Thirty years of garden ponds

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THIS is the third decadal account of amphibians living wild in a series of garden ponds that were first established in 1977. The garden is at around 80 m elevation above sea level, on the South Downs in East Sussex. To the west is a main road and then open fields with no standing water for over 1 km, making natural colonisation by amphibians very unlikely from this direction. However, to the east there are many gardens, some with ponds. Populations of Common frogs *Rana temporaria*, Smooth newts *Triturus vulgaris* and at least one of Common toads *Bufo bufo* certainly occur and have been potential sources of colonists. Four anuran and four urodele species currently breed in my ponds, and all were introduced deliberately by me irrespective of whether some natural colonisation occurred. In the first decade, a large population of Common frogs (more than 200 adults) became established, as did a small mixed population of water frogs (*Rana lessonae/ esculenta*) and substantial numbers of four newts (Smooth newts *T. vulgaris*, Palmate newts *T. helveticus,* Great crested newts *T. cristatus* and Alpine newts *T. alpestris*). The non-native species (water frogs and Alpine newts) were introduced before such activity became illegal under the Wildlife & Countryside Act of 1981. By 1986, Smooth newts in particular were extremely abundant (Beebee, 1986). Over the next decade, Common frogs and all the newts except alpines declined while the water frogs remained fairly stable but in low numbers (Beebee, 1996). The newt declines followed the introduction of Three-spined sticklebacks *Gasterosteus aculeatus* into one of the two large ponds in 1991, in a deliberate attempt to control newt numbers and relieve what had become very high predation pressure on frog spawn. Throughout the first 20 years various attempts to encourage Common toads *Bufo bufo* all failed. In this paper I describe events in the third decade, including an overview of the entire 30-year period.

The garden site

An outline of the main ponds used by amphibians, approximately to scale, is shown in Figure 1 together with dates in which the various ponds were created. The two largest ponds (1 and 3) are illustrated in Figure 2. Ponds 1–5 are all concrete (though 1, 2 and 3 started out as butyl liners), while ponds 6 and 7 are butyl. The numbering system for ponds 1–3 follows that of previous publications (Beebee, 1986; 1996), while ponds 4–7 were all created after 1996. Ponds 4 and 5 are connected by pump, with running water, and are little used by amphibians for breeding. Ponds 2, 3, 4, 5 and 7 receive sun for most of the day. Pond 1 is partly, and pond 6 very shaded. Pond 1 is the favourite of all four newt species and the only breeding site for *T. cristatus*, though many newts of the other species also use ponds 6 and 7. Common and water frogs, and recently Common toads, always spawn in pond 3. Pond 3 was also heavily used by newts prior to the introduction of sticklebacks, and this is the only pond with fish.

Amphibian numbers

Anurans – The numbers of Common frog spawn clumps laid in the garden over the past 30 years, more than 98% of which were in pond 3, are shown in Figure 3. The population increased rapidly during the first decade to a peak of more than 200 adults (assuming an equal sex ratio), but declined dramatically in the second decade. Since the mid 1990s the population has apparently stabilised in the region of 20–30 pairs, with indications of a revival over the past five years after a nadir in 1998. The decline in the late 1980s was commensurate with the development of large newt populations, and newts were watched after dark attacking spawn and eating the embryos. Frog tadpoles, let alone froglets, were virtually never seen at this time. However, the introduction of sticklebacks in 1991 was followed by declines in the newt population, especially that of great crested newts, specifically in pond 3 (see later). Since then, frog tadpoles and froglets have been observed fairly regularly though never in the numbers of the first decade. Immature frogs, and

