any additional terrestrial or aquatic variables corresponding to significant variations in site occupancy (as recognised by Chi^2 with $p<0.05$) in respect of distances from, or extent of coverage of, sites, respectively, were also entered.

Separate analyses were carried out for each species in each of five overall land-use types defined previously. All of the variables selected on the above basis were entered into the analysis initially. If the Chi^2 probability value indicating the significance of the separation between the "presence" or "absence" categories was more than 0.05, then those variables could not be regarded as predictors of species presence. If no combination of the variables produced a significant Chi^2 value, then there was no point in continuing with the analysis. This occurred in only one case - that of palmate newts in rough grassland, where no combination of variables produced significant separation between "newts present" and "newts absent" ponds. For the other samples, the most "doubtful" variables were dropped individually to see whether their exclusion lowered Wilks Lambda and probability values; if not, they were reinstated. Thus a further attempt was made to ensure that the combination of variables used in the analysis was that most likely to explain the observed distribution of animal populations.

5.4.3.3 Results

The results of the Discriminant Analysis - Chi^2, Wilks lambda and DFC values, and percentage prediction accuracy - are presented in Appendix 25.

5.4.3.3.(i) Frog

The discriminant function was not an accurate predictor of frog breeding sites within improved and rough grassland, woodland and garden land-use types. Within the arable sample however, the predictive value was much better, the discriminant function classifying 90% of breeding and 87% of non-breeding sites correctly. The positive correlates with highest DFCs (ie those apparently exerting the greatest influence on frog presence) were fish, rough grassland, woodland and the presence of flowing water. Important negative factors were hedges, roads and built-up areas. The presence of fish was probably an indicator of pond quality, and rough grassland and the woodland would have been areas of semi-permanent and permanent cover respectively; the flowing water indicated perhaps moist refugia or damp flood plains. Water courses may also facilitate adult frog migrations and juvenile dispersal. Contrary to expectation, hedges were not associated with species presence, possibly because they occur in most lowland agricultural landscapes - favourable or hostile to amphibians. They were also perhaps more likely to have been recorded as "significant features" in relatively featureless landscapes than in diverse land-use settings. Frogs have been demonstrated in this chapter to have catholic tastes in breeding sites and terrestrial environments, mixed farming landscapes found throughout Britain providing adequate habitats wherever there were water-bodies. Arable landscapes, however, present much more uniform and extreme environments where the species persistence may depend much more heavily on the presence of high quality ponds, and areas of permanent cover and ground moisture.

The only significant inter-variable correlation identified was between flowing water and woodland, which correlated negatively ($p<0.05$). The lack of correlations suggested each of the features identified above was important in its own right, and not just as an indirect indicator of some other factor.

5.4.3.3.(ii) Toad

Toads have been shown previously to have more exacting aquatic and terrestrial habitat requirements than frogs (Swan and Oldham 1989). Perhaps due to this relatively high habitat specificity, the selected variables provided good predictors of the species presence in each of the given land-use types, except gardens. In all of the land-use types, indicators of pond quality, such as presence of fish, or depth had relatively high DFCs, indicating them to be important factors. However, in the more homogeneous landscapes such as the improved grassland and arable, terrestrial features were also significant. In the intrinsically more heterogeneous habitats, such as woodland, or rough grassland, the important factors were almost exclusively aquatic.

In improved grassland landscapes, where 71% of breeding sites are identified correctly, the most important positive variable (ie largest DFC) was fish presence, followed by woodland and pond depth. Negative factors included a tendency to desiccate, hedges and flowing water. Thus, significant factors were pond quality and permanence, and presence of permanent terrestrial cover. Within this land-use type, hedges correlated negatively with both pond depth and woodland ($p<0.05$ in both cases) suggesting that "hedge" was an indirect indicator of shallow ponds and lack of substantial cover. It is unclear as to why flowing water should be a negative factor though, as in previous sections, toads were shown to occur at higher than expected frequency where water-courses were present within 10m of sites ($p<0.05$). No details of the sizes and characteristics of these water-courses in this sample were available, therefore it is possible that although some may provide bank-side cover, or dispersal/migration routes, others may act as barriers to movement and otherwise be a hostile element in the landscape.

