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EVALUATING THE SUITABILITY OF HABITAT FOR THE GREAT CRESTED NEWT (*TRITURUS CRISTATUS*)

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A modification of the Habitat Evaluation Procedure (USFWS, 1976) applied to crested newt habitats is described, using ten key habitat criteria, based upon the assumption that habitat quality determines population size. Seven of these criteria (pond area, permanence, shading and density, macrophyte density, number of waterfowl and terrestrial habitat quality) are assessed using objective habitat measurements, the other three (site geography, water quality and fish occurrence) using qualitative rule-bases, to produce a Habitat Suitability Index for each site. Preliminary validation of the method for a set of 72 sites provides a significant rank correlation between indices of population size and of habitat. The procedure has the potential to provide a simple method of habitat assessment, for site surveying or selection of host sites for translocation, and can be upgraded easily as knowledge of crested newt habitat requirements improves. There was an incidental indication from the validation exercise that the number of newts caught by bottle trapping was affected negatively by the presence of macrophytes.

Key words: Triturus cristatus, crested newt, habitat suitability index, habitat evaluation, translocation, monitoring

INTRODUCTION

Crested newts as individuals and as populations depend upon habitats with a certain range of characteristics. The quality and quantity of these characteristics in part determines the presence and size of the populations. If we can measure the appropriate characteristics of a site, with the important proviso that there is a source of colonizers, then the occurrence of a population can be predicted. Our knowledge of habitat requirements in most species is adequate to make only crude predictions. Nevertheless, species occurrence and population size both depend upon habitat quality and there is a clear practical need to make predictions for conservation management, especially for rare or threatened species such as the crested newt.

Several efforts have been made to identify the determinants of distribution in amphibians. Pavignano *et al.* (1990) used multivariate analysis and, from a sample of 61 ponds, demonstrated the influences of macrophytes, pond age, terrestrial habitat characteristics and human interference on the presence of two anurans and two *Triturus* species (not *T. cristatus*). They were unable to relate habitat features to population densities. Beebee (1985) used discriminant analysis involving five British species and 203 ponds (17 with crested newts). He was able to separate ponds into two groups, those used and those not used for breeding, on the basis of the habitat characteristics. For the crested newt, geological features and terrestrial habitat were of greatest value in discriminating between sites. Swan & Oldham (1993, 1994) applied discriminant analysis to data from the breeding sites of two anuran species and *Triturus cristatus* with a sample of 1503 sites (1322 for the newts) and a wide range of habitat characteristics. For the crested newt, relatively deep water, high macrophyte density and terrestrial habitat diversity were indicated as especially important. In Spain, in an analysis of 24 environmental variables, the populations of two toad species, *Bufo bufo* and *B. calamita* have been shown to vary in relation to the predictability of the climate (Romero & Real, 1996).

The approach used in the present paper is to identify readily observable habitat features and to assess to what extent they can be used to make worthwhile predictions. The objective is to produce a simple model for use by the non-specialist, which provides conservationists with an informed view of the value of a site and which can be upgraded readily as our knowledge of crested newt ecology improves.

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HABITAT SUITABILITY

A large number of habitat features is associated with the crested newt. However, as described by Oldham (1994) and Swan & Oldham (1994), some features can be isolated as of particular diagnostic importance and used as a basis for determining the likelihood of crested newt *occurrence*. These are not necessarily the most obviously important ecological features. For example, food is clearly vital to newt survival; other factors being equal, the more food there is the more newts can be supported. Food can be assessed, but not easily. However, from experience we know that abundant newt prey occurs under conditions characterized by easily observed habitat features, such as the diversity and density of vegetation. Taking each of the presumed habitat requirements in turn in this way it is possible to produce a list of key diagnostic features for newt habitat. The same features are probably important as indicators of the level of population *success* at a site, reflected in population size, as distinct from mere species occurrence.

Key habitat variables were used during the construction of three separate computer-based expert systems at De Montfort University (Jeffcote, 1991; Cain, 1993), designed to predict the suitability of habitat for crested newt occurrence. These were subject to intensive evaluation. As judged against 100 known field sites, in blind comparisons the most developed of the systems (Cain, 1993) provided reasonable correlations. Newts were absent from only 3% of cases where the expert system predicted that they would be present. The error was larger for predictions of newt absence. Twenty percent of sites contained newts when the expert system predicted that they would not do so, possibly due to the longevity of the species. Individuals may persist at a site long after it has ceased to be suitable for breeding, for at least four years at one English site (Atkins, 1998) and perhaps for 16 years or more (Hagstrom, 1977, 1980).

Once installed on a computer, expert systems are easily used and they have the benefit of providing the user with the reasoning underpinning the determinations. On the other hand, they are based upon complex, costly, and ever-changing technology, so that they cannot easily be upgraded or amended by the non-expert. They are not readily available to many of the voluntary groups who may want to take advantage of them.

An alternative approach with a similar conceptual basis, more amenable to general use is the Habitat Evaluation Procedure (HEP; US Fish & Wildlife Service 1976, 1980, 1981), developed in response to the need to document the non-monetary value of wildlife resources. The original publications are not easily available, but the procedure is summarized by several authors (e.g. Usher, 1986, Spellerberg, 1992, Treweek, 1999). It is based upon a method devised by Daniel & Lamaire (1974) and assumes, for any given species, that habitat quality and quantity can be described numerically. HEP involves the determination of a Habitat Suitability Index (HSI) for each relevant species.

The HSI is a numerical index ranging from 0, representing unsuitable habitat, to 1.0, representing optimal habitat. It is assumed that there is a direct correlation, usually a linear relationship, between the index and the species carrying capacity of the habitat. Although the index is numerical, the model used to derive it, as with expert systems, may be expressed numerically or by verbal description (a qualitative rule-base or word model, Starfield & Bleloch, 1983). HSI's have been applied successfully to a wide range of species (e.g. mammals: Cook & Irwin, 1985; Thomasma *et al.*, 1991; birds: Conway & Martin, 1993; Prosser & Brooks, 1998; fishes: Pajak & Neves 1987; marine invertebrates: Soniat & Brody 1988) including at least four species of urodele amphibians (Sousa, 1985; Storm *et al.*, 1993). In the following account a method of deriving an HSI for the crested newt is proposed, based upon 10 key habitat variables.

KEY DIAGNOSTIC HABITAT VARIABLES

The 10 key variables are selected on the basis of two criteria: established or presumed importance to crested newt survival, and ease of field determination. Seven of them – pond area, pond permanence, pond shading, number of waterfowl, pond density, proportion of "newt friendly" habitat and macrophyte content – are expressed quantitatively; the other three – geographic location, water quality and occurrence of fish – are expressed qualitatively. The effect on crested newts of each variable is considered separately. For example, the presence of waterfowl at a newt breeding site has a damaging effect on newt populations, for reasons discussed below. The effect is probably negligible at low bird densities, but increases in proportion to the number of birds present. The effect is expressed as a Suitability Index (SI), on a scale from 1 (optimal suitability to the newts) to 0 (totally unsuitable), and plotted against bird densities (Fig. 1, SI_6). The procedure is repeated for the seven key habitat variables that are expressed quantitatively. The other three are related to the SI using a word rule base. The ten Suitability Indices are combined using a geometric mean, to derive the HSI.