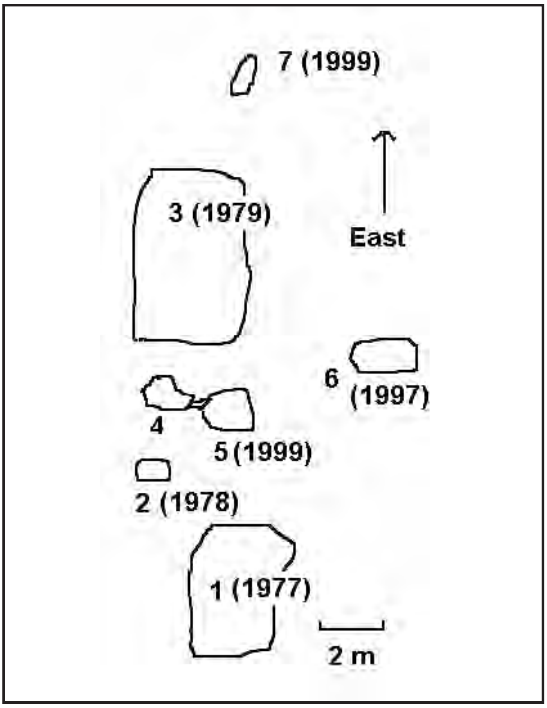

Figure 1. Layout of the garden ponds. Year of creation is in brackets.

small adults at breeding time, are now seen again every year. Common toads made sporadic attempts to breed, mostly in pond 3, during the early 1980s and again in the mid 1990s. Usually just one or two pairs spawned, and the subsequent tadpoles disappeared before metamorphosis. However, following the release of tadpoles in the newly created pond 6 in 1998, Common toads started to do well and have produced toadlets consistently (though never in pond 6!) since 2000, and especially in the last three years. In the springs of 2005 and 2006 pond 3 teemed with Common toad tadpoles. Forty adults, including 10 pairs, were seen on the best night in March 2006.

I have not tried to quantify water frog numbers, but there have certainly been some interesting changes. During the 1980s I could sometimes count up to 20 basking at any one time in summer, mostly a mixture of Pool and Edible frog adults. Although they spawned every year, much of the output was not viable (presumably due to *esculenta* x *esculenta* matings) and juveniles were rarely seen. By the late 1990s, however, best counts were 40–50 individuals and almost all were Pool frogs. Reproduction is now successful in most years, and a range of sizes including adults and immatures occurs.

Urodeles – The fate of newts in the garden ponds is summarised in Table 1. Numbers were estimated in the Aprils of 1986, 1996 and 2006 using a capture-mark-recapture approach. Multiple newt traps (Griffiths, 1985) were set in the ponds overnight. All newts caught in the traps were toe-clipped the following morning, and released immediately back into the pond where they were caught. Before dark, on the same day, the ponds were netted and all the newts caught were recorded as to whether they were clipped or not. Population sizes in each pond (1, 2, 3, 6 and 7) were estimated according to the equation:

$$N = \frac{a(n+1)}{r+1}$$

Where N = estimate of population size, a = number of newts toe-clipped, n = number of newts caught in second round (by netting), and r = the number of netted newts with toe clips.

Standard deviations (SDs) were estimated (per individual pond) by:

$$SD = \sqrt{\frac{a^2(n+1)(n+r)}{(r+1)^2(r+2)}}$$

These estimates of course only refer to newts in the ponds at the time, and there may also have been some living away from the ponds. I attempted to choose the time of peak numbers visible in the ponds during the three springs when the mark-recaptures were carried out, but if I got this wrong in any substantial way then the inter-year comparisons would be unreliable. I believe, however, that any such errors were minor relative to the numbers estimated. Although they have fared rather differently, the four species were still present 30 years after their introduction. All except the alpines seemed to decline in the second decade, relative to the first 10 years, but the three natives stabilised or recovered ground in the third. Thus Smooth newts increased dramatically in the first decade, declined by some 80% in the second, and remained at that level or a little higher during the third. Great crested newts, always the rarest species, are now fewer than in the 1980s probably because sticklebacks excluded them from pond 3 during the early 1990s. However, their numbers in pond 1 are essentially unchanged over 30 years. Palmate newts have remained stable or perhaps increased slightly, and seem to do particularly well in the relatively new pond 7 (data not shown in Table 1). Alpine newts thrived from the start, and by 2006 were the most abundant species, accounting for more than half of all the newts present in the garden ponds.

