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# A survey of the fish population in Buckingham Palace Garden lake

[1]S. M. KETT AND [2]R. S. KIRK

[1] *School of Health, Biological and Environmental Sciences, Middlesex University, Trent Park, London N14 4XS*

[2] *Division of Biology, School of Biological Sciences, Royal Holloway, University of London, Egham, Surrey TW20 0EX*

## Abstract

Seine-netting and electro-fishing surveys of the Buckingham Palace Garden lake demonstrated that the fish population was of low species diversity and density with low to normal growth rates. The population was dominated by roach *Rutilus rutilus*, with smaller numbers of gudgeon *Gobio gobio* and perch *Perca fluviatilis*. Isolation and eutrophication are suggested to be key factors in structuring the composition of fish populations in Buckingham Palace Garden lake.

## Introduction

Buckingham Palace Garden lake is unusual in several ways. It is a small lake maintained for purely ornamental purposes and is subject to only limited human impact. Although situated within the heart of the capital, it is unaffected by the increasing demand for lakes to be managed as locations for sporting pursuits. It could be considered an island within a 'sea' of urbanization.

Buckingham Palace and its Garden were remodelled as a private royal residence in the late eighteenth century. The lake was constructed as part of an informal parkland landscape (Anon 1993). Maintenance of water quality soon proved to be a problem. In 1854 the lake was due to be drained and converted into flowerbeds when the water source was found to be impure. Arrangements were made, however, to provide a clean water supply from an artesian well on Duck Island, St James's Park. Fish were introduced soon after, although they had to be relocated to Kensington Gardens in 1869 when the lake was concreted. Problems with water quality continued so that the lake was suspected to be a source of typhoid at Buckingham Palace in the hot summer of 1883, until an 'expert' sampled the water and declared it to be 'of excellent quality for dietetic purposes'. Regular maintenance improved water quality and, in 1941, the job of draining and cleaning was efficiently carried out by a gang of German prisoners of war (Coats 1978). The Royal Family have enjoyed the lake, both as part of a good view and for moments of relaxation. Queen Victoria, Prince Albert and their children regularly fed the wildfowl on the lake. As Royal Princesses, Elizabeth and Margaret showed great interest in the wildlife of the Garden and ensured that the royal fish were fed with regular supplies of water fleas, *Daphnia*, delivered in frozen portions by the 'flea man' (Peacock 1951). The walls built around the Garden have provided privacy for the Royal Family and created a protected enclave for the wildlife within.

As Buckingham Palace Garden lake is so isolated, it may be considered to possess many of the faunal characteristics of small oceanic islands. Within such habitats, species diversity and the probability of species extinction are likely to be influenced by habitat size (area) and the degree of isolation (MacArthur & Wilson 1967). Under natural circumstances, fish communities within isolated lake habitats, especially those of recent origin, tend to show poor species diversity because of difficulties of colonisation. Such isolated fish populations may fluctuate as a consequence of natural oscillations and cycles in breeding success, even to the point of population extinction. Unlike natural isolated lakes, however, Buckingham Palace Garden lake is buffered from many of the extreme environmental conditions such as drought or winter-kill that can influence fish population structure and composition. The impact of drought or lowering of the water level is reduced by supplementation with tap water. Additionally, the 'London heat island' effect serves to minimise the likelihood of prolonged freezing and consequent winter-kill.

In England and Wales, ponds and lakes may be spatially isolated, but they are not wholly subject to natural processes because they are accessible to human interference. Such water bodies are often popular resources, used for a variety of recreational activities and are therefore subject to management regimes. Angling constitutes the most popular participation sport in England, and thus many water bodies are maintained as fisheries. Management priorities frequently involve the introduction and maintenance of popular sporting fish populations, some of which may be non-endemic species, such as carp *Cyprinus carpio*, that may not be beneficial to lentic ecosystems. This form of management has become more prevalent with increasing urbanization of land around water bodies — the expansion of the human population resulting in a concomitant increase in the demand for recreational facilities. Fish populations at these sites are augmented by legal and illegal introductions and well-intentioned disposal of spare live-bait, unwanted pets and jam-jars of 'tiddlers' by the general public, particularly children acting under parental edict.