The accuracy of the discriminant function prediction of toad presence in rough grassland was slightly higher than in improved grassland, on the basis of the chosen variables (73%). All of the most significant features, in terms of DFC, were aquatic - fish presence, the extent of submerged vegetation and low probability of desiccation. Again, as for woodland, the general habitat value presented by the base landscape was good, therefore water-body quality was the main toad limiting factor.

The discriminant function for toads in arable landscapes classified 93% of breeding sites correctly on the basis of the 12 chosen variables. Of those, fish presence and lack of southern shade were the strongest determinants - both probable indicators of active pond maintenance. The presence of woodland and of gardens within 500m were also important positive correlates with toad breeding sites, and in this type of land use, flowing water was a positive feature. Gardens were indicated to be a positive factor in arable land, but built-up areas, although positively correlated with the former, ($p<0.05$), were strongly negative.

Although many of the variables appeared to contribute little to the overall discriminant function, the removal of any one of them resulted in a lowering of the accuracy of the classification of the breeding and non-breeding sites. Within each of the land-use types toads breeding sites were significantly larger than non-breeding sites ($p<0.001$ in each case) except for in arable landscapes. This indicated either that toads were breeding in smaller ponds within arable habitats or that some of the larger, apparently suitable water-bodies were unused. The size of toad breeding ponds was demonstrated not to differ significantly between land-use types ($p>0.05$ in all cases) therefore in the arable sample, the set of non-toad breeding sites must have included some within the appropriate toad size range. Thus, terrestrial factors may assume a greater importance relative to aquatic ones in determining the presence of toads in this type of landscape.

In woodland, aquatic features were the most important, the presence of fish and the extent of submerged vegetation cover having the highest positive DFCs, the most important negative factor being pond desiccation. Flowing water here was a positive correlate. The correct classification of only 68% of toad breeding ponds by the discriminant function was not as accurate, however, as for improved grassland or arable habitats. Within the woodland habitats as a whole, where cover and probably food supply are not limiting (Bullock and Cornish pers comm) it was presumed that other terrestrial features are less important.

In gardens, the predictive value of the DFC was low (61%), quite probably due to the fact that an unknown proportion of ponds in this category were artificially stocked (and possibly continually re-stocked) with animals. Therefore, presence of toads may not necessarily have signified that the conditions pertaining were adequate to sustain populations on a "standalone" basis. Apart from fish as positive features, ditches and flowing water within 500m had comparatively large DFCs. If some garden toad sites have been naturally colonised, these may have been factors facilitating the process.

Pond quality was therefore the key feature determining toad presence, with terrestrial features varying in importance according to the intrinsic heterogeneity of the "base" land-use.

5.4.3.3.(iii) Smooth newt

The discriminant function correctly classified over two thirds of smooth newt breeding sites in improved grass and arable land only (69% in each case). The degree of accuracy for the other main land-use types was lower, ranging from 61% in woodland down to 31% in rough grassland. Within improved grassland, pond size, productivity and permanence, indicated by emergent vegetation, depth and desiccation tendency, were important. The presence of built-up areas was a significant positive terrestrial factor, whereas woodland and flowing water were both negative. Terrestrial features were the most significant positive factors in arable landscapes, especially woodland and gardens. Roads and railway lines were negative. However, as stated previously, no separation was made between sites occurring within the ranges of the two small newt species nationally. Therefore, sites otherwise expected to contain smooth newts on the basis of selected variables may simply have been located outwith that species' distribution range. This is particularly likely to have been the case in rough grassland a habitat type often associated with upland areas in which the palmate newt is more likely to be the predominant species. However, despite these qualifications, general conclusions about the relative importance of habitat variables could still be drawn from the analysis. They were that:- aquatic factors assumed the greatest importance in each land-use type apart from arable, in which terrestrial ones predominated.