The effects of introducing sticklebacks into pond 3 can be inferred from Table 2. Between 1986–2006, Smooth newts declined by 74% overall in the garden, but by 90% in pond 3. Palmate newts increased by 50% overall, but declined by 45–50% in pond 3. Great crested newts declined by about 30% overall, but by at least 86% (and as a breeding species by 100%) in pond 3. By contrast, Alpine newts increased by 140% overall, and by 80% even in pond 3. Alpines are now the dominant species in all the ponds, and this is particularly marked in pond 3. Total newt numbers in pond 1 rose by about 25% between 1986 and 2006, whereas total newts in pond 3 declined by about 73% over the same period (and by about 37% in the garden as a whole, almost entirely due to the crash in Smooth newt numbers in pond 3).

Figure 2. Ponds 1 (above) and 3 (below), May 2006.

Amphibian breeding times

The dates upon which the first spawn of Common frogs and water frogs was laid in the garden ponds are shown in Figure 4. I inspect the ponds every day during the respective breeding seasons, so the dates should be accurate to within 24 hours. There has been no tendency for common frogs to spawn earlier over the past 30 years ($r = -0.172$, $P = 0.382$). The average for the period was day 58, i.e. February 27th, counting January 1st as day 1. The earliest date was February 13th, achieved in both 2002 and 2005, while the latest was March 13th in 1979. By contrast, there has been a dramatic change in the onset of spawning by water frogs and a highly significant trend towards earliness ($r = -0.608$, $P = 0.001$). Between 1978–1990 the average date was June 4th, while between 1991–2006 it was May 15th, an advance of nearly three weeks. Even so, 2005 and 2006 were both late following unusually cold spells in March.

First arrivals of all four species of newts have appeared earlier over the past 30 years. Dates for Smooth newts (those for Palmate and Great crested newts are almost identical) and for Alpines are shown in Figure 5. Ponds were inspected by powerful torchlight almost every night, excepting when frosts occurred, between November and February and data should be accurate at least to within 48 hours. Although the trends were all similar, Alpine newts consistently arrived later than the three native species, by an average over the 30 years of around 38 days. Overall the trend to earliness was significant for Smooth newts ($r = -0.623$, $P<0.001$) and for Alpines ($r = -0.786$, $P<0.0001$). Moreover, the trends were highly correlated between these two species ($r = -0.705$, $P<0.0001$), and among these and the others (data not shown). For Smooth newts the regression line indicates that first arrivals have become some 50 days earlier over the past 30 years, from late

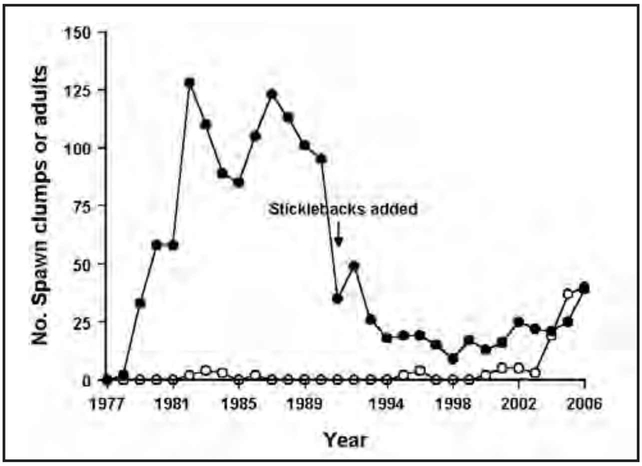

Figure 3. Numbers of common frogs and toads breeding in the garden ponds. Solid circles, numbers of frog spawn clumps; open circles, largest number of common toads seen on a single night. Arrow shows when sticklebacks were added to pond 3.