The high security walls of Buckingham Palace exclude the constant pressure of human interference and the lake is not subject to fisheries management. It is this very isolation and inaccessibility that makes it such an interesting habitat to study. A survey of the fish population within the lake at Buckingham Palace Garden was commissioned by the London Natural History Society and undertaken during the spring and summer of 1996. The purpose of the survey was to identify the fish species present within the lake and to investigate their status in terms of abundance, growth rates and condition.

## Site description

The lake is of irregular shape and has an area of 1.56 hectares (Figure 1). Two islands are present; the larger, a rough oval approximately 93 metres across its longest axis, forms a central landmass around which the main body of the lake is curved. It is connected to the bank by two bridges. The smaller island, more nearly circular in shape and approximately 13 metres in diameter, is located slightly to the south of the larger island and is unconnected to the bank. Both are vegetated and have trees growing upon them. The immediate surrounds of the lake comprise a mixture of formal garden including standard and ornamental trees, extensive lawns and some areas of habitat managed for wildlife (Page 1984). In addition to the bridges, two structures abut the lake; a set of stone steps and the foundations of a boathouse.

The lake is shallow with an average depth of less than 1.5 metres. The benthic substrate comprises thick, black silt mixed with twigs and organic debris, presumably from trees surrounding or overhanging the water. At the time of sampling the major water source was artesian well water pumped from St James's Park, supplemented by precipitation and runoff from the Garden. This supply was discontinued, however, in 1997 due to degradation of pipework (pers. comm. Mrs Jennifer Adams, LVO, The Royal Parks). A pump extracts the water from the south-eastern end of the lake via a grilled intake. The water re-enters by means of a waterfall at the end of the north-western arm of the lake. The pipe carrying the water is located within the lake, under the surface of the water, running from one end of the lake to the other. Measurement of the physico-chemical parameters of water samples taken on 14 April 1996 showed conductivity was 730 μS, pH 8.4, calcium hardness 115 mg/l and carbonate hardness 3.6 SBVμM/l. The water was green and turbid (Secchi depth 38 cm) and appeared eutrophic.



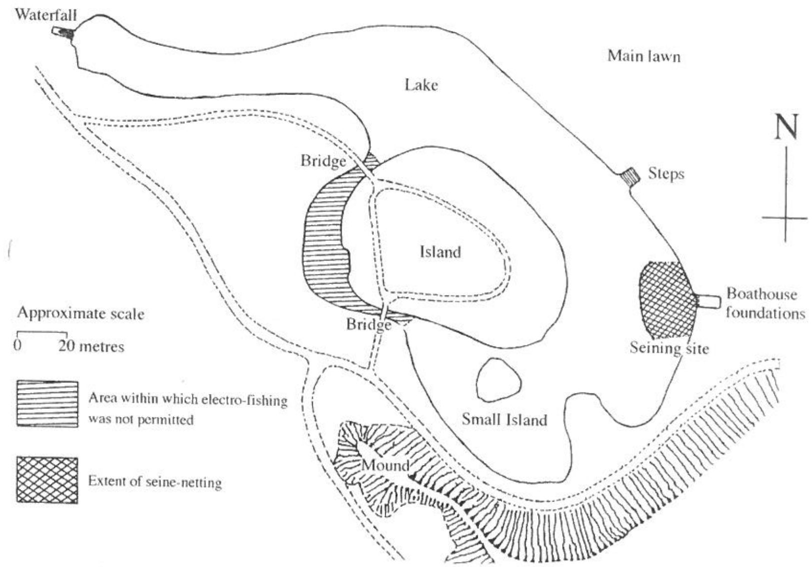


Figure 1: Buckingham Palace Garden lake, showing seining site.

