays mid	1987, 8732	1980s	0	3	13	0
Homefield summit	1992, 8809	1980s	0	2	12	0

restoration work had had an effect on other ponds. The number of ponds that held water throughout the summer increased to 15 in 1988, 17 in 1993 and 19 in 2000–2002, but in interceding dry summers numbers reduced to 2 in 1990, 4 in 1995 and to 6 in 2003.

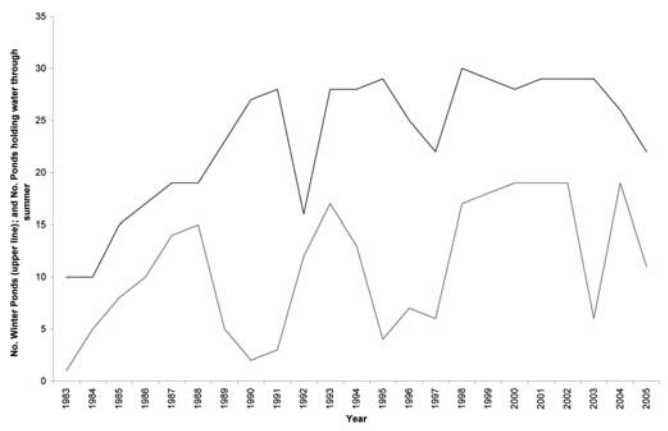


Figure 1. The number of ponds holding water in the winter (February/March), and throughout the summer at Fryent Country Park, 1983–2005.

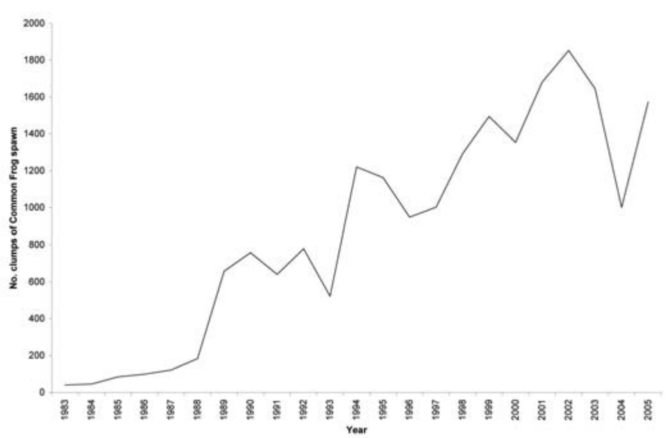
The investigation was in a semi-natural landscape surrounded by suburban London. Ponds were restored or created by human activity. The records accompanying the pond restoration programme noted the introduction of frogspawn, tadpoles and frogs from suburban ponds and some translocation of amphibians between ponds particularly in 1984. The notes suggested that these movements were proportionally greater towards the start of the investigation. This coincided with a national campaign (see Gibb & Foster, 2000) to 'rescue' excess frogspawn from garden and other ponds with the aim of stocking other ponds. Thus the initial colonisation of the Common frog to ponds that were restored at Fryent Country Park could have proceeded at a faster rate than that which may have occurred naturally. Removal of frogspawn from the Country Park by the public was also observed during the 1980s. The net effect of incoming and outgoing translocations is not known.

The total counts of clumps of Common frog spawn from 1983–2005 are shown in Figure 2. The total frog spawn in all ponds in the Country Park increased from 40 clumps in 1983 to a maximum of 1,852 in 2002. Though the general trend during the investigation was of increasing spawn, there were fluctuations from year to year. For example, in 2004 spawn declined to 1,000 clumps.

The majority of spawn was laid in a relatively small number of ponds, with almost half the total at one pond (the Fishpond), and a skewed distribution of lower counts at other ponds. Eight ponds accounted for 89% of the spawn. In the early years of the investigation, all or a majority of the spawn was laid at the Fishpond. Spawn in the Fishpond peaked at 900 clumps in 1998 but declined to 214 clumps in 2004, whereas the total of frog spawn in all the other ponds increased from none in 1983 to a maximum of 1,253 clumps (in 2005).

As the pond restoration and creation programme progressed, increasing numbers of ponds were potentially available, and used, for breeding. The utilisation rate varied from year to year. In the earlier years only a small proportion of ponds were used for breeding, but for much of the investigation

Figure 2. Total counts of clumps of Common frog spawn at Fryent Country Park, 1983–2005.



most of the ponds were used for breeding each year. The number of ponds used for breeding in any one year varied from one in 1983, to 17 in 1989 and peaked at 20 in 2000. Since 1983, a total of 27 ponds have been used for breeding.