January (circa 27/28th) in the late 1970s to early December (circa 5/6th) in the early 2000s. The corresponding change for Alpine newts has been greater at around 75 days, from circa March 20th to circa January 5th. However, the regression lines are somewhat misleading because the changes for both species over time were not linear. Between 1978–1992 there were strong and significant trends for both species (Smooth newts, $r = -0.778$, $P<0.001$; Alpine newts $r = -0.833$, $P<0.0001$), but between 1993-2006 there was no subsequent change (Smooth newts $r = -0.084$, $P = 0.785$; Alpine newts $r = -0.027$, $P = 0.928$). The same biphasic pattern also was seen with Great crested and Palmate newts. The scatter of first arrival timings over the past 10 years has been large for all species, but is still notable that the earliest arrivals (November 16th for Smooth newts in 2003, and December 2nd for Alpine newts in 2004) have all been in the last decade.

Table 1. Changes of total newt numbers during three decades.

Year	Smooth newts	Great crested newts	Palmate newts	Alpine newts	Total newts
1986	527	19	26	98	670
1996	103	9	15	103	230
2006	135	13	39	234	421

DISCUSSION

Current concerns about global amphibian declines (e.g. Beebee & Griffiths, 2005) make long time-series of population dynamics potentially important if we are to understand factors that may predispose extinction. Although these garden ponds are of course artificial, with the exception of Common toads there has been no manipulation of the species numbers since the original introductions which finished in 1981. The main breeding ponds also retain their original sizes and shapes, though extra small pools have been added within the last 10 years. I believe that over three decades the Woodingdean garden site has provided some interesting insights about the functioning of amphibian communities, but also posed some unanswered questions.

Frogs, newts and fish

The introduction of sticklebacks to pond 3 resulted in the outcome I hoped for, i.e. a reduction in the newt population and the revival of the frog population, albeit after a substantial lag phase of 5 years or so. Of course I cannot be sure that this was cause and effect, it could be coincidental, but it makes biological sense because newt larvae are now almost never seen in pond 3. Therefore the garden has retained its full amphibian biodiversity and even expanded it with the recent toad success, which may also be related to the presence of fish as toads generally do well in fishponds. The mechanism of fish avoidance by newts is interesting. Great crested newts can clearly recognise and avoid fishponds, but I believe this only works with potential new immigrants. Some, I guess those born in pond 3, continued to try and breed there in progressively smaller numbers in the few years following stickleback introduction (Beebee, 1996). Maybe philopatry is dominant over fish avoidance mechanisms in this species. As a minor aside, sticklebacks have never appeared in any of the other ponds over the past 15

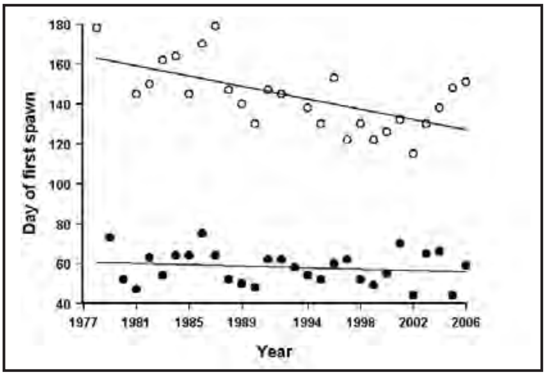

Figure 4. First spawn dates for Common frogs (solid circles) and water frogs (open circles).

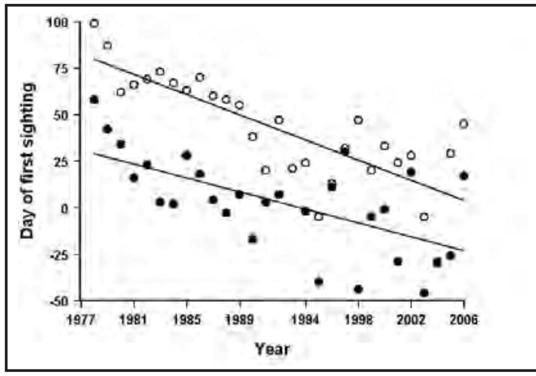

Figure 5. First arrival times of Smooth newts (solid circles) and Alpine newts (open circles).

years. This is despite the proximity of the pools, and their regular use for bathing by many birds. Evidently these small fish do not disperse easily in this kind of situation.