5.4.3.3.(iv) Palmate newt

The same qualifications apply to this set of data as for the smooth newt. Classification of the species breeding sites had very poor accuracy generally, ranging from 68% in improved grassland right down to 35 and 37% in rough grassland and woodland respectively. It was therefore not possible to have confidence in the relative importance of the habitat variables revealed by this analysis.

5.4.3.3.(v) Crested newt

The crested newt had a more discrete distribution range than either of the two small newt species, which could be defined by excluding several counties from the analysis. This allowed greater confidence in that "empty" ponds were likely to be true negatives, and not lacking the species simply through being outside of its distribution range.

The accuracy of prediction of the species' presence ranged from 51% in gardens to 70% in improved grassland. The 100% classification accuracy for arable land, although impressive, was unfortunately based on only four crested newt sites. Pond productivity was apparently an important factor, the submerged vegetation variable having relatively high DFCs in three of the five land-use types - improved and rough grassland, woodland. The presence of ditches also carried high coefficient values, positive in improved grassland, arable and garden habitats, but negative in rough grassland and woodland. This difference may perhaps have reflect the relative hostility of the base land-use terrain for movement; it is conceivable that migration or dispersal between sites in eg improved grassland or arable land was facilitated by these features.

In improved grassland, pond depth and submerged vegetation were apparently important positive determinants of the newt's presence, suggesting an avoidance of very shallow sites and a preference for well vegetated ones. In this land-use type, the presence of ditches was correlated positively with that of arable land, therefore it was not possible to ascribe importance to either factor separately. Arable land may be important in its own right as suitable habitat, but its positive DFC may alternatively signify that newts preferred mixed, probably lowland, landscapes: ie, that crested newts were usually found in productive areas, suitable for crop cultivation. Negative factors included flowing water, (with its attendant risk of fish introduction through flooding), hedges, and other still water-bodies. The presence of hedges correlated negatively with both the extent of submerged vegetation coverage and pond depth in this type of land-use ($p<0.05$), and thus may well be an indirect indication of landscapes with shallow, poorly vegetated ponds. The negative effect of still water-bodies is more difficult to explain, and is particularly anomalous in the light of the pond density data in Chapter 4 in which it is suggested that crested newts require a minimum pond density of about one pond per km^2. However, "still" water-bodies in this data set also represent marshland, which is not ideal habitat for the species.

In unimproved grassland landscapes, the discriminant function had low predictive accuracy for crested newt sites (57%) but correctly predicted a high percentage of the sites that did not contain the species (82%). The important determinants were apparently the presence of mineral extraction sites, submerged aquatic vegetation and woodland. The most strongly negative factor was flowing water.

The main conclusion regarding the arable sample is that extensive cultivated land coverage is clearly highly inimical to crested newts. Each of the four "arable" crested newt sites occurred in the vicinity of woodland, gardens or ditches suggesting that the species persisted only in the presence of areas of permanent cover, and possibly required dispersal routes in the form of ditches.

In extensive woodland however, crested newts were more likely to occur in the vicinity of cultivated land ie, in lowland rather than upland woods, and possibly where the woodland itself was somewhat fragmented. The presence of other still water-bodies was a positive correlate, but ditches, negative.

The discriminant function poorly classified crested newt sites within the garden pond sample. The strongest DFC was negative - fish presence. Positive factors were ditches and hedges, which were themselves positively correlated in this sample ($p<0.05$). The positive effect of ditches may have resulted from their role as dispersal/migration routes, enabling dispersal between sites.

5.5 Habitat requirement summary

5.5.1 General

In the above analyses, landscapes were simplified into two elements: "base" land-use and features present - which included small areas of other "base land-uses". No account was taken of underlying geology, soil type or site altitude which, to a large extent are reflected in land usage.