There were no submerged macrophytes within the lake. Emergent and floating macrophytes such as *Sparganium* sp. and *Iris* sp. and some small beds of waterlilies *Nymphaea* sp., were located mainly within the north-western arm of the lake, below the waterfall. Macroinvertebrates appeared scarce within the lake, those found in the survey by Plant (in press) consisting of Heteroptera typically associated with organically-enriched, highly eutrophic waters (Sládečk & Sládečková 1994).

## Methods

### Sampling

Seine-netting was carried out on 5 May 1996 from the site of the old boat house on the eastern bank (Figure 1). The site was chosen to encompass the greatest variation in depth and the largest, easily-netted expanse of open water. The seine-net employed was 25 metres long, 2 metres deep, with 3 mm micromesh. The net was laid parallel to, and approximately 15 m from, the shore from a rowing boat. The total netted area was 360 $m^2$. The net was hauled inshore with minimum disturbance, an operator in a dry-suit ensuring that the floatline remained at the surface and leadline on the bottom to prevent escape of enclosed fish. The net was hauled onto the bank for sorting of captured fish. These were identified, measured (fork length to nearest mm), weighed (to nearest gm) and three to five scales collected from the appropriate location on the left flank, depending on species (Steinmetz & Müller 1991) before being returned to the lake. Six roach were in poor condition and were taken to the laboratory for autopsy.

A qualitative, electro-fishing survey was undertaken on 30 June 1996 to confirm the species composition of the fish population indicated by the quantitative seining. Electro-fishing was carried out by three operators in a rowing boat, one rowing, one netting immobilized fish, and the third operating a battery-powered, 12v pulsed DC, portable electro-fisher. All accessible portions of the lake were surveyed over a three-hour period. Immobilized fish were netted, identified, examined for external evidence of pathogens and were immediately returned to the lake.

**Age and Growth Determination**

Fish ages were determined by scale reading. Scales were cleaned by soaking in distilled water and rubbing between the finger and thumb, and were mounted in distilled water on slides. They were examined under a binocular microscope at x20 or x40 magnification, depending on the size of the scale and were measured with an eyepiece graticule. Scales were initially examined blind (i.e., without knowledge of the length of the fish from which they originated) and then examined with access to length data. When the two values did not agree, scales were re-examined and discarded if ambiguous.

Data obtained from the samples were used to construct length-weight relationships for the fish species sampled. Regressions of fish body-length on scale-radius were used in later analyses (back-calculation). Fish biomass (kg/ha) and growth rates were also calculated. Roach relative growth rates were determined using a standard index (Hickley & Dexter 1979). Predicted maximum roach length was calculated using a Walford Graph (Ricker 1975).

Fraser-Lee back-calculations (Equation 1) were carried out for all fish species sampled. Back-calculation uses measurements made on a fish at one time to infer its length at an earlier time or times. Measurements utilized are length of fish at time of capture and dimensions of one or more marks on some hard part of the fish. In this case hard parts were scales, marks measured being annual checks in growth that are recorded upon scales as annuli.

**Equation 1: Fraser-Lee Back-calculation equation**

$$L_i = c + (L_c - c)\left(\frac{S_i}{S_c}\right)$$

*Where:* $L_i$ = *Fish length at time of i<sup>th</sup> radius*
$S_i$ = *Scale radius at time of i<sup>th</sup> radius*
$L_c$ = *Fish length at time of capture*
$S_c$ = *Scale radius at time of capture*
$c$ = *fish length at scale formation*

## Results

The survey indicated that the fish population was of low species diversity and consisted of three species: roach *Rutilus rutilus* (Linnaeus, 1758), gudgeon *Gobio gobio* (Linnaeus, 1758) (Order Cypriniformes) and perch *Perca fluviatilis* Linnaeus, 1758 (Order Perciformes). Total fish numbers and biomass caught by seine within the lake are given in Table 1, together with estimates of species biomass/ha. These data indicate that the lake supports approximately 80 kg/ha of the three fish species combined. The roach population contributes the majority of this biomass (over 78 per cent).

