Night counting, netting and population dynamics of Crested Newts (*Triturus cristatus*)

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ABSTRACT — Surveillance of a population of Crested Newts (*Triturus cristatus*) has been undertaken at Shillow Hill, Cambridgeshire during each breeding season from 1983 to 2002 by means of torch counts of adults. Reproductive success has been monitored by netting larvae each summer since 1986. The introduction of springtime netting for adults in 1993 enabled levels of recruitment and survival to be studied for the period 1993-2002. The population was at a low level in 1993 following drought in 1990-1992. Successful emergence in each year from 1993 to 1996 resulted in recovery between 1995 and 1998 through recruitment to the adult population two or three years later. Size of larvae at the end of development was inversely related to density. The adult population stabilised during 1998-2002, when the likelihood decreased of a larva returning as an adult, perhaps because of emigration of metamorphs. Annual survival of adults showed no significant trend during the study, mean survival being estimated at 71%. In 2001 and 2002, adults remained in the breeding pond for longer into the summer and few metamorphs emerged, apparently due to cannibalism. The effect of this regulation should be felt as reduced recruitment to the adult population during 2003-2005. Over the entire 20 years of surveillance, most of the larger inter-year fluctuations in counts of breeding newts resulted from changes in suitability of the pond rather than real changes in the level of the population.

ALTHOUGH the Crested Newt (*Triturus cristatus*) is widespread through much of lowland Britain, it is strictly protected by law and is the subject of considerable survey and conservation effort (Griffiths & Inns, 1998; Langton et al., 2001; Baker, 2002). Counting adult newts at night with a powerful torch is the usual method for determining the conservation status of populations breeding in sites with relatively clear water. An extension of such work is to repeat night counting over a period of years, perhaps to monitor populations subject to conservation action or potentially damaging operations, or because a population is of local or national importance.

An example of the last type of surveillance has been undertaken at Shillow Hill in Cambridgeshire since 1983. Mean numbers of adult Crested Newts counted at night each year, 1983-1993, varied between 3 and 183 (Cooke, 1995). While it was possible to speculate about the causes of a significant increase in adult numbers in 1985 and a decrease in 1989, there was limited underpinning evidence. To provide a better understanding of variations in numbers counted, additional field techniques, involving netting, have been introduced. These have now been in operation for at least ten years, and results for the years 1993-2002 are the main focus of this paper. The regular application of night counting and associated netting techniques over a number of years may further our understanding of the population processes of this species. Here this is based on comparisons rather than by deriving absolute population data as in other studies on this species (e.g. Arntzen & Teunis, 1993; Baker, 1999). Such knowledge is crucial to the surveillance and management of Crested Newt populations, both at specific sites and in general.

THE SITE

The site has been described by Cooke (1985, 1986, 1995 and 2002) and Cooke & Arnold (2001). The Shillow Hill site (grid reference TL 2882) is in Cambridgeshire and extends to 2 ha of semi-natural habitat. It is bordered by a road, the B 1040, and isolated by at least 500 m of arable farmland from its nearest neighbouring Crested Newt breeding pond. Significant natural immigration is therefore very unlikely; the extent of permanent emigration is unknown, but newts are found on the surrounding arable land close to the site at certain times of year.

There was a prolonged drought during 1990-1992; few newts were counted during the breeding seasons because of low water levels, and further desiccation in summer meant little or no emergence of metamorphs. During 1993-2002, successful breeding by Crested Newts was restricted to a single pond, Top Pond. When full, Top Pond has 48 m of edge and a depth of 1.4 m. Prior to creation of the sump in 1991, it was only 0.7 m deep. Crested Newts bred in Wood Pond in the 1980s, but this later suffered persistent desiccation problems and only a single Crested Newt was recorded there during 1993-2002.

METHODS

If pond and counting conditions can be strictly controlled, changes in numbers of adults counted at night in Top Pond may reflect changes in the size of the newt population using the pond. During 1984-1986, night counts in the pond were positively related to totals caught by a standardised bottle-trapping method, an independent quantitative measure (Cooke, 1995). In 1984, the mean night count of adults represented 23% of the total estimated to be present in Top Pond by mark-recapture methods (Cooke, 1985).

The number of adult Crested Newts that might be counted at night in a breeding pond depends on many factors. First, number of adults will depend on recruitment via immigration or young becoming sexually mature and on losses through emigration or death. Immigration at Shillow Hill can probably be discounted. Secondly, the proportion of the population in the water will depend on season, pond suitability and possibly population size. Even at the height of the breeding season, some newts will be on land. Thirdly, not all newts in the water will be counted. Newts in a pond may be inactive and/or may hide from view. Whether a newt is visible will depend on factors such as time of day relative to sunset, season and weather conditions. It is also possible that newt behaviour may be related to density in the pond. Fourthly, the nature of the pond will influence the count, with newts being easier to see in small ponds with clear water, little or no aquatic vegetation and where there is access for the observer to the whole shore. Finally, an ability to see and count newts at night depends on power of torch and the skill and care of the observer.