In general, the five widespread British amphibians were found in small to moderately sized, well vegetated, barely shaded ponds within each of the main types of land-use found on mainland Britain.

A diversity of terrestrial habitat was apparently important in determining the suitability of landscapes for supporting amphibians.

In base land-use types which are themselves diverse at ground level, such as woodland or unimproved pasture, it was indicated that amphibians were less dependant upon other landscape features, such as patches of scrub, gardens or ditches. In woodland, for example, leaf litter, tree roots, fallen or cut timber etc combine to provide ample cover and invertebrate food supplies; likewise the thick ground layer of rhizomes, uneven tussocks and patches of weeds present in unimproved or rough grassland. In contrast, the ephemeral nature of arable cover, and the barren ground surface afforded by well grazed improved pasture may be inadequate to sustain animals. Such habitats may constitute fruitful nocturnal foraging areas, but the lack of essential daytime retreats, refugia in time of drought, or winter hibernaculae renders them unsuitable. The data show that within the improved grassland and arable land-use types, terrestrial habitat features assume greater relative importance than in the more intrinsically diverse woodland or unimproved grassland landscapes.

5.5.2 Frog

Rana temporaria is ubiquitous within the UK and catholic in its range of breeding sites. It adapts very well to gardens, small ponds not detracting from the advantages of often diverse and relatively predator free suburbia. However, most colonisations are probably artificial, and ailing populations likely to be sustained by further introductions of spawn or tadpoles.

Outside gardens, frogs were found most frequently on moorland, a relatively easily definable habitat. Woodland and rough grassland were the next most preferred land-uses, followed by improved grassland, and by far the least suitable, arable land.

Overall aquatic preferences were for completely unshaded ponds well covered with either or both emergent or submerged vegetation, with or without fish. Breeding site sizes ranged from less than five m^2 to at least $1km^2$, although probably only the well vegetated margins of the large ones were used.

Preference for sites within 500m of flowing water probably indicated the necessity for moist environments. Frogs have been demonstrated to use streams and ditches as migration routes (Swan 1986), but the extent to which these are relied upon for breeding or dispersal movements is unknown, and probably varies between terrestrial habitats. Arable land was inimical to frogs, even when present as a mere feature within a landscape dominated by other land-uses. Perhaps factors other than habitat structure could be responsible for the shortfall of frog populations - chemical toxicity for example.

All types of grassland habitats were apparently enhanced for frogs by the presence of ditches within 100m of ponds. Arable land was habitable where patches of rough grassland or woodland, domestic gardens or flowing water were present, also within 100m of water-bodies. Rough grassland was further improved where woodland was found within 500m of ponds.

5.5.3 Toad

Bufo bufo is also ubiquitous in mainland Britain, but inhabiting sites within a narrower range of aquatic and terrestrial characteristics than frogs. Optimum pond size is around $1,000m^2$, although anything above $100m^2$ would be acceptable. Ponds which never desiccate, with up to 50% emergent and 75% submerged vegetation cover are recommended. Water-bodies managed as small fishing lakes appear suitable if adequate terrestrial cover is provided.

Toads do occur in gardens, breeding in a range of smaller pond sizes than in the field. Again, the extent to which garden toad populations result from artificial or from natural colonisation processes is unknown. Very few ponds within the size range occupied in gardens are known to be breeding ponds in the greater countryside.

Outside the garden habitat, the preferred terrestrial land-use type for toads was woodland, followed by rough grassland. Both arable and moorland habitats were preferred to improved grassland, the least favoured. Toad habitat suitability could be governed by the presence of extensive areas of woodland or scrub within 100m of sites. Flowing water and other small water-bodies within 100m also served to increase the probability of toad occupation.

Within improved grassland, the presence of woodland in particular, but also other small water-bodies and flowing water within 100m of ponds increased their potential as toad breeding sites.