Generally, the first spawning would occur within two years of the restoration or creation of a pond, albeit the presence of frogs in the Fishpond at the start of the investigation and introductions of frogs to some ponds during the early years of the investigation. Subsequently, spawning did not appear to conform to a simple pattern. Though there was often a rapid increase in spawn following colonisation, over longer periods the patterns varied. Apparent re-colonisations could follow declines and the absence of spawn in some years. Within the period 1983–2005, the peak spawn counts at some ponds did not occur until 20 years after the initial restoration.

There was a strong correlation (Spearman Rank Correlation Coefficient, $r_s = 0.804$, $p < 0.001$) between the size of ponds at the time of spawning taken as an estimation of the surface area in the winter of 2003/2004, and the average number of clumps of frogspawn taken as the average number of clumps for those years between 1983–2005 that the pond held water at the end of the winter. The surface area of a pond could be considered as a proxy for the size of a pond and hence the ability of a pond to retain water throughout the year, albeit ponds could vary in relative depths and profiles.

There was a strong correlation ($r_s = 0.783$, $p < 0.001$) between the annual total counts of Common frog spawn and the number of water-holding ponds for the 23 winters from 1983–2005. This correlation also held between the total counts of frogspawn and the number of water-holding ponds during the previous winter ($r_s = 0.787$, $p < 0.001$), but tailed to a modest and lower correlations for the winters of earlier years. The trend of increasing spawn since the start of the pond restoration programme in 1983 was broken by a decline of spawn in 1993, possibly as a consequence of the reduced number of ponds available during the dry winter of 1991–1992. Field notes indicate that in early 1992 the water levels in some ponds (Little Hillcroach, Warrens, Oldefield Mid and Oldefield North) were so low that the spawn was laid in puddles within the pond basins and, as a consequence the survival rate was probably low. However, other declines in spawn, including that during 2003-2004, did not correspond with marked reductions in the number of ponds available in winter.

As frogspawn is laid in February/March, any causal relationship with the number of summer water-holding ponds would need to take account of the number of ponds in previous years. There was a strong correlation ($r_s = 0.700$, $p < 0.01$) between the annual total counts of frogspawn and the number of ponds that held water in the previous summer for the 22 data sets from 1984-2005. This reduced to a modest correlation ($r_s = 0.562$, $p > 0.01$) for the previous but one summer for the 21 data sets from 1985–2005.

Though the quantity of light at ponds during the investigation was not measured, it was noted that the shaded Honey Slough Pond that held water continuously since late 1983 accounted for less than 0.1% (13 clumps) of the total spawn. Conversely, Hedge 7 Pond which did not hold water throughout any summer was used for spawning in seven years with a total of 82 clumps (0.4% of the total). Other apparent anomalies included Coneyvale Glade Pond which held water in only one summer since 1983 but accounted for 0.7% (145 clumps) of spawn.

Two other amphibian species were encountered during the investigation. Smooth newts (*Triturus vulgaris*) were observed at some ponds, while the adults were noted away from ponds. It is possible that the Common toad (*Bufo bufo*) was either absent from the Country Park at the start of the investigation or present at a low density as one strand of toadspawn was found in the Fishpond in 1985. Following rescue translocations from suburban and other ponds during the 1980s, the Common toad established throughout much off the Country Park to breed in several ponds.

DISCUSSION

The results suggested that there were strong correlations between the spawn laid and hence the population size of the Common frog, and the size and number of ponds in winter, and the number of ponds that held water in the previous summer. There were also correlations with the number of ponds in recent winters and summers prior to the current year. The net contribution of each of these effects, and of factors that were not monitored and of any interactive effects were not separated out.

Nevertheless, the population of the Common frog appeared to increase in response to the pond restoration programme, though seasonal weather was a major factor in year to year fluctuations in the quantity of spawn laid.

Only a small proportion of spawn reaches adulthood and hence the environmental conditions during the early seasons of life would affect the number of frogs that enter the breeding population. Cooke & Oldham (1995) in their investigation of the translocation of frog spawn to a new site found that frogs tended to reach maturity and lay spawn from the second year following their own introduction as spawn; a figure which appeared to be typical from other introductions in lowland Britain that they cite and from the first spawning at restored or created ponds at Fryent Country Park.

As weather comprises many factors each of which could affect the various stages of a life cycle, the measurement of relevant factors and their correlation with population data can be problematic as noted by White & Lindley (1976). In practice, the presence of winter and summer water in ponds acted as an indicator of the combined effects of the pond restoration programme and of recent weather. Whilst the counts of the number of clumps of frogspawn relied on estimations using a standard method, and the number of ponds that held water in the winter was easy to quantify, it was less easy to measure the number of ponds that held water during the summer. In part this was due to variation of the timing and duration in which ponds could dry. Tadpoles of the Common frog are dependent on ponds that hold water throughout the spring / early summer. At Fryent Country Park, with shallow spawning ponds prone to seasonal drying, a dry summer could result in the loss of a high proportion of that year's spawn, and affect the number of mature frogs that would be available to spawn in the future. Part of the effect of dry summers on frog survival could also act via drought conditions on the terrestrial habitats that frogs use at other times of the year.