Seine-netting showed that the roach population was composed of 1–6+ (year old) individuals with a length range of 69–151 mm. A Walford graph suggests that roach in the lake may reach a maximum size of approximately 200 mm (Figure 2). Comparison of length:age data with a standard curve constructed from national data (Hickley & Dexter 1979), shows that growth is close to average when the roach are in their first year, but decreases markedly with age giving a population average of 83.6, much lower than the standard of 100. This calculation is supported by data obtained by scale analyses, the roach showing low mean annual growth increments (Figure 3a). Back-calculation data also indicate that growth patterns have probably remained similar for at least the past four or five years with little variation shown in the year-class:length relationship (Table 2). Some individuals of less than one year were obtained whilst electro-fishing, indicating that the roach population had reproduced the previous spring. Analysis of stomach contents of six roach taken for autopsy demonstrated that the fish diet at that time consisted of silt, plant material, oligochaete worms, crustaceans and insects. One roach was heavily infected with ectoparasitic protists *Trichodina* sp. that had covered the gill filaments. The other five roach were uninfected by parasites.

Netting results indicated that the gudgeon population was composed of fish aged 0–4+, 40–142 mm, but comprised mainly juvenile fish. Out of a total of 25 individuals analysed for age, 18 were immatures of two years old or younger.

Their back-calculated growth rate, however, conformed with normal growth values suggested by Maitland & Campbell (1992) for the species. At the end of their first summer they had reached 46 mm, 100 mm by the end of their second year and 114 mm by the time they were three years old (Table 3, Figure 3b). Although the number of older fish caught by seine was low, many adult fish were seen shoaling at the base of the waterfall during the electro-fishing survey, suggesting under-representation in the net sample. As with roach, young-of-the-year gudgeon were obtained by electro-fishing, indicating that breeding had been successful in the previous spring.

Both electro-fishing and netting demonstrated that the frequency of perch within the lake was low, although those caught appeared to be in good condition and ranged from 2–5+ and 94–175 mm in length. An insufficient number of individuals were caught for reliable analyses of population age or size structure. These data suggested that the perch in the lake were attaining lengths close to those suggested as normal by Maitland & Campbell (1992). As in the other two species, a few young-of-the-year perch were obtained by electro-fishing, indicating that breeding had occurred in the previous spring.

TABLE 1.
Number and biomass of fish caught by seine in Buckingham Palace Garden lake on 5 May 1996

| Fish Species | Number in seine | Biomass (kg) | Biomass (kg/ha) |
|---|---|---|---|
| Roach | 150 | 2.27 | 63.07 |
| Gudgeon | 45 | 0.35 | 9.73 |
| Perch | 8 | 0.27 | 7.50 |
| Total | 203 | 23.34 | 80.30 |

## Discussion

Data obtained from the survey indicate a lake with a low diversity and density of fish with low to normal growth rates. Most still waters will support coarse fish populations of 300–800 kg/ha (Cooper 1991) and therefore the population density estimate of some 80 kg/ha suggests that the lake is below estimates for an optimal environment for supporting fish.