In the rough grassland sample, mineral extraction sites as landscape features appeared likely to benefit toads. Also suggested as factors promoting toad occupation were flowing water, other small water-bodies, scrub and woodland within 100m.

In arable land, woodland, scrub and ditches within 100m may be necessary to sustain the species.

The presence of hedges or flowing water within 100m of woodland ponds may improve the habitat for toads, but are not essential in an otherwise adequate terrestrial environment.

Overall, providing that suitably large open ponds are present, landscape features which increase the level of cover and which are likely to provide a relatively high biomass of invertebrates (eg woodland) will sustain toad populations, especially if within 100m of breeding sites. In grassland, relatively high pond densities may be required. The data also suggest that within 100m of ponds, water-courses are important features, probably as dispersal/migration routes.

5.5.4 Smooth newt

Although breeding in water-bodies within a wide range of sizes, the optimum within most habitats is between 100 and 400m^2. Cover vegetation immediately surrounding ponds is important, but should shade no more than 25% of the pond; all shading should be reduced as far as possible. Aquatic vegetation is essential, but more than 75% is apparently inimical. Although fish stocked sites are not avoided completely, ponds which dry out occasionally are preferred; desiccation may reduce all types of aquatic predator populations to tolerable levels.

Triturus vulgaris breeds successfully in a greater percentage of garden than non-garden ponds. These may therefore currently be regarded as a significant, but not necessarily long-lived, habitat resource.

In the field, rough grassland dominated landscapes contained the highest percentage of newt sites, followed in order by arable, improved grassland and woodland. Ponds with a narrow woodland buffer around them (probably not more than 10m wide) were preferred to those surrounded by extensive woodland. Ponds with arable land within 500m, but no closer than 10m of their edge were preferred to those with cultivated land extending right up to them. Ie, within an open agricultural landscape, the smooth newt needs some permanent cover at the edge of breeding sites. Gardens and mineral extraction sites within 500m, and rough grassland within 100m, of potential breeding sites also probably enhance the landscape for smooth newts.

Although the most important factors affecting newt presence in improved grassland were aquatic (emergent vegetation cover and depth), the presence of scrub or built-up areas within 500m were also indicated to have some positive influence.

As with toads, mineral extraction sites or built-up areas within 500m of ponds in rough grassland situations increased the likelihood of newt presence. Otherwise, this type of land-use was shown to be adequate without further enhancement with other landscape features.

In the more extreme arable landscape, the presence of woodland, gardens, improved grassland or scrub within 500m are probably necessary for sustaining the species' terrestrial phase. It must be remembered however, that, unlike the anurans, the urodele adults can feed in water and are therefore less dependant on terrestrial habitats to provide food. Nevertheless, they still require frost-free hibernaculae and terrain suitable for breeding migrations and juvenile dispersal.

Excessive shading renders ponds unsuitable for newts, which factor may be responsible for the low percentage of woodland ponds occupied by the species. Within woodlands, short grassland at pond edges was preferred.

5.5.5 Palmate newt

The optimum size range for *Triturus helveticus* breeding sites of 90 to 400m^2 was very similar to that of the smooth newt. Breeding sites need to contain submerged, but not necessarily emergent vegetation; and not desiccate frequently.

Palmates were shown to breed in gardens, occurring with approximately equal frequency there as in the field.

Outside gardens, they were found most frequently in heathland or moorland sites, followed by woodland. They were considerably less common in rough grassland, improved grassland and arable. In general, landscapes containing heathland, moorland or dune slack were preferred. Flowing water or woodland present within 100m also increased the palmate newt potential of ponds.

In predominantly improved grassland landscapes, flowing water within 500 and small water-bodies or scrub within 100m increased the likelihood of palmate presence.

Within rough grassland dominated habitats, flowing water within 500m or heathland within 100 increased the probability of the species' occurrence.

Woodland ponds were enhanced for palmate newts by the presence of heathland habitat within 10m or sand dunes within 500m; ie, upland or coastal woodlands provide good habitat for this species.