The pattern of the relationship between waterfowl densities and habitat suitability, and the other patterns shown in Fig. 1, are essentially conjectural, based upon our long-term field experience, and informed by a number of sources, especially the results of National Crested Newt Survey and the National Amphibian Survey (Oldham & Nicholson, 1986; Swan & Oldham, 1993, respectively). These provide data on the aquatic and associated terrestrial characteristics of over 3000 potential crested newt breeding sites and are augmented by information in the literature (Beebee, 1981, 1983, 1985; Dolmen, 1980; Green, 1984; Strijbosch, 1979). In the account that follows the rationale for including each key variable is described. The actual assessment is detailed in Appendix 1 and Fig. 1.

1. GEOGRAPHIC LOCATION (SUITABILITY INDEX 1, SI_1: APPENDIX 1).

Fig. 2 is based upon existing maps of newt distribution (Arnold, 1995). This provides a shorthand method of accommodating all the large-scale habitat features which affect the newt, including climate, substrate and altitude. There are no sharp boundaries, however, between geographic regions of suitability, and this feature does not provide a linear relationship between suitability and location.

With this Suitability Index, as with some others, the lowest value is set at 0.01 rather than zero. A zero score for any one of the ten suitability indices would produce a Habitat Suitability Index for the site of zero. The very low SI value of 0.01 avoids this and in this instance reflects the possibility that unusual circumstances may favour the occurrence of a newt population, despite an apparently unfavourable geographic location – for ex-

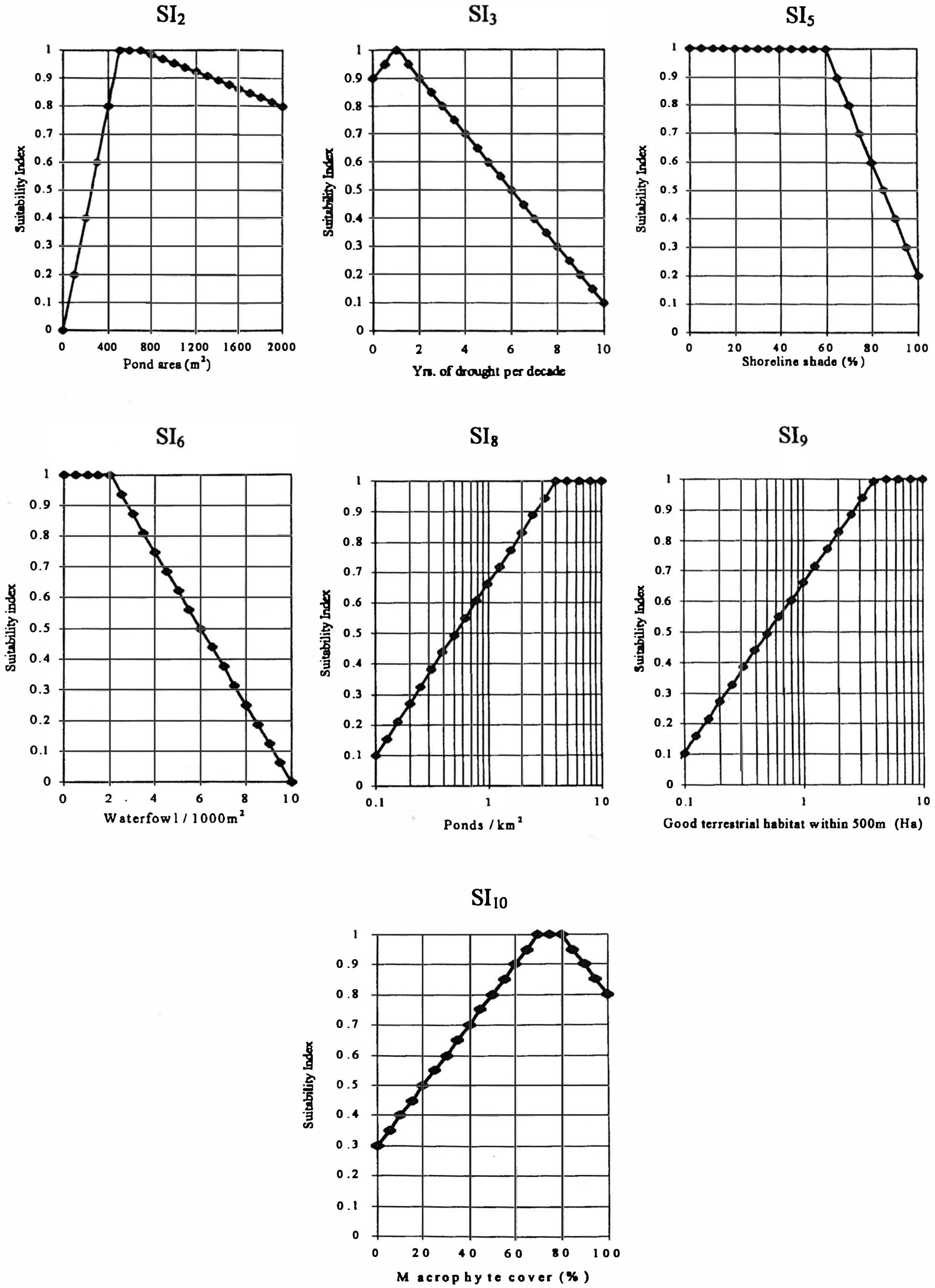

FIG 1. Suitability index derivation based upon seven separate habitat features.

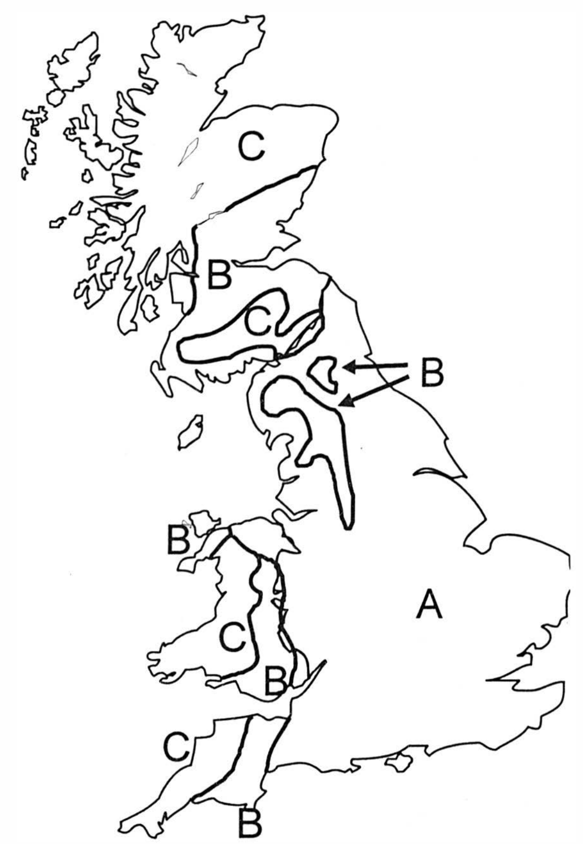

FIG. 2. Map used to determine the Suitability Index for location (SI_1), based upon the known distribution of the crested newt. Zone A (optimal) has a high probability of crested newt occurrence within each 10 km square; zone B (marginal) with patchy distribution and a low probability of occurrence; zone C (unsuitable) with a very low probability of occurrence, mainly outside the recorded range of the species.

ample, through human intervention. Again, since the distribution map is based upon observer records, there is a possibility that the species is marked as absent through observer error rather than species absence.