Each breeding season 1993-2002, five night counts were undertaken in Top Pond at roughly fortnightly intervals from the second week of April to the first week of June (numbers of counts 1983-1992 are given in the legend of Figure 1). Over the last 20 years, there has been no significant trend in the timing of the peak count. Counts were made between 50 and 120 minutes after sunset. Whenever possible, counting was avoided when rain was falling or at air temperatures of < 5°C. Each night visit consisted of counting, on a single circuit, adult and immature Crested Newts seen in the whole of the margins of the pond plus its centre. Smooth Newts (*Triturus vulgaris*) also breed in the pond but their numbers are not reported in this paper.

Water conditions in Top Pond were classified each spring (as well as each summer and autumn) as: 'full' (if the whole bed of the pond was covered), 'sump' (if only the sump held water), or 'dry'. In early April each year, filamentous algae and twiggy debris were raked from the edges of the pond. When counting at night, percentage cover of surface vegetation was recorded and a stick was used to move aside surface or submerged vegetation that might be obscuring newts. Water turbidity was scored by eye from 0 (clear) to 3 (turbid). If possible, counting was avoided for several nights after heavy rain, because turbidity usually increased. All night counting was undertaken by the authors, with the aid of torches of up to 70,000 candlepower. So, while many factors could be controlled, this was not (completely) the case with amount of water in the pond, amount of aquatic vegetation or turbidity. Some precautions could be taken, but the principal approach with these variables was to record them, and check later whether they may have influenced results. For instance, a major difference in turbidity in successive years could produce a spurious inter-year comparison.

Other fieldwork involved netting adults in the spring and larvae in the summer. Once per year since 1993, during late April or early May, about 30 minutes were spent netting at night. Adult Crested Newts were caught, weighed and measured from tip of snout to end of tail and returned to the pond. An index of body condition was derived by dividing the weight (in mg) by the cube of the length (in cm). Adults were classified as 'large' (males > 106 mm, females > 120 mm) or 'small', these size thresholds were derived by measuring a sample of adults in 1993 after three years of virtually total breeding failure (Cooke, 2002). The inference was that large newts tended to be aged at least four and small ones tended to be three years old or less. If it is assumed that small and large newts can be seen or caught with equal ease, then mean numbers counted at night can be apportioned into the two classes. This forms the basis for understanding fluctuations in recruitment and for estimating adult survival. Annual adult survival was derived by dividing the estimated mean number of large newts counted in a year by the total number of adults (i.e. small + large) counted in the previous year.

During July and August 1986-2002, Top Pond was netted during daylight on four occasions, usually at about one week intervals, to provide an indication of relative larval abundance at metamorphosis. For each metre of shore, a 2 m sweep was made through the water and aquatic vegetation. When water remained only in the sump, one sweep was made per 2 m^2 of surface area. Newt larvae were identified and counted. Length was measured for Crested Newt larvae at the 'walking' stage, immediately prior to emergence (Cooke & Cooke, 1992). Any adults or immatures that were caught were recorded. All newts were returned to the pond.

RESULTS

During night counting in six of the ten years, 1993-2002, Top Pond was full, had a mean turbidity score of 1 or less, and aquatic plant cover reached at least 60%. Such conditions are taken to be typical. Conditions in the four remaining atypical years are listed in Table 1, together with predicted effects on numbers of newts in the pond and the ease with which newts might be seen. In the spring of 1997, only the sump was available, conditions which had previously resulted in few newts attempting to breed (Cooke, 1995); the small size of the sump should have made the newts easier to see, but turbidity was high. In 1999, high turbidity would have made them harder to see, but this effect might have been cancelled out by less plant cover. Very high turbidity in 2001 probably reduced counts, but low plant cover in 2002 should have made them easier to record; comparisons of night counts in 2001 and 2002, in particular,

Year	Water level	Mean turbidity	Maximum plant cover (%)	Effect on newt numbers in pond	Effect on ease of seeing newts
1997	Sump	1.3	-	Reduction	?
1999	Full	1.6	30	No effect	?
2001	Full	1.8	60	No effect	Harder
2002	Full	0.9	35	No effect	Easier

Table 1. Conditions during the four years when suitability of Top Pond and the ease of seeing newts were considered to be atypical.