Non-native species

Alpine newts have prospered, but apparently not at the expense of the three native species despite my earlier concerns about Smooth newt declines (Beebee, 1986). The implication is that despite remarkably high densities of newts in most of the garden ponds (much higher than I have seen in most rural ponds), interspecific competition has not been severe over this 30-year timescale. Perhaps this is not too surprising, since all these species coexist in parts of France (Arntzen & de Wijer, 1989). Alpine newts surely have the potential to spread widely in Britain, and I find it surprising that they have not yet done so. The water frogs have fared increasingly well, partly I think because Edible frogs in the original mixture, obtained from Beam Brook in Surrey (Gillett, 1988), have mostly died out leaving Pool frogs that produce viable spawn and are probably better adapted to northern climates than the hybrid *esculenta*. I suspect that adding extra ponds has also helped. The segregation of juveniles into pond 7, for example, is very noticeable and in general a mosaic of pools is considered highly conducive to the maintenance of water frog metapopulations (Sjogren Gulve, 1994).

Breeding times

With Common and water frogs, breeding in the garden is relatively explosive and most spawn is deposited within a week or two of the initial clump. First spawning dates are therefore an accurate indication of overall breeding time. Common frogs have not changed their breeding season significantly, while the water frogs now breed much earlier in most years than they did in the 1980s. The spread of water frogs in south east England in recent decades (Wycherley & Anstis, 2001) may well be a result of this change, and a consequent increase in metamorphic success, since the tadpoles now have longer to develop before winter sets in. In my ponds, water frog tadpoles still in the ponds when ice forms – even a thin and incomplete cover – invariably die, and litter the pond bottom. For newts, the story is rather different because first arrivals do not accurately reflect overall breeding times. It

Table 2. Changes of newt numbers in pond 1 (no fish) and pond 3 (fish added in 1991).

Year	Smooth newts		Great crested newts		Palmate newts		Alpine newts	
	Pond 1	*Pond 3*	*Pond 1*	*Pond 3*	*Pond 1*	*Pond 3*	*Pond 1*	*Pond 3*
1986	115(32)	364(111)	12(4)	7(2)	8(3)	13(4)	43(12)	39(21)
1996	23(12)	55(29)	7(2)	0(0)	9(5)	6(3)	33(19)	41(10)
2006	72(34)	35(16)	12(6)	1(0)	12(5)	7(3)	128(42)	70(29)

remains true that most newts arrive much later than the vanguard, and though I have not tried to quantify peak time it is evidently in March and early April for all the species in most years. This is probably an advance on the situation 30 years ago, but not by anything like as much as the vanguard records suggest. In mid-Wales, median migration times of Smooth and Palmate newts were one to three weeks earlier in the late 1990s than they were in the 1980s (Chadwick *et al*., 2006).

Presumably all these differences represent responses to climate change, and they certainly correlate with temperatures that are likely to be important for gamete maturation (Beebee, 1995). With newts, the vanguard may be approaching a limit on potential earliness in November, perhaps because there is a minimum time needed after the previous breeding season to accumulate resources for reproduction. The question remains, however, as to whether the main newt breeding season will eventually advance to catch up with the vanguard.

Common toads

Toads have been the most perplexing species in the garden. It remains unclear why they experienced such poor breeding success in the early years. Pond 6 was constructed with toads in mind, and produced many toadlets from introduced spawn in 1998 and 1999, but returning adults in subsequent years never used it and have suddenly started to prosper in pond 3. Actually pond 6 is particularly odd because over the past three years five female toads have entered it and died for no obvious reason. Other amphibians visit pond 6 regularly with no ill effects. As usual there is always more to learn, but garden ponds are excellent and convenient outdoor laboratories with, I am sure, much more to offer.

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