2. POND AREA (SI_2: APPENDIX 1 AND FIG.1)

Pond area is a determinant of the magnitude of biological productivity of the pond ecosystem upon which the newt population depends. In the Netherlands, Laan & Verboom (1990) demonstrated a positive relationship between species richness and pond size for ponds more than seven years old. In the National Amphibian Survey (Swan & Oldham, 1993) pond areas were categorized into 11 bands. The median area of 2987 surveyed ponds (1322, excluding garden ponds) was 175 m^2 (375 m^2 for non-garden ponds). The optimum size for crested newt occupancy in both cases was in a band between 500 and 750 m^2. Fig. 1 (SI_2) is constructed with this band as optimum (Suitability Index = 1), falling away for ponds with larger areas in line with the values seen in the National Survey. Ponds of zero area are clearly unsuitable for newts and SI values between 0 and 1.0 are interpolated linearly in Fig. 1. It must be admitted that very small ponds (<26 m^2) sometimes contained newts and it might be argued that the interpolation would be better on a transformed scale, such as logarithmic. However, we are attempting to reflect newt success, indicated by population size, rather than simple occurrence and it is unlikely that the smaller ponds support viable breeding populations. In fact, use of a logarithmic – rather than a linear – scale made virtually no difference to the performance of the model.

Theoretically, pond depth is less significant than area since productivity depends more upon the surface area receiving sunlight than upon water volume. Depth is also more difficult to measure than area and has been omitted as a key factor.

3. POND PERMANENCE (SI_3: APPENDIX 1 AND FIG. 1)

Pond permanence is essential to permit the completion of metamorphosis in any given year. A succession of years in which the pond dries before metamorphosis is complete will lead to population extinction, in the absence of immigration. However, intermittent drying out may have an overall beneficial effect, preventing colonization by fish and other aquatic predators that are even more dependent upon permanent water than the newt. There is little quantitative information on the relative performance of ponds showing differing degrees of permanence. The National Amphibian Survey (Swan & Oldham, 1993) indicated that ponds that dried during drought years contained crested newts significantly more often than those which never dried and those which dried annually. The optimal frequency of drying is assumed to be one year per decade. Regression lines above and below this value are speculative. The value of SI 0.1, instead of zero, for 10 years of drying out is used to allow for the possibility of metamorphosis in some years before drying occurs.

4. WATER QUALITY (SI_4: APPENDIX 1)

The adult crested newt is capable of using atmospheric oxygen – indeed, its respiration depends upon it – and is relatively tolerant of eutrophic conditions. The gill-breathing larva is more vulnerable and shares the need for reasonably well-aerated water with a number of aquatic invertebrates. Water quality can be measured precisely using chemical analysis, but this depends upon relatively sophisticated equipment, especially if temporal variation is included. Instead, the presence of indicator organisms can be used to assess water suitability, in much the same way as they are used to assess running water (e.g. Abel, 1996; Boon & Howell, 1997). They have the advantage over chemical methods of integrating temporal variability without repeated measurements. A qualitative rule base is used to derive SI_4, using a four-point scale (Appendix 1). This is based upon the experience gained during development of an expert system (Cain, 1993; Jeffcote, 1991). The lowest SI value is set at 0.01, rather than zero, to guard against the possibility of mistaken identification of water quality and of changes in quality which can occur rapidly, with changing weather.

5. POND SHADING (SI_5: APPENDIX 1 AND FIG. 1)

Shade counteracts the growth of macrophytes and the benefits they provide. Additionally, excessive tree cover may increase the organic content through leaf fall and cause eutrophication. However, if not excessive, leaf fall may increase the nutrient level and enhance productivity. The National Amphibian Survey (Swan & Oldham, 1993) provided no evidence that a complete absence of shade reduces a pond's suitability for newts, but newt occurrence was significantly reduced above a threshold of 75% shade. The findings of Cooke *et al.* (1994), based upon crested newt larvae, suggest a somewhat lower threshold and a value of 60% is taken as the cut-off point (Fig. 1; SI_5). The low value of SI 0.2 in this figure is conjectural. A value of zero was thought to be inappropriate because in some cases central parts of the pond continue to receive sunlight even when the circumference is totally surrounded by trees. In Appendix 1 the emphasis is on the circumference, rather than the total area, because of the relatively greater importance of biological production in the shallow edges of ponds.

6. NO. OF WATERFOWL (SI_6: APPENDIX 1 AND FIG. 1)

Common waterfowl, such as moorhens and mallards, in naturally occurring numbers have little adverse effect upon newt populations. They are included in the list of factors because sometimes, when encouraged by supplementary feeding, they can seriously damage the habitat, partly by direct mechanical interference, but also by excessive nutrient enrichment, with resultant high BOD and reduced community diversity. The shape of the SI curve (Fig. 1, SI_6) is conjectural and is based upon a few instances with which the authors are familiar. Herpetofauna Conservation International (1991) quote a slightly lower threshold. They describe geese or duck densities of over 4 pairs per hectare of open water (approximately 1 bird per 1000 m^2) as a negative indicator for crested newt translocation.

7. OCCURRENCE OF FISH (SI_7: APPENDIX 1)

The effect of fish varies according to the species present and probably according to the pond habitat, although not in a manner that can be predicted readily. Some species, such as goldfish and carp, in some conditions, appear to be benign. Others, such as the stickleback, sometimes seem to have a serious impact – probably both predatory and competitive – and at other times to coexist with a healthy newt population. The larger predatory fish species such as perch and trout rarely coexist with crested newt populations. There are many records in the National Amphibian Survey (Swan & Oldham, 1993) of great crested newt populations surviving, probably in suppressed numbers, in the presence of fish. These may result from high adult newt longevity and immigration. The difficulty of assessing fish populations, coupled with uncertainty as to the impact of some species, makes this feature problematic. Nevertheless, the overall strength of the correlation observed in the National Amphibian Survey and elsewhere means that it cannot be ignored. The qualitative rule base (Appendix 1, SI_7) reflects the above uncertainty.

8. POND DENSITY (SI_8: APPENDIX 1 AND FIG. 1)

In the National Amphibian Survey, Swan & Oldham (1993), using records of all ponds, not just those suitable for crested newts, suggested a minimum pond density threshold of about 0.7 ponds km^{-2} for great crested newts to occur in an area. Only about 30% of study areas where pond densities were below this threshold supported the species, in comparison to 60% above it. Only at the much higher pond density of four ponds km^{-2} did all the study areas contain crested newts. Grayson (1994) describes similar evidence. Pond densities above 4 km^{-2} are therefore taken as optimal (Fig.1, SI_8). At lower pond densities a logarithmic interpolation (in line with the original relationship in the National Amphibian Survey) provides more realistic SI values than a linear interpolation. The threshold density of 0.7 ponds km^{-2} relates to an SI between 0.5 & 0.6.