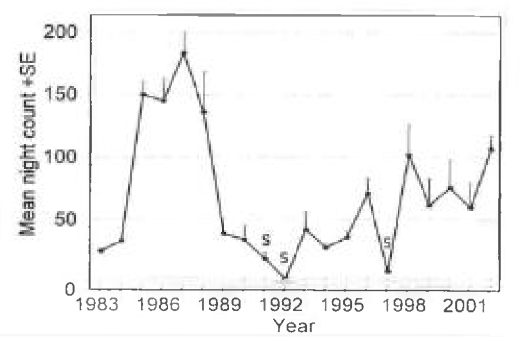

Figure 1. Mean night counts (+SE) of adult Crested Newts in Top Pond, 1983-2002. Means are based on a single count in 1983, nine counts 1984-1987 and five counts 1988-2002. Springs when only the sump was available are indicated (s).

should therefore be treated with caution.

Mean night counts for 1993-2002 are depicted in Figure 1, together with counts for the previous ten years. The period 1993-2002 was preceded by a drought between 1990 and 1992, when few adults attempted to breed and virtually no metamorphs emerged. There was a general increase in adults counted from 1993 to 2002 ($r_s = 0.636$, $P < 0.05$). Testing between mean counts of adults in pairs of years, 1993-2002, counts increased significantly in 1996 (Table 2, $t_8 = 2.54$, $P < 0.05$) and 1998 ($t_8 = 3.83$, $P < 0.01$), with a decrease in 1997 ($t_8 = -4.70$, $P < 0.01$). The decrease in 1997 and subsequent recovery in 1998 confirmed the expected temporary reduction in 1997 resulting from the unusual pond conditions described above. During 1993-2002, counts of immature newts were highest in 1994 and lowest in 1997 when there was water only in the sump (Table 2).

Using the observed proportion of small newts in the population (Table 2), mean night counts have been divided into two components representing small and large individuals (Table 3). The small newts are assumed to be the newer recruits to the adult pool, but they may have been breeding for more than one year. To provide some information on the age of newts in the two size classes, estimated number of small or large newts counted each year was compared in rank correlation tests with mean numbers of larvae caught a certain number of years before (N_{-i}). Larval counts 1993-2002 are listed in Table 4 and those prior to 1993 are given in Cooke (1995). Adult count data from the unusual year of 1997 have been omitted because their inclusion could result in misleading conclusions (see Cooke & Arnold, 2001).

For small adults, there were no significant relationships with reproduction in any individual previous year, but numbers of small adults were related to mean catch of larvae in combinations of the following consecutive years: two-three years before, $(N_{-2} + N_{-3})/2$ ($r_s = 0.717$, $P < 0.05$); and two-four years before (N_{-2} +

Year	Spring water level	Mean adult count ±SE	Mean immature count ±SE	Propn small adults in netted sample (no. in sample)	Mean body condition index ±SE for large adults (no. in sample)
1993	Full	42 ± 14	0.2 ± 0.2	0.00 (15)	6.3 ± 0.2 (15)
1994	Full	28 ± 3	5.2 ± 3.5	0.00 (11)	6.0 ± 0.2 (11)
1995	Full	36 ± 5	1.0 ± 0.0	0.29 (21)	5.7 ± 0.2 (15)
1996	Full	71 ± 13*	2.4 ± 0.7	0.65 (20)	5.3 ± 0.3 (7)
1997	Sump	9 ± 4**	0.0 ± 0.0	0.60 (25)	5.2 ± 0.2 (10)
1998	Full	102 ± 24**	1.2 ± 0.7	0.35 (17)	6.8 ± 0.3 (11)
1999	Full	62 ± 21	3.4 ± 1.5	0.33 (9)	5.1 ± 0.4 (6)
2000	Full	76 ± 22	2.2 ± 0.7	0.30 (30)	6.4 ± 0.2 (21)
2001	Full	60 ± 20	1.2 ± 0.6	0.23 (13)	5.6 ± 0.3 (10)
2002	Full	107 ± 11	2.2 ± 0.7	0.24 (29)	5.8 ± 0.2 (22)

Table 2. Results of spring fieldwork, 1993-2002. Mean counts of adult and immature Crested Newts are based on five night visits. The proportion of small adults and body condition index for large adults are based on a single netting visit. See text for definitions of small and large adults. * Significantly different from previous mean, P < 0.05; ** P < 0.01; *** P < 0.001.

$N_{-3} + N_{-4})/3$ ($r_s = 0.679$, $P < 0.05$). Numbers of large adults were related to N_{-4} ($r_s = 0.779$, $P < 0.05$); they were also related to N_{-2} ($r_s = 0.654$, $P < 0.05$), but not to N_{-3} ($r_s = 0.050$) nor to N_{-5} ($r_s = 0.179$). It is probably more relevant for the large adults to examine when increases in their numbers occurred: 1998, 2000 and 2002. Both 2000 and 2002 were two and four years after years of high larval numbers. 1998 was two years after the productive year of 1996. However, 1998 was also five years after the initial productive year of 1993; had water conditions been suitable in 1997, this might also have been a good year for large adults. The initial productive year of 1993 was not followed two years later by an increase in large adults. These results are consistent with the small adults mainly being two and three year olds and large adults tending to be four years of age or older. They do not, though, exclude the possibility of older newts occurring in the sample of small adults and younger newts being in the sample of large individuals.