Populations of the Common frog could also have been affected by factors that were not recorded as part of this investigation. These include water quality, disturbance, light/shade, vegetation, the spatial relationship between ponds and frog populations both within and beyond the study area, the quality of habitat around ponds, climatic change, competition, predation and disease. Neither was this investigation under experimental control which limited the application of statistical analysis. Oldham *et al.* (2000) used ten habitat criteria to produce a Habitat Suitability Index to assess sites holding or with the potential to support populations of the Great crested newt (*Triturus cristatus*). Ehrlich & Hanski (2004) in describing the spatially realistic metapopulation theory noted that the population capacity of an area increases with the number, average size and average connectivity of representative habitat. While it was assumed that the Common frogs within Fryent Country Park represented one meta-population, in practice there may have been more than one meta-population and/or movements of frogs with nearby populations in suburban gardens. Movement of the Common frog within the Country Park was assumed to have contributed to the colonisation of newly restored and created ponds. Baker & Halliday (1999) noted that *Rana temporaria* colonised new ponds at distances of up to 950 m from existing ponds. Frazer (1983) noted that during their migration between the hibernation site and the breeding pond, Common frogs travel through a series of ponds; and that within a group of closely-spaced ponds the majority of the spawn would not necessarily be laid in the same pond each year. At Fryent Country Park, there were ponds in which two areas were used for spawning in some years, and this was often repeated for several years.

Though the net effect of translocations of spawn, tadpoles and frogs was not estimated during this investigation, Cooke & Oldham (1995) suggested that in Huntingdonshire, there was a net loss of spawn from rural ponds due to the collection of frogspawn for garden ponds in the 1970s and early 1980s, but that the net effect had been reversed by the late 1980s due to deposition of surplus spawn from garden ponds into some rural ponds. Baker & Halliday (1999) found that the presence of Common frogs at new ponds in a rural area of Northamptonshire, west Bedfordshire and north Buckinghamshire was associated with introductions of frogspawn, though amphibians were readily able to colonize new ponds on farmland.

Only the Fishpond maintained fish populations throughout the investigation. Fish were found in a small number of the other ponds but as these were susceptible to drying in some summers, the fish populations would have then been lost. The Smooth newt has been observed at locations throughout the Country Park and is considered to be predatory on young Common frog tadpoles (Beebee, 1996).

It would appear that the better ponds for encouraging breeding of Common frogs were those that were larger, held water at the time of spawning and throughout most summers. Such conditions were probably conducive also to other pond fauna and vegetation, and a lack of shade may be beneficial too. These criteria conform to those suggested by Frazer (1983) in that breeding Common frogs were attracted to ponds by the smell of glycolic acid produced by algae. Algae is more frequent in ponds that held water into the early summer and as the algae was a foodsource for the young tadpoles, these factors increased the chances of survival by allowing the young froglets to reach a life cycle stage at which they could leave the water. The inference was that small water bodies that dried up each summer and ponds that were heavily shaded were unlikely to support algae in quantity.

Using the same assumptions as Cooke & Oldham (1995), that all of the frogspawn was found, that an adult female frog lays one clump of spawn per annum and that there was a sex ratio of unity, the adult frog population during recent years was in the range of 2,000–3,700. That would approximate to a density of 19–36 adults / ha for the Country Park area, though the edge effect with neighbouring areas is not known.

Taking the number of ponds that held water throughout typical recent years as 19, the average density of ponds in the 103 ha Country Park was 18.4 per square km in 2005. This compared with an average of 1.4 ponds per square km in rural Britain (Swan & Oldham, 1993 cited in Latham, 1995) and with 1.7 ponds per square km in England in 1996 (Williams *et al*., 1998). Haines-Young *et al*. (2000) estimated that the number of lowland ponds in England and Wales increased by about 6% between 1990 and 1998, with much of the net increase in the years 1996-1998.

The pond restoration programme was undertaken, in part, to reverse the effects of the natural infilling of ponds. At Honey Slough Pond, excavation in 1983 worked through layers of sediment and embedded artefacts dating from the 1930s and earlier, though undated material was found below that level, and it was not possible to estimate when the pond was last cleared or originally excavated. Sediment accumulations within the range of 0.5–4 cm per year have been suggested by Williams *et al.* (1998) based on measured rates within young ponds of 2.5–3.0 cm per year. Obviously these rates could vary as a consequence of leaf fall from trees, nutrients, local soil types and whether a pond was acting as a silt-trap.

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