The crested newt is generally accepted as exhibiting metapopulation dynamics (e.g. Griffiths & Williams, 2000) and population persistence depends, in part, upon the distance separating breeding sites (Halley *et al.*, 1996). If ponds are separated by more than the range of dispersal, or if there are barriers within the range (e.g. frogs: Reh & Seitz, 1990; toads: Hitchings and Beebee, 1998), genetic heterogeneity will diminish and colonization and recolonization will be inhibited, even if there is good terrestrial habitat. The situation may be complicated in ponds with especially large populations (e.g. Latham *et al.*,1996). In this case metapopulation dynamics may be less significant and the population may be viable in the long-term, even if isolated (Halley *et al.*1996). A low value of SI_8 at such isolated sites might result in unreasonably low HSI values. To allow for this possibility a correction is applied in the HSI calculation, as described below.

9. PROPORTION OF "NEWT FRIENDLY" HABITAT (SI_9: APPENDIX 1 AND FIG. 1)

The habitat occupied by crested newts is highly variable and we do not understand the species' detailed requirements at different phases of their life on land. However, we know from discriminant analysis based upon National Amphibian Survey data (Swan & Oldham, 1993, 1994) that newts occurred more frequently on land with low intensity use (crudely classified as scrub and woodland), than on pasture and arable and this is consistent with the findings of Arntzen *et al.*(in prep.) and Laan & Verboom (1990). Scrub, unimproved grassland, woodland (both deciduous and coniferous) and gardens are regarded as providing newt-friendly habitat, unlike improved pasture, arable and urban land. The greater the area of good habitat, the greater the confidence that the site was suitable.

Additionally, certain habitat features, notably hedges and ditches, enhance the suitability of a site. Swan & Oldham (1994) demonstrate that both these landscape features are significant positive determinants of crested newt occurrence in low diversity, – improved grassland and arable – habitats. Evidence of their value is also provided by Jehle (2000). They are probably important not only in enhancing habitat diversity and providing resources, but also in supplying stable refugia in a landscape subject to sudden, intermittent and massive change during normal agricultural practice. A hedge was considered good newt habitat when it was densely vegetated with good ground cover. Dry stone walls covered by dense, long vegetation from the ground upwards were also considered to be good habitat. Ditches were considered good habitat if they had good bank vegetation and imperceptibly moving water.

The presence of barriers to terrestrial dispersal of newts modifies the importance of newt-friendly habitat within range of the breeding site. Roads and rivers are perhaps the two most serious amongst the many man-made and natural barriers interfering with newt migration. Five hundred metres is selected as an appropriate distance for the ranging of crested newts on the basis of several studies (e.g. Baker & Halliday, 1999; Oldham & Humphries, 2000; Oldham & Nicholson, 1986). Arntzen & Wallis (1991) provide evidence of 1 km annual movement, but this is based upon range extension and probably applies mainly to juveniles which spend considerably longer on land between metamorphosis and adulthood than do the adults between one breeding season and the next. We used 4 ha as the lower critical limit of newt-friendly habitat within 500 m of the breeding site needed to sustain a thriving crested newt population (Oldham, unpublished). As in the previous section we consider that a logarithmic interpolation provides more realistic SI values when the areas of favourable habitat are low (Fig. 1, SI_9).

For each barrier a threshold of impact is needed, above which it has a serious effect on the likelihood of newt population occurrence. For example, at one extreme, motorways and dual carriageway roads in Britain almost certainly do seriously affect newt dispersal, whilst unpaved country lanes probably do not. In between, a judgement must be made in terms of the width of the carriageway and the density of night-time traffic. Anything less than about 20 vehicles per hour is probably not a serious threat. Rivers are less prevalent in the landscape, but there is evidence in two studies of their importance. In a regression analysis comparing the characteristics of 260 Leicestershire ponds, and their surroundings, with the occurrence of crested newts (Arntzen *et al.* in prep.) the proximity of the pond to a river proved to be the most important negative correlate. Similarly, discriminant analysis based upon the National Amphibian Survey data (Swan & Oldham, 1994) emphasized the importance of flowing water as a negative feature in the crested newt landscape. The prevalence of fish in water bodies in floodplains may exacerbate the effect of the physical barrier. As with roads, a judgement must be reached on the likelihood of an impact; width is again important and rate of water flow replaces traffic volume as a key feature.

Barriers also influence metapopulation dynamics. Reh & Seitz (1990) and Hitchings & Beebee (1998) demonstrated reduced genetic heterogeneity in populations of *Rana temporaria* separated by roads, and in *Bufo bufo* by inimical habitat respectively. In the present state of our knowledge we have no way of incorporating this aspect into the habitat assessment.

Barriers: modification to "newt-friendly" habitat assessment. The impact of barriers is assessed in terms of the proportion of the available habitat within 500 m radius of the pond which is excluded from use, as a result of the barrier's presence. Subjective judgement is involved and a simple rule base is used as a guide to assessment (Appendix 1). The resulting values are used to modify the impact of SI_9, as described in Appendix 1.

10. MACROPHYTE CONTENT (SI_{10}: APPENDIX 1 AND FIG. 1)

Although not a direct food source for crested newts, macrophytes fulfil a number of roles. They provide a food source (direct or indirect) for prey organisms, cover from predators and a substrate for egg attachment. A paucity of plant life is normally associated with low pond productivity. Beyond a certain plant density, however, they restrict the space available for newt activity, including courtship, and a pond in a late stage of succession, especially when dominated by emergent vegetation, may provide limited aquatic space. Natural succession is the most commonly perceived threat to great crested newt populations (Oldham & Swan, 1991). Consequently, there is an optimum macrophyte content (Fig. 1, SI_{10}). National Amphibian Survey data (Swan & Oldham, 1993) showed the highest occurrence of great crested newts in ponds with emergent vegetation cover between 25 and 50% and submerged vegetation between 50 and 75%. For simplicity, in Fig. 1, the two are combined, giving an optimum of between 70% and 80% macrophyte cover. Although there was a clear optimum, in the National Survey newt occurrence was reported over the entire range of observed macrophyte-cover values. In Fig. 1 (SI_{10}), the SI values of 0.3 and 0.8 – chosen to represent, respectively, the upper and lower cover values – reflect the observed levels of occupancy in the National Survey.

Duckweed, especially *Lemna minor*, presents a special problem. It intercepts light, but occupies little space and can fluctuate markedly, both within and between seasons, and even within a day during strong winds. It is common knowledge that crested newts tolerate duckweed at breeding sites, and in the absence of information on its impact, we have elected to exclude it from the vegetation cover calculation in Appendix 1.