TABLE 2. Back-calculated lengths of Buckingham Palace lake roach *R. rutilus* obtained from measurement of scale annuli.

| Age | Roach length (mm) at age: | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | *n* | 0 | 95% | 1 | 95% | 2 | 95% | 3 | 95% | 4 | 95% | 5 | 95% | 6 | 95% | 7 |
| 1 | 3 | 41 | 17 | 62 | 8 | *74* | *21* | | | | | | | | | |
| 2 | 16 | 38 | 2 | 60 | 4 | 83 | 4 | *97* | *2* | | | | | | | |
| 3 | 6 | 37 | 7 | 61 | 8 | 80 | 9 | 98 | 10 | *109* | *5* | | | | | |
| 4 | 11 | 37 | 1 | 58 | 4 | 78 | 8 | 101 | 7 | 118 | 4 | *125* | *4* | | | |
| 2 | 38 | 31 | 63 | 89 | 83 | 111 | 34 | 127 | 54 | 137 | 104 | *144* | *89* | | | |
| 6 | 1 | 39 | – | 52 | – | 67 | – | 105 | – | 122 | – | 135 | – | 145 | – | *150* |
| | mean | 38 | 1 | 60 | 2 | 81 | 3 | 99 | 3 | 116 | 4 | 128 | 4 | 144 | 18 | 150 |
| | *n* | 39 | | 39 | | 39 | | 36 | | 20 | | 14 | | 3 | | 1 |

*n* number of fish in sample 95% 95% confidence interval age fish age in years (birthday taken as 1 June)
length in *italics* are 'plus growth' i.e., growth increments derived from the measurement taken from the annulus to the edge of the scale representing the growth since the fish's last birthday.

TABLE 3. Back-calculated lengths of Buckingham Palace lake gudgeon *G. gobio* obtained from measurement of scale annuli.

| Age | Gudgeon length (mm) at age: | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | *n* | 0 | 95% | 1 | 95% | 2 | 95% | 3 | 95% | 4 |
| 0 | 16 | 47 | 3 | *60* | *4* | | | | | |
| 1 | 4 | 45 | 4 | 76 | 6 | *107* | *8* | | | |
| 2 | 5 | 44 | 11 | 73 | 10 | 96 | 10 | *113* | *11* | |
| 3 | 1 | 47 | – | 75 | – | 104 | – | 119 | – | *132* |
| | mean | 46 | 2 | 65 | 4 | 100 | 6 | 114 | 9 | *132* |
| | *n* | 25 | | 26 | | 10 | | 6 | | 1 |

*n* number of fish in sample 95% 95% confidence interval age fish age in years (birthday taken as 1 June)
length in *italics* are 'plus growth' i.e., growth increments derived from the measurement taken from the annulus to the edge of the scale representing the growth since the fish's last birthday.



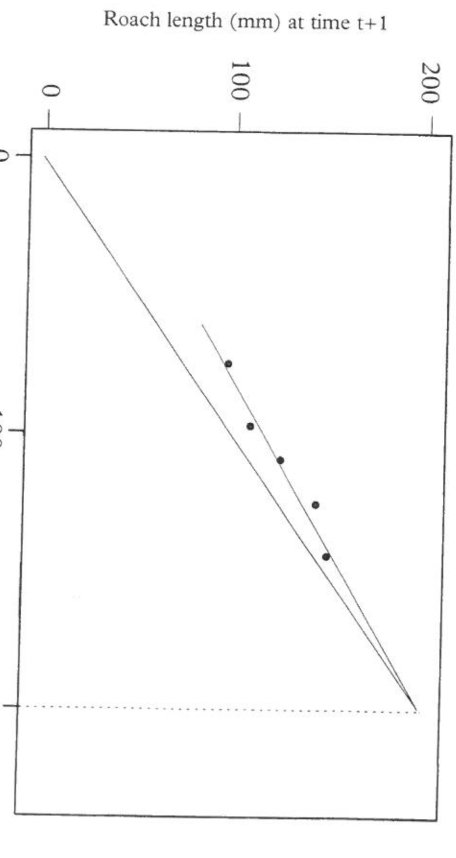


Figure 2:
Walford graph of Buckingham Palace Garden lake roach population.