For numbers of small adults, the best fit was found with larval numbers two-three years previously. How the ratio of small adults per larva varied over time is examined in Figure 2. No small adults were recorded in 1994 (data from 1993 were used to define the size classes). Small adults were first recorded in 1995, and numbers per larva reached a peak in 1996, the first year of the study in which two year olds and three year olds could return. After 1996, a small adult was less likely to result from a larva dating from two or three years before. Taking 1993 as Year 1 and 2002 as Year 10, numbers of small adults can be described by the quadratic equation: Number = 0.463Year - 0.0397Year^2 - 0.521 ($F_{2,6} = 6.38$, $P < 0.05$).

Estimates of annual adult survival (Table 3) will be lower than true survival if some newts breed as small adults for more than one year, but higher than true survival if some newts breed for the first time as large adults. The first two estimates of annual survival (67% for 1993/1994 and 93 % for 1994/1995) will not incur the first of these errors because small newts did not return to breed until 1995. Survival was not estimated for 1996/1997 or for 1997/1998 because of the unusual conditions in 1997. The estimated survival of 135% for 2001/2002 probably exceeded 100% because of the difficulty in counting in the first year and the ease of counting in the second. There was no significant trend towards better or worse survival during 1993-2002, the average of the seven figures for annual survival being 79%. However, the estimate for 2001/2002 is

Year	Estimated mean count		Adult survival (%)
	Small adults	Large adults	
1993	0	42	-
1994	0	28	67
1995	10	26	93
1996	46	25	69
1997	-	-	-
1998	36	66	-
1999	20	42	41
2000	23	53	85
2001	14	46	61
2002	26	81	135

Table 3. Estimated mean counts of small and large adults and estimated annual survival, 1993-2002. Large males are those > 106 mm, large females > 120 mm. Data are omitted from the unusual year of 1997. Adult survival is calculated as the number of large newts in a year divided by the total number of both small and large newts in the previous year.

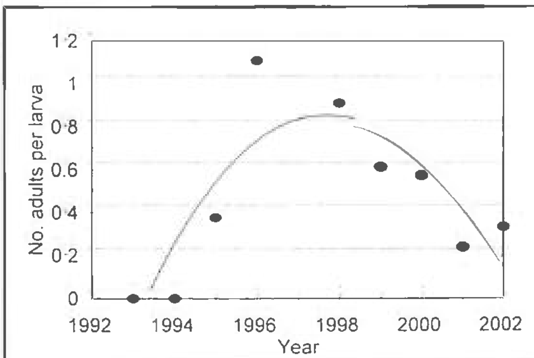

Figure 2. Variation over time, 1993-2002, in the estimated count of small adult Crested Newts divided by the mean number of larvae caught two and three years previously. Data for the unusual year of 1997 are omitted. The line shown is: Number = 0.463Year - 0.0397Year^2 - 0.521 (where 1993 = Year 1 etc).

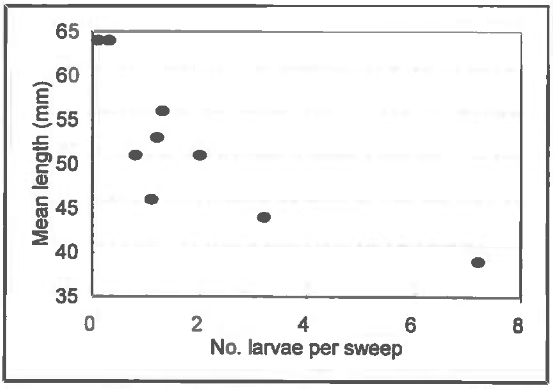

Figure 3. The relationship between mean larval length just prior to emergence and mean number caught per sweep of the net. Each dot represents data from a single year, 1993-2002. No larvae survived in 1997.

unrealistically high and that for 2000/2001 is probably too low. The mean of the remaining five estimates, 71%, is likely to be a more accurate overall figure.

Body condition index varied with size and sex, being greater for smaller individuals and males. Condition index for the large adults (Table 2) was not significantly related to their survival (Table 3, $r_s = 0.546$), but in two years for which survival data were unavailable, 1993 and 1998, condition index was high following a year or more of minimal breeding activity. It should also be noted that in 1999, survival and condition index were both at their lowest values. Condition index did not change over time ($r_s = -0.103$).