Whilst there are good reasons to believe the relationship shown in Fig. 1, SI_{10}, is a real one, it must be admitted that a direct relationship is likely between the

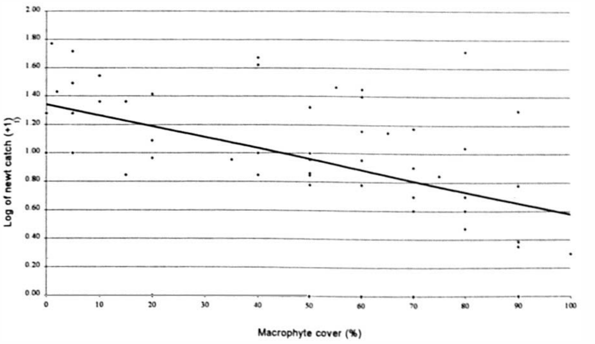

FIG. 3. The negative relationship between newts caught in bottle traps and the macrophyte cover (submerged, emergent and floating plants combined) in 53 ponds.

macrophyte biomass and the ability of the observer to detect newt presence. A population of newts in a plant-free pond is much more evident than the same population in a plant-dominated pond. This may have biased the results obtained in the National Amphibian Survey. Ponds with submerged vegetation cover values in excess of 75%, and emergent vegetation values in excess of 50%, might have contained newts more often than indicated by the survey. In the validation exercise described below, however, whilst there was a clear negative rank correlation between plant presence and newt catch in funnel traps (r_s = -0.53, n=53, P<0.001, Fig. 3), there was no such relationship between plants and newt count by torchlight (r_s = 0.002, n=70, P>0.1). This suggests that trapping by funnel traps is influenced by plant presence, whilst there is no evidence that this is the case for newt counts. The National Amphibian Survey data – based upon torchlight survey – may, after all, be meaningful. The solution to this problem lies in an independent method of population assessment, such as perimeter fencing, but these data are not available in sufficient quantity. In their absence, we have elected to provide the factor as an optional tenth Suitability Index, but to omit it from the validation exercise.

CALCULATION OF THE HABITAT SUITABILITY INDEX

The HSI for a site based upon a pond is determined as a geometric mean, the tenth root of the product of all the suitability indices, each relating to a key habitat variable, using the following equation[1]:

$$HSI = (SI_1 * SI_2 * SI_3 * SI_4 * SI_5 * SI_6 * SI_7 * SI_8 * SI_9 * SI_{10})^{1/10}$$

where: HSI = Habitat Suitability Index; SI = Suitability indices (expressed as values between 0 and 1) in respect of each of the key habitat features, distinguished by subscripts as follows: 1, geographic location (evaluation of location relative to the map of national distribution, Fig. 2); 2, pond area (m^2); 3, pond permanence (years of drying out per decade); 4, water quality (via rule-base on extent of eutrophication); 5, shade (% of perimeter affected); 6, waterfowl (resident birds using the pond per 1000 m^2); 7, fish (evaluation of impact using a rule-base); 8, pond density (pond density per km^2); 9, terrestrial habitat (% "newt-friendly habitat" within 500 m); 10, macrophyte cover (% plant cover). Details of the derivation of each SI value appear in Appendix 1.

Halley *et al.* (1996) suggest that large breeding populations of newts are much less prone to extinction than small ones and are less dependent on influx of animals from adjacent sites. In other words, populations living in very suitable habitats are likely to be less influenced by pond density than are those in relatively unsuitable sites. This was given expression by applying a correction to the HSI values such that pond density was incorporated into the calculation only if the preliminary HSI (calculated using all SIs except pond density) was less than 0.75.

The result of the above HSI calculation is a single number between 0 and 1. In our evaluations the lowest HSI obtained at a site known to support breeding crested newts was 0.43, the highest 0.96.

EVALUATION OF THE INDEX

The proof of the model is its ability to predict crested newt population status. Population status itself is difficult to define and a complete understanding would depend upon a knowledge of the proportions of each life stage as well as age structure and total numbers. However, if we accept adult population size as a measure of status, the model may be examined using a set of crested newt populations of known population size.

There are at least two difficulties in making such an examination. Firstly, crested newt populations exhibit well known annual fluctuations in population sizes and recruitment (e.g. Arntzen & Teunis, 1993, Cooke, 1994, 1995, 1997, Baker, 1999), meaning that either data from a large series of sites, or means from several years, are needed. Secondly, no easily applicable census method gives results which can be applied reliably and consistently to a set of sites with diverse habitat characteristics. Methods adopted by different workers include perimeter fencing (e.g. Arntzen *et al.*,1995), trapping, dip netting and counting by torchlight (e.g. Cooke, 1995, Griffiths & Raper, 1994; Griffiths *et al.*, 1996), egg counts (e.g. Grayson, 1994), and mark, release and recapture (MRR) (e.g. Baker, 1999). Some of these – such as fencing and MRR – are too costly, in time, money and expertise, to be appropriate. Some are too disruptive of the habitat (e.g. netting). In some, such as egg counts, the relationship between the count and adult population size is not well understood. Furthermore, all the methods produce results which vary in relation to detailed habitat structure. For example, torchlight survey in a pond covered by duckweed, or bottle trapping in a pond with only 50% accessibility to observers, are both likely to produce unreasonably low counts.

[1] A *Microsoft Excel* spreadsheet is available (send senior author a blank $3^1/_2$" disk) to assist in the rapid calculation of HSI values based directly upon basic field measurements.

TABLE 1. Summary of data and Suitability Indices (SI) collected from 72 sites during validation of the Habitat Suitability Index (HSI). Details of the parameters are provided in Appendix 1.

Parameters	"Units"	Range of values recorded	Median value	Range of SI recorded	Median SI
Location	3 point scale (0.01, 0.5, 1.0) based upon map, Fig. 2	1–1	1	1	1.00
Area	m²	1250–35	156	1–0.07	0.31
Permanence	Years of drought per decade	10– 0	0	1–0.01	0.90
Water quality	Rule base on extent of eutrophication (4 point scale)	4–0	3	1–0.25	0.75
Shade	% of perimeter affected	100–0	35	1–0.20	1.00
Waterfowl	Resident pairs per 1000 m² using the pond	5–0	1	1–0.60	1.00
Fish	Evaluation of impact using a rule-base (4 point scale)	4–0	0	1–0.01	1.00
Pond dispersion	Pond density per km²	13–0	1	1–0.10	1.00
Terrestrial habitat	% "newt-friendly habitat" within 1 km² sometimes modified by existence of barriers	75–0.3	4.9	1–0.01	0.70
Barriers	Significance of terrestrial barriers using a rule-base	1–0.25	0.75		
Macrophyte cover	% plants reaching water surface	100–0	57.5	1–0.31	0.71
HSI	Habitat suitability index	0.96–0.31	0.66		
Newt count	0–164	4			
Newt catch	0–58	8			

Our initial efforts to validate the model, reported below, suffer from both sets of problems. Site selection has involved a compromise. To enhance the reliability of the comparison we have included as many sites as possible, but excluded those sites for which appropriate readings could not be obtained (e.g. sites with very limited access). On the other hand, most of the sites were assessed for population status in only one season. Although this introduces limitations, the approach serves to illustrate the potential of the method, which can be enhanced as data accumulate.

Sites. The data derive from a set of 72 ponds (Table 1), mainly in Leicetershire and Gloucestershire. None of the sites was used in the original National Amphibian Survey upon which the model is based. The largest was a pond of 1250 m², the smallest 35 m². Four sites for which we have no evidence of crested newt presence were included. Both site habitat evaluations and population assessments were made during late spring and summer, between 1996 and 1999. The 34 Gloucestershire site determinations were all made in the same season (1999). At each site the habitat was assessed using the criteria listed in Appendix 1.