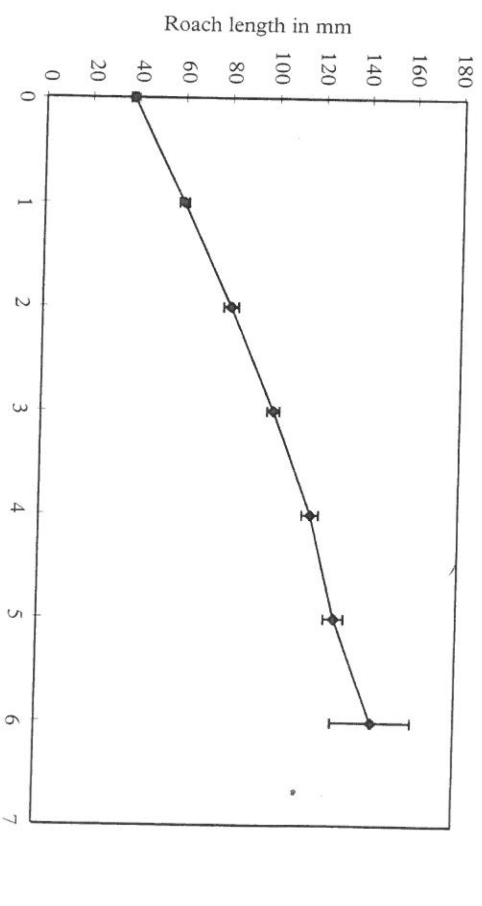


Figure 3a:
Growth curve for roach *R. rutilus* in Buckingham Palace Garden lake.
Mean lengths for each year class are shown ± 95% confidence intervals.

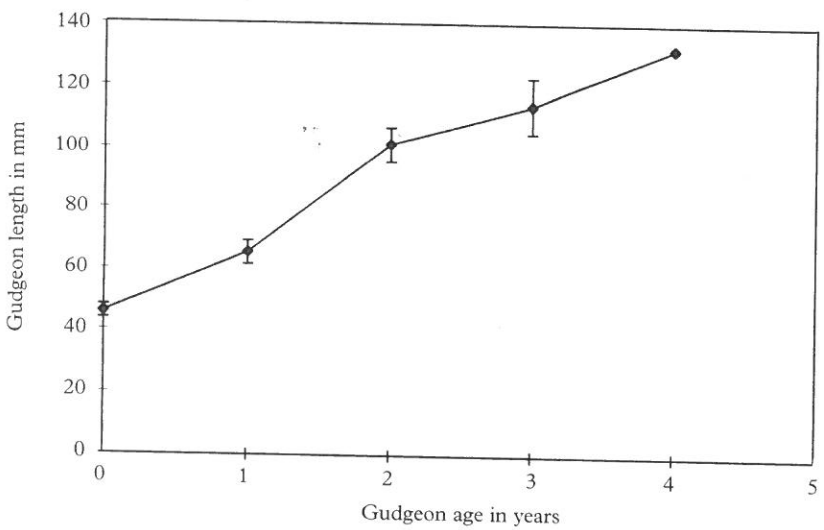


Figure 3b:
Growth curve for gudgeon *G. gobio* in Buckingham Palace Garden lake.
Mean lengths for each year class are shown ± 95% confidence intervals.

The roach is a common member of the carp family found in the majority of waterways of lowland Britain. It is tolerant of a wide range of environmental conditions and is thus found in many different aquatic habitats. It is essentially omnivorous in habit and the size of individuals within a population will be strongly dependent upon the nature and productivity of the environment. The roach in the lake are small in comparison to the length of roach in other habitats such as the River Thames, but not unusually so in comparison with other small, urban lakes (Kett, unpublished data). Comparison with Hickley and Dexter's index of roach growth shows that the roach in the lake grow well in their first year, but that growth rates decline as the fish approach adulthood.