5.5.6 Crested newt

The optimum breeding site size for *Triturus cristatus* is fairly small - approximately 100m^2. The species requires some pond edge vegetation cover and is more tolerant of shading than the two small newts, anything between one and 75% being acceptable. Both emergent and submerged vegetation are essential, with 50 to 75% of the latter being preferred. Fish predation can cause extinction. Preference for ponds which desiccate occasionally may reflect the species' avoidance of sites which support fish.

A lower percentage of garden than field ponds supported this species, indicating that the suburban garden resource is of less value to crested newts than for any of the other species. Possibly, garden ponds are too frequently stocked with fish, not allowed to develop sufficient vegetation coverage; or are simply too small to support viable populations.

Outside gardens, crested newts preferred rough grassland dominated habitats to woodland or improved grassland. Extensive arable land was apparently avoided. Overall, pond edge cover, such as a narrow woodland buffer, improved ponds.

Improved grassland, arable land or flowing water within 100m were strongly inimical but some improved or grazed grassland within 500m correlated with increased newt frequency. The suggestion is that crested newts require landscapes in which a variety of land-uses are present within 500m of ponds but which specifically contain areas of permanent cover within 100m

In improved grassland dominated landscapes, ditches may enable newts to survive. Site occupancy rates are also higher within 500m of built-up areas. The lack of terrestrial features indicated to affect crested newt presence in this type of habitat suggests either that pond quality is the important factor, or that grassland itself is not inimical to the species. Perhaps their morphology allows not only the crested but also the small newt species to utilise smaller refugia than the frogs and toads. Frogs tend to hibernate, or take refuge from unfavourable climatic conditions, in water, so that wetland or generally moist habitats close to the water-table are important to this species. Toads bury themselves within soil or leaf litter or hide beneath or within clumps of vegetation; scrub or unimproved grassland, and soft substrate should therefore be important to them. Newts, on the other hand, having a more vermiform body are able to squeeze into smaller refugia .

Rough grassland, though itself a preferred habitat, is enhanced for crested newts by the presence of woodland within 100m of ponds, and mineral extraction sites within 500m.

In arable farmland the presence of woodland, gardens, ditches and improved grassland enable a few sites to support the species, but essentially, crested newts cannot survive in landscapes dominated by intensively cropped fields.

Woodland in itself is a good habitat for crested newts where ponds are not over-shaded. However, woodland interspersed with arable or grassland is more suitable than blanket coverage.

5.6 Conservation implications

Amphibians were found in greater abundance in the natural, semi-natural or least intensively farmed landscapes in the UK - woodland and rough grassland, and, in the case of frogs and palmate newts - moorland and heathland. In agricultural landscapes, habitat diversity was important.

However, in improved grassland or arable land, amphibian population frequency was increased in the presence of additional landscape features, such as patches of semi-natural vegetation, other wetlands (flowing and non-flowing), human habitation or ditches. From the present data, it was apparent that the presence of hedges did not enhance the amphibian-supporting capacity of a landscape.

Four of the five species were also relatively commonly found in garden ponds.

The crested newt exhibited a narrower range of aquatic and terrestrial habitat tolerances then the other species and had colonised fewer garden ponds. This provides further evidence that *Triturus cristatus* is more vulnerable to certain land-use changes than the other four widespread species.

Section 5.5 above contains basic guidelines for amphibian habitat management at a local scale. However, the data could also be used to provide the basis for a national strategy for the conservation of amphibian habitats in Britain, incorporating the following aims :-

1) The conservation or restoration of Britain's remaining natural or semi-natural habitat; to include maintenance of water-bodies where appropriate.
2) The incorporation into agricultural policy of incentives or obligations to maintain, restore or create landscape features likely to increase the occurrence of amphibians within lowland agricultural Britain.

3) The support and promotion of pond protection, management and restoration schemes.

4) The promotion of the concept of "gardens as wildlife sanctuaries" with special emphasis on the value of ponds.