Top Pond was dry during the summer of 1997 and reproduction failed totally, while the pond was reduced to the sump in the summers of 1995, 1996 and 2002 (Table 4). Even in years when the pond remained full in summer, number of larvae caught varied considerably from three in 2001 to 119 in 2000. A feature of the summer netting was the incidental capture of adult and juvenile newts. Adults were caught in four summers, especially in 2001 and 2002 (Table 4). In those two years, adult numbers tended to decrease through the sequence of four netting visits: 4, 5, 2 and 0 adults respectively in 2001; 7, 1, 0 and 0 in 2002. Single juveniles were caught in 1998, 2001 and 2002. Multiple regression analysis of mean number of larvae caught against mean number of adults counted in the spring and mean number of adults caught in summer with all 10 years' data showed that larval catch was positively related to adult night count ($t = 2.63$, $P < 0.05$) and negatively related to number of adults netted in summer ($t = -2.71$, $P < 0.05$). Larval numbers could be defined as: Number = 4.4 + 0.877Adults^{spring} - 28.3Adults^{summer} ($F_{2,7} = 4.99$, $P < 0.05$). If data from the unusual summer of 1997 are omitted, the negative relationship with numbers of adults caught in summer remained ($t = -2.53$, $P < 0.05$), but the positive one with adults counted in spring disappeared. The overall relationship with both variables was no longer significant ($F_{2,6} = 3.59$, $0.1 > P > 0.05$).

Mean number of larvae caught per sweep of the net is a comparative measure of larval density each summer (Table 4). This varied from 0.1 when few larvae survived in the full pond in 2001 to 7.1 in the sump in 1996. Larval length was inversely related to numbers caught per sweep (Figure 3, $r_s = -0.750$, $P < 0.05$).

Year	Summer water level	Mean no. sweeps ±SE	Mean no. larvae caught ±SE	Mean no. larvae per sweep ±SE	Mean larval length ±SE mm (no. in sample)	Mean no. adults caught ±SE
1993	Full	47 ± 1	53 ± 4	1.1 ± 0.1	46 ± 1 (12)	0.0 ± 0.0
1994	Full	38 ± 3	30 ± 5	0.8 ± 0.2	51 ± 1 (8)	0.0 ± 0.0
1995	Sump	19 ± 5	14 ± 4	1.2 ± 0.6	53 ± 1 (8)	0.0 ± 0.0
1996	Sump	15 ± 6	65 ± 13	7.1 ± 2.6	39 ± 1 (15)	0.3 ± 0.3
1997	Dry	0	-	-	-	-
1998	Full	38 ± 2	80 ± 22	2.0 ± 0.5	51 ± 3 (11)	0.5 ± 0.3
1999	Full	25 ± 4	36 ± 11	1.3 ± 0.4	56 ± 1 (25)	0.0 ± 0.0
2000	Full	37 ± 4	119 ± 16	3.2 ± 0.1	44 ± 1 (17)	0.0 ± 0.0
2001	Full	34 ± 4	3 ± 1	0.1 ± 0.0	64 (1)	2.8 ± 1.0
2002	Sump	15 ± 4	5 ± 2	0.3 ± 0.1	64 ± 3 (6)	2.0 ± 1.7

Table 4. Results of summer fieldwork, 1993-2002. Mean number of sweeps and mean numbers of Crested Newts caught are based on four visits. Larval length was measured just prior to emergence.

DISCUSSION

The Crested Newt population at Shillow Hill declined significantly in 1989 (Figure 1). Severe drought from 1990 until 1992 saw Top Pond reduced to its sump in the spring of 1991 and throughout the first half of 1992; and dry in the summers of 1990 and 1991. As a consequence, night counts of adults declined further to a mean of only three in 1992. Virtually no emergence occurred in any of the three summers 1990-1992 (Cooke, 1995; Cooke & Arnold, 2001). In the spring of 1993, it was anticipated that, with the pond full again, more adults would return to breed - this expectation was realised with a mean count of 42 adults. Many of the adults probably originated from the successful breeding seasons in the late 1980s (Cooke, 2002). The second expectation was that, in the absence of prolonged drought in the future, the level of the population would recover further as breeding became successful again and recruitment occurred (Cooke, 1995). Apart from 1997, drought conditions did not return. The years of 1993, 1994, 1995, 1996 and 1998 had very similar count conditions allowing comparisons in adult counts to be made. A steady rise was recorded for these years from 1994 until 1998, with a significant increase between mean counts in 1995 and 1996. After 1998, there were no significant changes. It is possible, therefore, to define two recent periods for the newt population at Shillow Hill: recovery during 1993-1998 and relative stability during 1998-2002.