Gudgeon are more usually associated with riverine habitats or gravel-bottomed lakes. Their streamlined shape enables them to maintain their position in running water. They are a small fish, rarely reaching more than 150 mm under optimum conditions. Their presence in the lake is unexpected, bearing in mind the high organic content of the benthic substrate. It is probable that their long-term survival in the lake has been assisted by the water recirculation system and particularly the waterfall where shoals of gudgeon were observed during the electro-fishing survey. Spawning usually takes place in shallow water, over gravel, but in the lake spawning probably occurs at the base of the waterfall where oxygenation levels are highest. The lake probably supplies sufficient benthic invertebrates to support good growth of this species. Their low overall biomass as part of the sample may be a result of under-representation in the seine. Their benthic habit and fusiform morphology mean they were the species most likely to escape the net by slipping underneath it during the haul.

Very few perch were found during the survey and this may reflect the turbid nature of the water within the lake. Perch are predatory fish, feeding on zooplankton in their first year and then macroinvertebrates until they are large enough to be capable of consuming prey such as juvenile fish of their own and other species. Perch are characteristic of slow and still waters where they ambush



their prey from stands of vegetation or similar refugia. The low number of perch is probably a consequence of the eutrophic nature of Buckingham Palace Garden lake and interspecific competition with roach for prey. Persson (1987) has shown that roach outcompete perch when foraging for zooplankton, especially when both species are in their first year of growth. Interspecific competition with roach can force juvenile perch to switch to feeding on macroinvertebrates sooner than normal, leading to increased intraspecific competition with older year class conspecifics. Persson & Greenberg (1990) refer to this phenomenon as a 'juvenile bottleneck'. Relatively few perch under these conditions manage to reach a sufficient size to make the change from macroinvertebrates to fish as the main diet component. These factors, together with the lack of macrophytes required for spawning, are likely to have combined to limit successful recruitment within the perch population. This is not an uncommon situation in eutrophic lakes, indeed, Persson (1987) states that under such conditions it is usual for roach to be numerically dominant over coexisting perch.

The previous survey of the Garden reported that the lake supported a population of roach, gudgeon, perch and dace *Leuciscus leuciscus* (Linnaeus 1758) (Evans et al. 1964), but no evidence of the latter species was found by either method of survey. Although absence of evidence is not evidence of absence, the thoroughness of the survey precludes the likelihood of their continued presence in the lake. Dace are characteristic of running-water habitats and, although adaptable, are unlikely to maintain a self-sustaining population under present conditions. It is probable that the common origin of the four species found originally in the lake was the Serpentine, as suggested by Evans et al. (1964). The disappearance of the dace is likely to be due to the isolation of the lake and changes in the nature of the water.

Eutrophication may be a key factor in ordering the composition of fish populations in Buckingham Palace Garden lake. The lack of submerged macrophytes within the lake has already been mentioned, together with the concomitant paucity of macroinvertebrates. These factors, together with abundant waterfowl and the fish, contribute to the summer turbidity of the lake. In non-eutrophic lakes, macrophytes form the major habitat for rich faunas of macroinvertebrates and larger species of planktonic Crustacea, e.g., waterfleas, *Daphnia pulex* (De Geer). Such communities form major prey components of foraging fish (Hulsmann & Mehner 1997). However, dense macrophytes also constitute refugia for invertebrates against fish predation (Moss et al. 1998). Planktonic Crustacea, safe in macrophyte refugia, restrict phytoplankton population growth by filter-feeding (Stephen et al. 1998). Additionally, photosynthesizing macrophytes reduce dissolved plant nutrient concentrations and produce algicidal compounds inhibiting phytoplankton populations (Moss 1980).

