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Habitat Fragmentation: Its effects and the production of guidelines for its assessment.

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ABSTRACT

This paper explores the very real environmental threat of Habitat Fragmentation. There is an analysis of Fragmentation's definition and an examination of the various effects it has upon landscapes and the species therein.
The paper explains and critically evaluates a series of models previously published to analyse the effect of fragmentation on habitats and species. There is a summary of current environmental legislation and the effectiveness of Environmental Impact Assessments in dealing with ecological and fragmentation issues.

Using the information researched on the effects of fragmentation and the examination of theoretical models a new technique for the assessment of fragmentation and habitat protection is proposed in the form of the Habitat Assessment Model (HAM).
HAM takes an integrated approach to development and assessment. It utilises a combination of models, particularly Metapopulation ones to create a methodology for the assessment and prediction of the impacts of fragmentation. The model includes a species database, a breakdown of species and habitat responses and is designed to be used by anyone, even those without ecological training.

The paper highlights a gap in legislation and environmental protection, where the effects of fragmentation are often overlooked. The proposed model is very basic and needs considerable development before it is widely applicable, but it provides a focus and framework for the further research that is discussed later in the paper.

CHAPTER 1
INTRODUCTION

The problem of Habitat Fragmentation is not a new one, the debate and relevance of it in nature conservation has been brought in to the limelight in the past 40 years. It was brought in to sharper focus by MacArthur and Wilson's theory of Island Biogeography in 1967.

Recently the importance of habitat protection and fragmentation has come to the forefront. Studies have shown that the quantity of Neutral Grassland has fallen by 95% since 1930, Calcareous Grassland by 80% since 1940 and Lowland Heath, Fens and Mires by 50% since 1950 (English Nature, 1996). This catalogue of habitat loss and fragmentation has profound implications for species survival and the maintenance of the United Kingdoms biodiversity. It is clear that there is a need for a greater understanding of fragmentation within the planning and development process. The government aims in its planning and policy guidance notes:

"to make adequate provision for development and economic growth whilst ensuring effective conservation of wildlife and natural features" (DoE, 1994).

The only way that this goal can be achieved is with sound advice and guidance for planners, decision-makers and developers.

This studies main objective is to review the literature and current thinking on Habitat Fragmentation and try to draw out over a series of aspects a methodology for the assessment and quantification of fragmentation impacts and effects.

The study puts forward a Habitat Assessment Model (HAM) as a means to quantify and predict fragmentation effects. HAM provides a format for guidance on fragmentation issues and is designed to fit in to existing Environmental Impact Assessment practices.

The need for such guidance is highlighted by Verboom (1993) who states that:

"Guidelines for landscape management are badly needed"

Such guidelines need a good understanding of the relationships between landscape and species (Verboom, 1993) and whilst there is still little understanding of ecological processes, hypotheses and suggestions can still be made to ensure that habitat fragmentation as a national problem is mitigated.