What processes lay behind the recovery? Breeding was reasonably successful in the summer of 1993 (Table 4). No small adults were recorded in the spring of 1994 (Table 3), but there were comparatively high numbers of immature newts (Table 2). Small adults were first recorded in the spring of 1995 (Table 3), presumably being two year olds from 1993. The spring of 1996 saw an increase in adult numbers, with about two thirds being small adults. These small newts will tend to have been two year olds from 1994 and three year olds from 1993. Elsewhere, Crested Newts have been reported to mature as early as two years of age, but with others maturing at three or older (Smith, 1969; Dolmen, 1983; Francillon-Vieillot et al., 1990; Arntzen & Teunis, 1993; Baker, 1999; Kupfer & Kneitz, 2000; Cummins & Swan, 2000). Numbers of large adults decreased steadily from 1993 to 1996 as survivors from the 1980s died (Table 3). The population had a lean year in 1997: few adults were counted in the sump in spring (Table 2), and breeding failed in the summer when the pond desiccated (Table 4). By 1998, 35% of the adults were small, a percentage that changed little over the rest of the study (Table 2). Numbers of small adults counted for each larva caught two or three years previously were highest in 1996 and 1998 (Figure 2).

	Years	% change in mean night count	Reason for change
Increase	1992/1993	+1300	Recovery in pond suitability
	1997/1998	+1000	Recovery in pond suitability
	1984/1985	+360	Good recruitment
	1995/1996	+97	Good recruitment
	2001/2002	+78	Variation in counting conditions
Decrease	1990/1991	-44	Pond less suitable
	1988/1989	-71	Poor survival of adults and immatures
	1991/1992	-84	Pond less suitable
	1996/1997	-87	Pond less suitable

Table 5. Occasions when mean night counts of Crested Newts in Top Pond changed by > 40% between years, with the likely principal reason for each change.

How then did the period of stability, 1998-2002, differ from the previous period of expansion? A reduction in adult survival can be discounted, as survival did not change significantly over time (Table 3). There was, however, evidence of a higher probability of a small adult originating from a larva in 1996 and 1998 than in later years (Figure 2). Arntzen & Teunis (1993) noted in their French population that adult survival was stable for several years, but there were few immatures when adult numbers became high. One explanation for this observation is that, as adult (and immature) numbers built up, there was increasing pressure on metamorphs to migrate away from the site. Kupfer & Kneitz (2000) contrasted the high site fidelity of adult newts with the wider-ranging behaviour of metamorphs; the latter migrated from their natal pond in an arable field by up to 860 m in a few weeks. In a study at Shillow Hill in 1985, metamorphs were not trapped on the surface of the adjacent arable fields (Cooke, 1986), and any attempts at emigration were more likely to occur along ditches between the fields.

However, this observation of possible density-dependence is only part of the story. In 2001 and 2002, adults tended to remain in the pond in significant numbers until further into the summer (see also weekly netting data for adults, mid March-early July 1986; Cooke, 1995). The presence of the adults in 2001 and 2002 was associated with considerably reduced numbers of larvae (Table 4), the inference being that the adults preyed on the larvae. For much of their development, Crested Newt larvae tend to be pelagic, which may reduce the risk of cannibalism by the more benthic adults (Beebee & Griffiths, 2000). Nevertheless, in a small, densely-populated pond such as Top Pond, there must be frequent opportunities for cannibalism. At what stage in development cannibalism may occur remains to be elucidated, but observations at this site of adult Crested Newts occasionally swallowing adult Smooth Newts suggests they can tackle even full-grown larvae of their own species. Significant predation by invertebrates can be ruled out as there is no evidence that they control numbers of larval newts at this site, and counts of invertebrate predators were low or moderate in 2001 and 2002 (Cooke, 2001 and unpublished). Fish have been shown to be important predators of Crested Newt larvae (e.g. Baker, 1999) but fish have not been recorded in Top Pond. It is possible that a high density of newts on land triggers a response in adults to remain longer in the pond. In addition to the adult population having stabilised, 2001 and 2002 immediately followed the year with the highest recorded larval production (Table 4). This apparent cannibalism should result in lower recruitment to the adult population during 2003-2005. With hindsight, the effects of cannibalism may have been apparent in the 1980s. For instance, 1987 had the highest mean night count of adults (183, Figure 1), yet mean larval catch was only 16 despite the pond remaining full into the summer (Cooke, 1995; Cooke & Arnold, 2001).

There is a trade-off in the pond between larval density and size (Figure 3). The few larvae that managed to survive to metamorphosis in 2001 and 2002 tended to be large. This may have put them at a selective advantage in maturing earlier (Arntzen & Teunis, 1993). There was no evidence from our study, however, of larval size markedly affecting recruitment to the adult population in subsequent years. Thus, the small larvae comprising the metamorphosing cohorts in 1993, 1996 and 1998 appeared to result in later increases in adult numbers.