These balanced, complex systems are vulnerable to perturbations, ultimately affecting the nature and status of lake fish populations. Such perturbations may have influenced the present state of the lake. Changes were probably gradual; accumulation of debris from surrounding terrestrial vegetation concentrated organic material in the lake as did constant addition of waterfowl faeces. Run-off from surrounding surfaces introduced organic and inorganic nutrients which accumulated in the sediments. Under these conditions, organic materials decomposed, releasing nutrients. Foraging waterfowl and fish disturbed benthic sediment, resuspending nutrients in the water column. Phytoplankton and filamentous algae bloomed, shading and blanketing submerged macrophytes which slowly died. Perch lost spawning substrate and ambush sites. Macroinvertebrates and large zooplankton were deprived of habitat and refuge from fish predation. These processes reduced predation pressure on phytoplankton and increased water turbidity. Further up the food chain, the fish community were affected in other ways. Juveniles grew more slowly as a result of the prevalence of smaller zooplankton species. This increased both competition for, and predation pressure on, the zooplankton community.

The processes operating within Buckingham Palace Garden lake have kept it in a eutrophic state and reduced the diversity, growth and abundance of the fish community. The loss of the dace population was very likely a result of these processes. Eutrophication decreased their foraging efficiency and availability of suitable spawning substrate. Perch are, however, more characteristic of still waters than dace and were probably less disadvantaged by the eutrophication. They persist within the lake, albeit at a low population density, where the dace have, apparently, become extinct. Roach, however, are less disadvantaged under such conditions. They are able to outcompete perch under conditions of eutrophication, being more effective filter feeders on zooplankton and able to subsist, if poorly, on phytoplankton and detritus (Persson 1983). Roach are also more eclectic in spawning substrate, utilising, in the absence of other substrates, tree roots or even stones (Holcik & Hruska 1965). Deprived of weedbeds within which to forage and facing competition from perch for macroinvertebrates and zooplankton, the Palace lake roach increasingly fed by processing benthic silt for the macroinvertebrates living within it. Disturbed silt is soft and flocculant and a poor substrate for macrophyte roots. Badly anchored, shaded and outcompeted by algae, macrophytes were easily uprooted by foraging fish. Of all the fish species within Buckingham Palace lake, roach are hardiest, capable of surviving elevated water temperatures and low levels of dissolved oxygen. The lake is rich in decomposing organic material and exists in the midst of a metropolitan heat island. Oxygen levels are likely to fall in very hot summers, giving roach a vital competitive edge, permitting their domination of the fish community. Perch, gudgeon and dace, and especially their spawn, all require lower temperatures and higher dissolved oxygen levels to thrive.

Such small populations are most vulnerable to random fluctuation in numbers (Williamson 1989). Perch, low in number, outcompeted by roach and short of spawning substrate are the next most likely candidates for extinction under present conditions. The isolation of Buckingham Palace Garden precludes likelihood of natural recolonization, but anthropogenic influence could work to counter the processes that are presently causing deterioration of the lake fish population.

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# Amphibians and reptiles in Buckingham Palace Garden

COLIN W. PLANT
*14 West Road, Bishops Stortford, Hertfordshire CM23 3QP*

## Abstract

A record of the common frog *Rana temporaria* in Buckingham Palace Garden is given. There are old records of both frogs and the common toad *Bufo bufo* in the Garden, but no other amphibian species and no reptiles have ever been reported here.

## Amphibians

The only amphibian noted during the 1995-97 survey of Buckingham Palace Garden would appear to be the common frog *Rana temporaria*.

Frogs have been seen intermittently in the Garden over the past thirty years, though always on land (Mark Lane, pers. comm.). Knight (1964) reported that frogs were very rare in the Garden and listed only a single female found in 1953, adding that no one had ever seen tadpoles or spawn in The Lake. During the 1995-97 survey, single adult frogs were seen on two occasions only, in long grass near The Stoneyard and in grass adjacent to the Back Path, both in the autumn.

The presence of frogs in central London is not a surprise. Langton (1991) remarked that 'In much of urban London you are probably never more than tens of metres from the nearest common frog, making it one of the commonest terrestrial vertebrates and possibly ...... numerically one of the most abundant'. His distribution maps show that the frog was then present throughout much of the urban area of London.