Population assessment. Population status at each pond was usually assessed by two methods, both conducted during the breeding season between the end of March and the beginning of June: counting at night by torchlight, and trapping in bottle traps. Torchlight surveys involved walking around the accessible perimeter of the pond after dusk, at a speed which depended on the conditions, but never more than 25 m per minute, and counting all the newts seen. Surveys were conducted only when there was negligible wind and rain and a temperature of at least 8°C.

Two-litre transparent bottles, set as described by Griffiths *et al.* (1996), were used for the bottle trap survey. Bottles were set, one to two hours before dusk, at 2 m intervals around the accessible shoreline of each pond at a depth of about 0.5 m. They were emptied between one and four hours after sunrise. The median number of inspections was two by torchlight and two by bottle trapping. The median interval between first and second surveys was approximately one month for both survey methods. Values of population size using both survey methods were corrected in proportion to the length of shore surveyed, to compensate for partly inaccessible sites.

Results. Population counts and catches were plotted against HSI for 66 and 55 sites, respectively. The respective Spearman rank correlation values were r_s = 0.51 and r_s = 0.62 (P< 0.001 in each case). The median count was four and the median catch eight, and there was a strong positive correlation between the two (r_s = 0.63, P<0.001). For sites with both kinds of assessment, catch exceeded count in 47% of 49 cases, count exceeded catch in 37% and there was equality in the remaining 16%. At best, both methods reveal a fraction of the adult population. When the maximum value for each site, count or catch, is plotted against the HSI (Fig. 4) the correlation is correspondingly increased (r_s=0.73, n=72, P<0.001).

In Fig. 4 there are a number of outliers, and an examination of them is instructive. The site labelled "A" in Fig. 4 was one of three crested newt sites remaining after the other two had been filled in. Previously the other two sites contained big populations and it seems likely that site "A" contained unusually high numbers through immigration. The group of 12 sites labelled

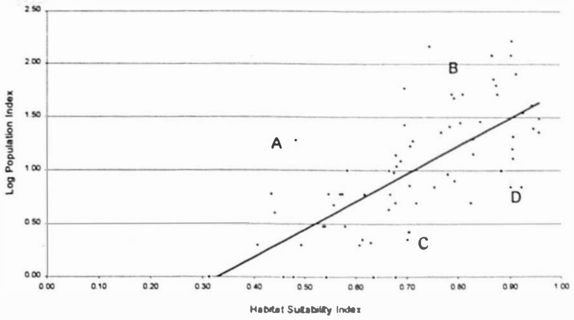

FIG. 4. Positive relationship between population index (maximum numbers of newts caught or counted on a single occasion) and Habitat Suitability Index in 72 ponds. A – D discussed in text.

"B" in Fig. 4 all contained more newts than expected on the basis of the HSI values. In each case the HSI values were the result of low individual SI scores, especially pond area, perhaps indicating that the negative impact of this feature was overstated in the formula. In one instance stone walls may have been undervalued as a habitat. The two sites labelled "C" were from a similar geographical location, in an area of poor terrestrial habitat, but with a number of ponds, and perhaps a thinly spread population. In both of the ponds labelled "D", counting and catching were impeded in various ways. The sites with a zero score were all in areas close to crested newt populations. Hence the zero score is likely to reflect habitat conditions rather than an absence of immigration.

As discussed in Section 10 above, SI_{10} (macrophytes) was not included in the validation exercise. The addition of macrophytes altered the value of the above correlation value only marginally.

In an effort to establish whether any single index was predominantly responsible for the level of the correlation, each SI was tested in turn against the population indices. The model performed progressively better as the number of SI values was increased. The most useful indices in this sample were fish presence, water quality and terrestrial habitat; the least useful were waterfowl, macrophytes and shade. Although it is tempting to modify the index by enhancing the weight of the most useful parameters and reducing that of the least useful, this has been resisted, because the result may simply reflect the features of the relatively small sample of sites used in the validation exercise.

DISCUSSION

When an expert herpetologist assesses a series of sites for their suitability to support a crested newt population, he or she takes into account a range of features, weights their relative significance using knowledge of well studied sites and then integrates the information and comes to a judgement. As with an expert system, the method we have used attempts to formalize the knowledge possessed by an expert. However, the system cannot replace genuine expertise. A simple system of this nature does not cover all eventualities and predictions must be treated with caution, as indicated by the number of outliers in Fig. 4.

Use of the HSI is based upon the simple premise that the quality of the crested newt's habitat is reflected in the status of the population it supports. Whilst there are good reasons to believe that this is true, the practical step of relating the two parameters is beset by difficulties. The methods of habitat definition are crude, including, in several cases, the use of subjective criteria. The relationship between each Suitability Index and population status (Fig. 1 and Appendix 1), whilst based upon evidence, are essentially conjectural. Validation of the method depends upon the assessment of relative population size, which is itself problematic. In the face of these difficulties it is encouraging to arrive at a statistically significant correlation between HSI values and estimated newt status.

The range of values represented in our sample (Table I) is reasonably wide for most of the key variables, although there is some tendency to emphasize sites with permanent ponds of relatively small size in agricultural areas. More seriously, because our sample was taken from the central part of the species range in England, the value of SI_1, location, was 1.0 in all cases and we have not evaluated model performance in peripheral parts of the range. It is possible that the interaction of habitat characteristics may have different effects on populations in these areas. Furthermore, evaluation of the index would be difficult because a site with a perfect habitat score may not support a population simply because there are no colonizers. In the central parts of the range, even with the declining status of the species (Cooke & Scorgie, 1983, Hilton-Brown & Oldham, 1991), it is still sufficiently well distributed for most potential sites to be open to colonizers.

The model developed in this paper emphasizes the aquatic habitat. For some populations this may be appropriate, since crested newts have been found to concentrate their activity within a few hundred metres of the breeding site (Jehle, 2000). There is a paucity of information in this species on the terrestrial habitat, although in American species similar exercises have tended to emphasize the terrestrial habitat (Sousa, 1985, Storm *et al.*, 1993). It is possible that terrestrial landscape characteristics may be a better predictor of population persistence over long time scales.

The result of comparing macrophyte cover with newt catch (Fig. 3) was unexpected. It might suggest that newts caught by trapping are those involved in display in open water, rather than those in "normal" movement amongst the vegetation. The fall in trap catches following the peak of the crested newt breeding season (e.g. Oldham, 1994) may result from the same tendency.

The system proposed does not provide a definitive solution to habitat evaluation but we hope that it will provide a useful first step. At best it will help to rank a series of sites in order of merit as newt sites. It can also be used as a guide in conservation management by providing a checklist of factors to be taken into account during site evaluation. As demonstrated for translocation exercises by Oldham & Humphries (2000), there are many instances where the application of a system such as that now proposed, could have eliminated unsuccessful host sites from consideration.

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REFERENCES

Abel, P. D. (1996). *Water pollution biology.* Taylor & Francis: London.