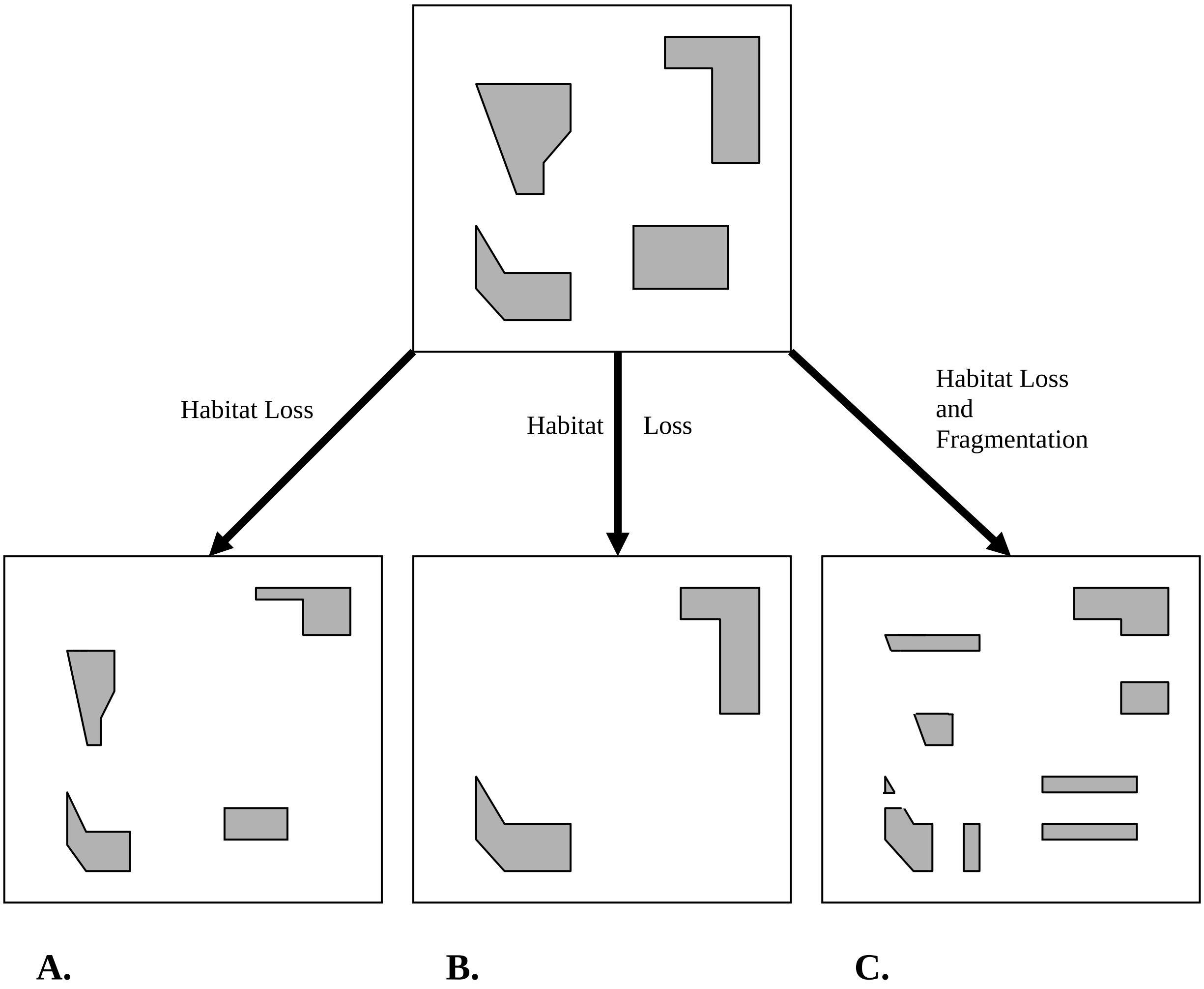
The term Habitat Fragmentation is subject to much discussion. Its strict definition has evolved over time. Originally fragmentation was assumed to involve two factors, loss of habitat and sub-division (or increasing isolation) of patches (Rolstad, 1991 and VanApeldoorn, 1992). However, Bright in 1993 defined it as a process that leads to increased isolation and a decrease in the patch area, this he maintained was distinct from habitat loss. This view of separating loss and isolation was maintained by Fahrig (1997, 1998a, 1998b) and Hanski (1994, 1999). Fahrig saw fragmentation as the breaking apart of habitats whereas loss is actual destruction, thus making loss a far more dangerous threat to nature conservation (Fahrig, 1998a). Hanski (1999) supported this by stating that fragmentation results in no overall change in area, but a change in the number of patches which that area is represented. Figure 1 illustrates some of the different views of habitat fragmentation.

When examining the question of fragmentation effects as a result of development, it is difficult o imagine a scenario where the habitat is not damaged or lost but merely separated or more isolated. To this end it is perhaps more prudent to follow Andren (1994) view that fragmentation is the process of subdividing a continuous habitat in to smaller pieces; with three major components, loss of original habitat, reduction in patch size and increasing isolation. It is this definition that is adopted though out this document whereby loss can be considered a factor of fragmentation.

Fragmentation affects the landscape and the habitats within it, the structure of these components needs some defining.

A Habitat is the part of the physical environment or biosphere in which a plant or animal can live (Parker, 1997; Krebs, 1994). This definition means that a habitat is not restricted by size, for example the habitat for an eagle can be several square