Mean annual survival for adult newts at Shillow Hill was estimated at 71% for 1993-2000. Elsewhere, annual estimates have been between about 30 and 100%, with most being in the range 50-90% (e.g. see Arntzen & Teunis, 1993; Oldham, 1994; Baker, 1999; Cummins & Swan, 2000; Kupfer & Kneitz, 2000). Adult survival would be expected to be good within the Shillow Hill site. Food and refugia should be plentiful, vehicle access within the site is relatively rare and disturbance to habitat is restricted. The situation is different beyond the boundaries of the site. A main road runs past the site about 70 m from Top Pond, but live or dead newts have never been seen on it and it is unlikely that many newts try to cross (see also the radio-tracking study of Jehle, 2000). Newts do, however, utilise the adjacent arable land around the other three sides of the site, this being especially true of adults prior to harvest (Cooke, 1986). While there, they will be exposed to hazards such as spraying, combining and, in the past, straw burning. Mean night count in Top Pond decreased from 136 in 1988 to only 39 in 1989, a decrease of 71% which could not be explained by any change in the condition of the pond (Cooke, 1995). A change of this magnitude must have been due primarily to unusually poor survival, catastrophic losses presumably occurring outside the site. As this is likely to have affected immatures as well as adults, recruitment failure will also have resulted and the population remained low into 1990 (Figure 1).

The need for long-term studies is often emphasised (e.g. by Arntzen & Teunis, 1993; Cooke, 1995; Baker, 1999). Surveillance at Shillow Hill is the longest continuous study on this species, and it is worthwhile examining by how much and why adult night counts varied during the entire surveillance period, 1983-2002. As Baker (1999) has pointed out, while longevity and relatively high rates of survival of adults provide the potential for population persistence, population size may fluctuate considerably. At Shillow Hill, inter-year comparisons of counts varied by < 40% for ten of the 19 pairs of years. Such variations will have tended to stem from fairly minor fluctuations in population level, in pond suitability or in counting conditions. Of the remaining nine occasions, four involved decreases of 44 to 87%, and five were increases of 78 to 1300%. These years and likely reasons for change are listed in Table 5, and the information reinforces the view that many of the major fluctuations in counts at this site resulted from changes in pond suitability. The most extreme example of this effect was in 1992 when the mean count was only three; because of the small size of the pond and because a stick was used to move aside water plants, it should have been possible to count all of the newts in the water (Cooke, 1995). When the pond refilled in 1993, the mean count was 42, all of which were large adults (Table 3), demonstrating that an unusually small proportion of the adult population was in the water at any one time in 1992. In the study of Arntzen & Teunis (1993), all adults were believed to breed each year. At Shillow Hill, it is not known whether the low counts, as in 1992, resulted from all of the newts returning to the water for unusually short periods or a only few newts returning for normal periods of time.

Turning to apparently real changes in the population (as opposed to changes in the counts), only a single decrease of > 40% was recorded (in 1988/1989), the likely reason being poor survival, as discussed above. There were two examples of increases of > 40% (1984/1985 and 1995/1996), both probably being due to good recruitment. Attention should also be drawn to the increase of 78% in 2002 (Table 5). The years 2001 and 2002 were the only pair during the detailed study of 1993-2002 when counting was difficult one year but easy the next. Precisely how much this counting discrepancy contributed to the observed change is unknown. However, survival was estimated at 135% in 2002; if high turbidity in 2001 depressed the mean count by, say, 20% but low weed cover in 2002 elevated the count by 20%, then survival would be lowered to a more "realistic" level of 90%. Survival in 2001 would then be estimated at 73% (from 61%). Such a 20% adjustment to both counts in 2001 and 2002 would result in an increase in night count in 2002 of only 19% over that in 2001.

These observations emphasise that pond and count conditions may greatly influence surveillance results. While it is not possible to make quantitative adjustments to counts without detailed studies on changes in the probability of detecting individuals under different ambient conditions, being aware of these limitations allows some data to be ignored or qualified, and conclusions to be derived more objectively. It is also worth noting that if water conditions make a pond unattractive to newts, there may be similar effects on any population assessment based on studying newts at the breeding site, irrespective of the degree of scientific rigour with which it is undertaken.