Arnold, H. R. (1995). *Atlas of amphibians and reptiles in Britain.* Inst. Terrestrial Ecol. Res. Publ. No.**10**. H.M.S.O.: London.

Arntzen, J. W., Oldham, R. S. & Latham, D. M. (1995). Cost effective drift fences for toads and newts. *Amphibia-Reptilia* **16**, 137-145.

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

Arntzen, J. W. & Wallis, G. P. (1991). Restricted gene flow in a moving hybrid zone of the newts *Triturus cristatus* and *T. marmoratus* in Western France. *Evolution* **45**, 805-826.

Atkins, W. (1998). "Catch 22" for the great crested newt. *Brit. Herp. Soc. Bull.* **63**, 17-26.

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. & Halliday, T. R. (1999). Amphibian colonization of new ponds in an agricultural landscape. *Herpetological Journal* **9**, 55-63.

Beebee, T. J. C. (1981). Habitats of the British amphibians. IV.Agricultural lowlands and a general discussion of requirements. *Biol. Conserv.* **21**, 127-139.

Beebee, T. J. C. (1983). Amphibian breeding sites in Sussex 1977-1983: pond losses and changes in species abundance. *Brit. J. Herpetol.* **6**, 342-346.

Beebee, T. J. C. (1985). Discriminant analysis of amphibian habitat determinants in South-east England. *Amphibia-Reptilia.* **6**, 35-43.

Boon, P. J. & Howell, D. L. (Eds.) (1997). *Freshwater Quality: Defining the undefinable*, Scottish Natural Heritage, HMSO.

Cain, M. F. (1993). Second generation knowledge based systems in habitat evaluation. Unpublished PhD thesis. De Montfort University.

Conway, C. J. & Martin, T. E. (1993). Habitat suitability for Williamson's sapsuckers in mixed-conifer forests. *J. Wildl. Manage.* **57**, 322-328.

Cook, J. G. & Irwin, L. L. (1985). Validation and modification of a habitat suitability model for pronghorns. *Wildlife Soc. Bull.* **13**, 440-448.

Cooke, A. S. (1994). "Fluctuations in night counts of great crested newts at eight sites in Huntingdonshire 1986-1993". In: *Conservation and management of great crested newts*: Proceedings of a symposium held at Kew Gardens. *Ed.* A. Gent and R. Bray. English Nature report **No. 20.**

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. (1997). Monitoring a breeding population of crested newts (*Triturus cristatus*) in a housing development. *Herpetol. J.* **7**, 37-41.

Cooke, A. S. & Scorgie, H. R. A. (1983). The status of the commoner amphibians and reptiles in Britain. *Focus on Nature Conservation* **No.3**. Nature Conservancy Council, Peterborough.

Cooke, S.D., Cooke, A.S. & Sparks, T.H. (1994). "Effects of scrub cover of ponds on great crested newts' breeding performance". In: *Conservation and management of great crested newts*: Proceedings of a symposium held at Kew Gardens. *Ed.* A. Gent and R. Bray. English Nature report **No. 20.**

Daniel, C. & Lamaire, R. (1974). Validating the effects of water resource developments on wildlife habitats. *Wildlife Soc. Bull.* **2**, 114-118

Dolmen, D. (1980). Distribution and habitat of the smooth newt, *Triturus vulgaris* L. and the warty newt, *T. cristatus* (Laurenti) in Norway. *Proc. Euro. Herp. Symp.* Oxford 127-139.

Grayson, R. F. (1994). "Surveying & monitoring great crested newts". In: *Conservation and management of great crested newts*: Proceedings of a symposium held at Kew Gardens. *Ed.* A. Gent and R. Bray. English Nature report **No. 20.**

Green, D. (1984). A study of the great crested newt (*Triturus cristatus*) in Durham and the Tyne & Wear, South. Unpublished report for Durham County Conservation Trust Ltd.

Griffiths, R. A. & Raper, S. J. (1994). *Evaluation of a standard method for surveying common frogs* (Rana temporaria) *and newts* (Triturus cristatus, T. helveticus and T. vulgaris) JNCC Report, **No.259** Peterborough, Joint Nature Conservation Committee.

Griffiths, R. A., Raper, S. J. & Brady, L. D. (1996). *A review of current techniques for sampling amphibian communities.* JNCC Report, **No. 210** Peterborough, Joint Nature Conservation Committee.

Griffiths, R. A. & Williams, C. (2000). Modelling population dynamics of great crested newts (*Triturus cristatus*): a population viability analysis. *Herpetol. J.* **10**, 157-163.

Hagstrom, T. (1977). Growth studies and ageing methods for adult *Triturus vulgaris* L. and *T. cristatus* Laurenti (Urodela, Salamandridae). *Zool. Scripta.* **6**, 61-68.

Hagstrom, T. (1980). Growth of newts (*Triturus cristatus* and *T. vulgaris*) at various stages. *Salamandra* **16**, 248-251.

Halley, J. M., Oldham, R .S. & Arntzen, J. W. (1996). Predicting the persistence of amphibian populations with the help of a spatial model. *J. Appl. Ecol.* **33**, 455-470.

Herpetofauna Conservation International (1991). Proposed guidelines for the translocation of crested newts (*Triturus cristatus*) at "wild" sites. *Herpetofauna News* **2**, 5-6.

Hilton-Brown, D. & Oldham, R. S. (1991). *The status of the widespread amphibians and reptiles in Britain, 1990, and changes during the 1980's.* Focus on Nature **131**. Nature Conservancy Council.

Hitchings, S. P. & Beebee, T. J. C. (1998). Loss of genetic diversity and fitness in common toad (*Bufo bufo*) populations isolated by inimical habitat. *J. Evol. Biol.* **11**, 269-283.

Jeffcote, M. T. (1991). The role of expert systems in conservation management. Unpublished M.Phil. thesis. De Montfort University.

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

Laan, R. & Verboom, B. (1990). Effects of pool size and isolation on amphibian communities. *Biol. Conserv.* **54**, 251-262.

Latham, D. M., Oldham R. S., Stevenson M. J., Duff R., Franklin, P. & Head, S. M. (1996). Woodland management and the conservation of the great crested newt (*Triturus cristatus). Aspects of Applied Biol.* **44**, 451-459.

Oldham, R. S. (1994). "Habitat assessment and population ecology." In: *Conservation and management of great crested newts*: Proceedings of a symposium held at Kew Gardens. *Ed.* A. Gent and R. Bray. English Nature report **No. 20.**

Oldham, R. S. & Nicholson, M. (1986). *Status and ecology of the warty newt,* Triturus cristatus. Report to the Nature Conservancy Council (Contract HF 3/05/123), Peterborough.

Oldham, R. S. & Swan, M. J. S. (1991). "Conservation of amphibian populations in Britain." In: Seitz A. & Loeschcke V. (Eds.) *Species conservation: A population-biological approach.* Birkhauser Verlag, Basel:141-158.

Oldham, R. S. & Humphries, R. N. (2000). Evaluating the success of great crested newt (*Triturus cristatus*) translocation. *Herpetol. J.* **10**, 183-190.