FIGURE 1 Explanatory Diagram of Fragmentation and Loss



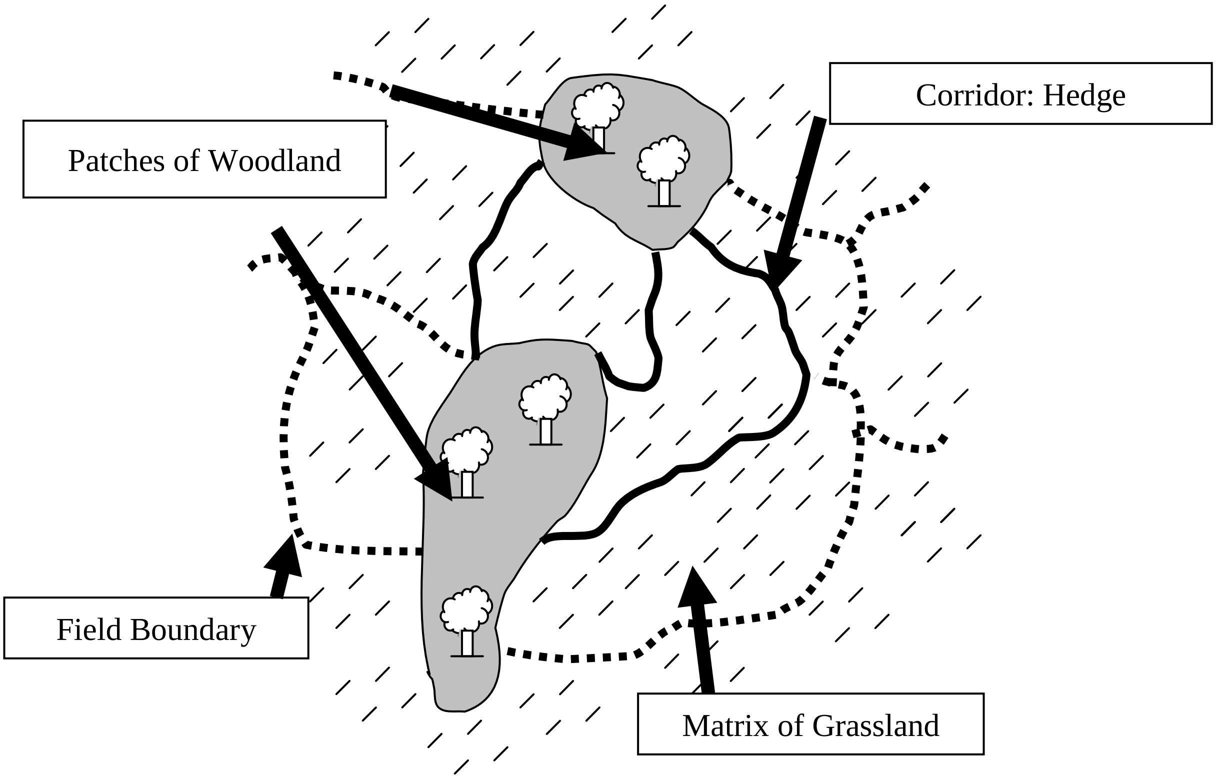
A - If habitat loss results in a constant number of smaller patches, then patch size effects are due to habitat loss alone.
B - If whole patches are removed from the landscape, then isolation of remaining patches increases but fragmentation per se is actually decreased since they are due to habitat loss alone.
C - When the number of patches increases by the breaking apart of habitat, both habitat loss and fragmentation per se are involved in decreasing size and increasing isolation of habitat patches.

kilometres whereas the habitat for a beetle may be just one tree. Habitats can be described in terms of landscape elements (Andren, 1994).
Landscapes are composed of a variety of layers. The basic element is the matrix, the background vegetation type, upon which the other elements are super imposed. It has the greatest relative area and most connectivity (Bell, 1994).

Patches are homogenous areas that differ from the surrounding matrix (Bell, 1994), like a piece of woodland on an area of arable farmland. Patches have three components, the interior, the boundary and the edge. The interior is composed of the dominant vegetation type. The boundary is the line or interface between the two vegetation types where matrix meets patch, and the edge is the transition or ecotone of vegetation over this boundary.

Corridors often link Patches; these are linear elements and effect the flows, which pass through and within the eco-system. A corridor could be a river or in the case of the example above, a hedgerow linking the wood to another some distance away (Bell, 1994).
The landscape pattern can be divided in to spatial and spatio-temporal patterns (Harrison and Fahrig, 1995) which affect the landscapes formation.
Patches are maintained by the flows of immigration and emigration of individuals. The probability of a species presence in a patch is given as a function of four factors, Area, Quality of habitat, Isolation from other patches and Time since isolation from nearby patches (Taylor, 1991).
The size of a patch is crucial to the survival of both the patch and the population contained within it. Figure 2 shows the various components within the landscape.