Under ideal conditions, the Shillow Hill site can support a Crested Newt population that equates to a mean night count of 100 or more adults (Figure 1). Catastrophic losses in 1988/9 and drought during 1990-1992 and 1997 meant such counts were not realised between 1989 and 1997 inclusive. In 1984 when mean night count was 33, the adult population was estimated to be in the region of 500, based on recapture on land of newts caught and marked during the aquatic phase (Cooke, 1985, 1995). While the relationship between counts and population size will vary between sites, a mean night count of 100 at Shillow Hill may suggest a population of about 1500 adults at a density of 750 per ha for the core area of 2 ha. Even with hindsight, it is difficult to see what could have been done to have improved population levels between 1989 and 1997. The initial mortality seemingly could not be prevented, and regional drought had substantial effects in the early 1990s. The sump was created in 1991. Its value to conservation of the population lies not in providing suboptimal aquatic habitat to the few adults in the sump in drier springs, but in allowing emergence in drier summers such as 1996 (Cooke & Arnold, 2001). It is important to take a strategic long-term view of Crested Newt conservation.

In Britain, a Pilot Monitoring Project on Crested Newts was undertaken in four areas in 2002 as preparation for a future national scheme to measure trends in population status (Baker, 2002). Night counting of adults provides a key component of this work. Hopefully, results and conclusions from our study at Shillow Hill will be of value to those responsible for this national scheme at various stages from planning through to interpretation.

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REFERENCES

Arntzen, J.W. & Teunis, S.F.M. (1993). A six year study on the population dynamics of the crested newt (*Triturus cristatus*) following the colonization of a newly created pond. *Herpetol. J.* **3**, 99-110.

Baker, J.M.R. (1999). Abundance and survival rates of great crested newts (*Triturus cristatus*) at a pond in central England: monitoring individuals. *Herpetol. J.* **9**, 1-8.

Baker, J.M.R. (2002). Great Crested Newt Pilot Monitoring Project. *Herp-line* **9**, 1-2.

Beebee, T.J.C. & Griffiths, R.A. (2000). *Amphibians and Reptiles.* London: Harper Collins.

Cooke, A.S. (1985). The warty newt (*Triturus cristatus*) at Shillow Hill. Numbers and density. *Report Huntingdon Fauna & Flora Soc.* **37**, 22-25.

Cooke, A.S. (1986). The warty newt *Triturus cristatus* at Shillow Hill. Ranging on arable land. *Report Huntingdon Fauna & Flora Soc.* **38**, 40-44.

Cooke, A.S. (1995). A comparison of survey methods for crested newts (*Triturus cristatus*) and night counts at a secure site, 1983-1993. *Herpetol. J.* **5**, 221-228.

Cooke, A.S. (2001). Invertebrate predation on larvae of the Crested Newt (*Triturus cristatus*). *Herpetol. Bull.* **77**, 15-19.

Cooke, A.S. (2002). The influence of breeding success on adult length in a population of Crested Newts. *Herpetol. Bull.* **81**, 8-11.

Cooke, A.S. & Arnold, H.R. (2001). Deepening a crested newt breeding site. *Report Huntingdon Fauna & Flora Soc.* **53**, 35-38.

Cooke, A.S. & Cooke, S.D. (1992). A technique for monitoring the final phase of metamorphosis in newts. *Herpetol. Bull.* **42**, 10-13.

Cummins, C.P. & Swan, M.J.S. (2000). Long-term survival and growth of free-living great crested newts (*Triturus cristatus*) pit-tagged at metamorphosis. *Herpetol. J.* **10**, 177-182.

Dolmen, D. (1983). Growth and size of *Triturus vulgaris* and *T. cristatus* (Amphibia) in different parts of Norway. *Holarctic Ecol.* **6**, 356-371.

Francillon-Vieillot, H., Arntzen, J.W. & Geraudie, J. (1990). Age, growth and longevity of sympatric *Triturus cristatus*, *T. marmoratus* and their hybrids (Amphibia, Urodela): a skeletochronological comparison. *J. Herpetol.* **24**, 13-22.

Griffiths, R.A. & Inns, H. (1998). Surveying. In *Herpetofauna Workers' Manual*, pp. 1-13. Gent, A.H. & Gibson, S.D. (Eds.). Peterborough: J.N.C.C.

Jehle, R. (2000) The terrestrial summer habitat of radio-tracked great crested newts (*Triturus cristatus*) marbeld newts (*Triturus marmoratus*). *Herpetol. J.* **10**, 137-142.

Kupfer, A. & Kneitz, S. (2000). Population ecology of the great crested newt (*Triturus cristatus*) in an agricultural landscape: dynamics, pond fidelity and dispersal. *Herpetol. J.* **10**, 165-171.

Langton, T.E.S., Beckett, C.L. & Foster, J.P. (2001). *Great Crested Newt Conservation Handbook.* Halesworth: Froglife.

Oldham, R.S. (1994). Habitat assessment and population ecology. In *Conservation and Management of Great Crested Newts*, pp. 45- 67. Gent, A. & Bray, R. (Eds.). Peterborough: English Nature.

Smith, M. (1969). *The British Amphibians and Reptiles.* 4th edition. London: Collins.