Pajak, P. & Neves, R. J. (1987). Habitat suitability and fish production: a model evaluation for rock bass in two Virginia streams. *Trans. Am. Fish. Soc.* **116**, 839-850.

Pavignano, I., Giacoma, C. & Castellano, S. (1990). A multivariate analysis of amphibian habitat determinants in north-western Italy. *Amphibia-Reptilia* **11**, 311-324.

Prosser, D. J. & Brooks, R. P. (1998). A verified Habitat Suitability Index for the Louisiana waterthrush. *J. Field Ornithol.* **69**, 288-298.

Reh, W & Seitz, A. (1990). The influence of land use on the genetic structure of populations of the common frog *Rana temporaria. Biol. Conserv.* **54**, 239-249.

Romero, J. & Real, R. (1996). Macroenvironmental factors as ultimate determinants of distribution of common toad and natterjack toad in the south of Spain. *Ecography* **19**, 305-312.

Soniat, T. M. & Brody, M. F. (1988). Field validation of a habitat suitability index for the American oyster. *Estuaries* **11**, 87-95.

Sousa, P. J. (1985). *Habitat suitability models: red-spotted newt.* USDI Fish and Wildlife Services, Biological Report **82**. Fort Collins, Colorado, 18pp.

Spellerberg I. F. (1992). *Evaluation and assessment for conservation.* Chapman & Hall, London.

Starfield, A.M. & Bleloch, A. L. (1983). Expert systems: An approach to problems that are difficult to quantify. *J. Env. Manage.* **10**, 261-268.

Storm, G. L., Yahner, R. H. & Bellis, E. D. (1993). Vertebrate abundance and wildlife habitat suitability near Palmerston Zinc Smelters, Pennsylvania. *Arch. Environ. Contam. Toxicol.* **25**, 428-437.

Strijbosch, H. (1979). Habitat selection of amphibians during their aquatic phase. *Oikos* **33**, 363-372.

Swan, M. J. S. & Oldham, R. S. (1993). *National amphibian survey.* English Nature Research Report. **No.38**. 223pp & 10 appendices.

Swan, M. J. S. & Oldham, R. S. (1994). "Amphibians and landscape composition." In *Fragmentation in agricultural landscapes* (Ed. Dover, J.W.) Proc. 3rd annual Internat. Assoc. Landscape Ecol. (UK) Conf. Preston.:176-183.

Thomasma, L. E., Drummer, T. D., & Peterson, R. O. (1991). Testing the Habitat Suitability Index model for the fisher. *Wildl. Soc. Bull.* **19**, 291-297.

Treweek, J. (1999). *Ecological impact assessment.* Blackwell, Oxford.

US Fish & Wildlife Service (1976). *Habitat Evaluation Procedures.* Division of Ecological Services, Department of the Interior, Washington, DC.

US Fish & Wildlife Service (1980). *Habitat Evaluation Procedures (HEP).* ESM 102. Division of Ecological Services, Department of the Interior Washington, DC.

US Fish & Wildlife Service. (1981). *Standards for the development of habitat suitability index models for use in the habitat evaluation procedures (HEP).* Division of Ecological Services, Department of the Interior, Washington, DC.

Usher, M. D. (1986). *Wildlife conservation evaluation.* Chapman and Hall.

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APPENDIX 1. Suitability Index definitions.

SI	Factor	"Units"	Derivation of SI value
1	Location	Measured as map location	Refer to Fig. 2: If site occurs in zone A, location is optimal & SI = 1. If site occurs in zone B, location is marginal & SI = 0.5. If site occurs in zone C, location is unsuitable & SI = 0.01.
2	Pond area	m^2	Measure pond surface area. Measure axes in field for regularly shaped ponds or estimate from an OS map. Read off SI value from Fig. 1, chart SI_2.
3	Pond	years	Years out of ten that pond dries out during the spring or early summer. This depends upon access to long-term local knowledge of the site. Read off SI value from Fig. 1, chart SI_3.
4	Water quality	subjective scale	Water quality scored on a 4-point scale where: 4 = good quality; water normally clear and with an abundant and diverse invertebrate community including relatively sensitive groups such as mayfly larvae, water shrimps, amphibians (smooth newts and frog tadpoles) and fish (other than crucian carp); SI = 1. 3 = moderate quality, moderate invertebrate diversity; SI = 0.67. 2 = poor quality; low invertebrate diversity, with emphasis on species characteristic of low oxygen tension such as midge and mosquito larvae, and worms; few submerged plants; SI = 0.33. 1 = bad water quality; clearly polluted, only pollution-tolerant invertebrates such as rat-tailed maggots; usually turbid; no submerged plants; SI = 0.01.
5	Shade	%	Estimate of the % of perimeter shaded (usually by trees). Include only trees close enough to pond to shade water to at least 1 m from shore. Read off SI value from Fig. 1, chart SI_5.
6	Fowl	count	Number of waterfowl seen per pond or per 1000 m^2 in large ponds. Read off SI value from Fig. 1, chart SI_6.
7	Fish	subjective scale	Subjective based on clues or local knowledge: 4 point scale: 4 = Absent; SI = 1. 3 = Possible; SI = 0.67. 2 = Minor (crucian carp and sticklebacks); SI = 0.33. 1 = Major (other species or carp/sticklebacks in dense populations); SI = 0.01.
8	Pond	count	Number of ponds occurring within 1 km of the target site (excluding the target site and ponds on the distal side of important barriers). Use an OS map of at least 1:25 000 scale or field survey an area previously marked on the map. Divide the number of ponds by π (=3.14). Read off SI value from Fig. 1, chart SI_8.
9	Terrestrial	map	OS map with 500 m radius around pond shaded to indicate "newt-friendly" habitat, viz.: habitat judged as woodland, scrub, long grass, meadow, or gardens. Calculate the area shaded (Ha). Also mark good hedges and ditches on the map and estimate length. Calculate total area of shaded and linear features (using 2.5 m as hedge and ditch width, unless determined otherwise). The resulting value (A, in Ha.) is multiplied by the barrier factor (B), described below. The value AB is read off as an SI value from Fig. 1, chart SI_9. Barriers subjective. Barriers scored on a 5-point scale, where: 5 = no serious barrier within 500 m; effectively none of habitat unavailable to population; factor B = 1. 4 = minor barrier (such as minor road with light night traffic); up to approx. 25% of habitat, within 500 m of pond, difficult of access by newts; B = 0.8 3 = moderate barrier (road, river, buildings) with up to 50% of available habitat difficult of access; B = 0.6. 2 = major barriers with up to 75% of habitat difficult of access; B = 0.4. 1 = almost total barrier to newt movement in vicinity of pond, so that newts are virtually confined to the pond and its immediate surroundings; B = 0.2.
10	Macrophyte	%	Estimate of the % of the pond surface-area occupied by macrophyte cover (sum of emergents, floating plants and submerged plants reaching the surface, except duckweed). Estimate with help of chart (Appendix 2) between May and the end of September. Read off SI value from Fig. 1, chart SI_{10}.

APPENDIX 2. Guide for use in assessment of the proportions of vegetation cover in a pond. The percentage of each circle shaded in the figures is indicated.The circles simulate a variety of vegetation dispersion patterns.