FIGURE 2 Illustration of Landscape components



CHAPTER 2

CAUSES OF FRAGMENTATION

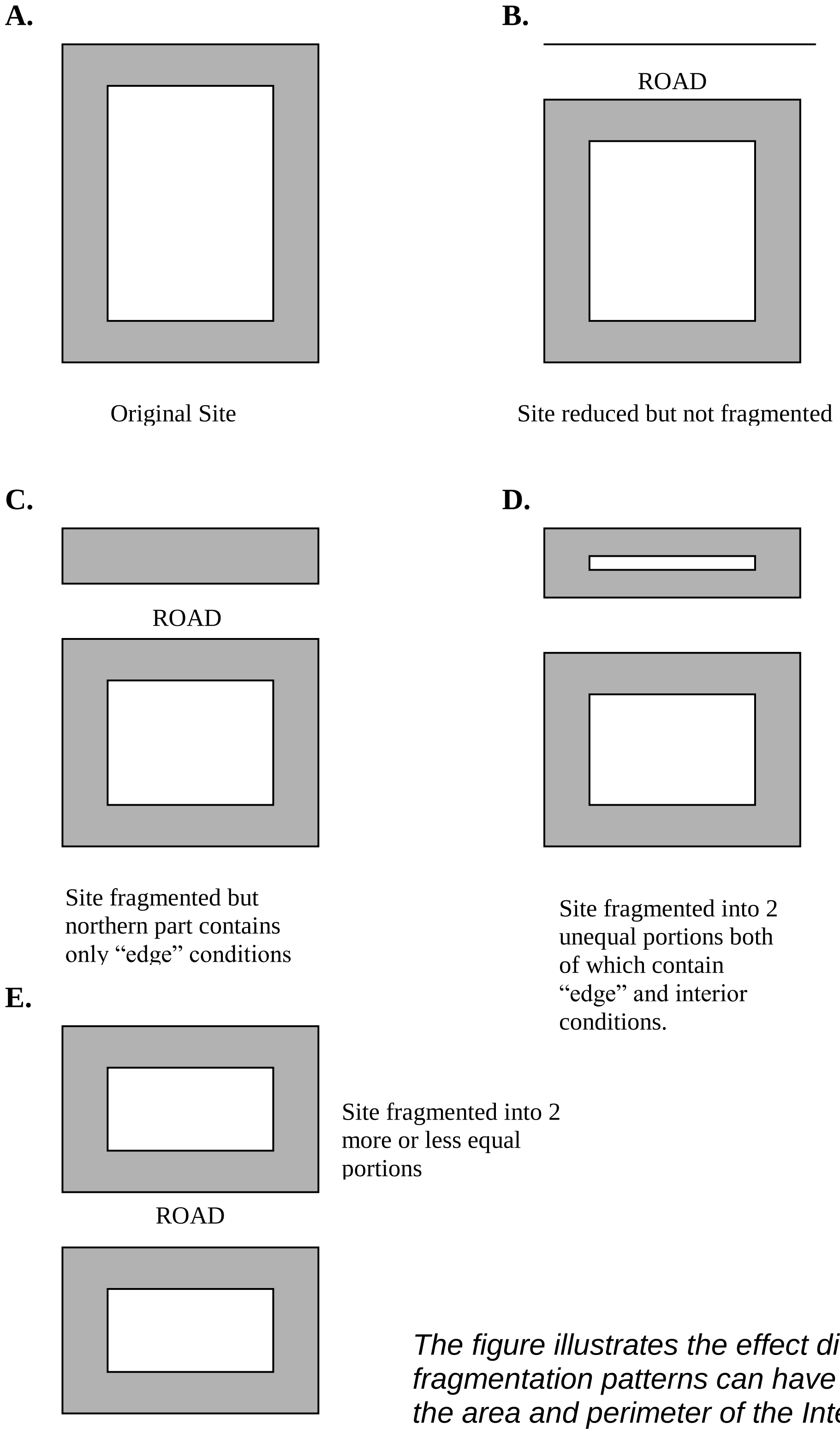
Fragmentation of natural and semi-natural habitats occurs at an alarming rate both naturally and due to human influence. Andren (1994) lists the single largest cause as the expansion and intensification of human land use. The impacts of fragmentation are further magnified where edge habitats and remnant vegetation are involved (Lindenmayer, 1999).

Road construction perhaps has the greatest fragmentation effect. Roads create very effective barriers to almost all taxa and noise and air pollution creates significant disturbance effects (Reijnen and Foppen, 1994). Up to 60% of breeding wader populations were disturbed up to 1800m from a road (English Nature, 1993). Aside from bisecting and disturbing habitats, roads also present a considerable risk to individuals attempting to cross them. On a road with a limit of 50 mph 0.86 Amphibians, 1.43 Reptiles, 1.31 Birds and 0.31 Mammals were killed per mile over a 116 day period (Oxley, 1974). Figure 3 demonstrates the possible fragmentation patterns of a road project in a wooded environment.

In the past 50 years changing agricultural practices have increased the isolation of remnant patches. Large monoculture fields, the removal of hedgerows and the destruction of ponds have contributed to vast areas of land being unsuitable for a wide variety of native species.

Alongside road construction and agriculture increased human population pressure in the United Kingdom has intensified the need for more housing and industry. These human causes along with the natural of fragmentation factors such as fire, windfall and earthslides increase fragmentation considerably; additionally many of these natural causes are often amplified by human action.

FIGURE 3 Examples of different types of Fragmentation as a result of road construction



The figure illustrates the effect different fragmentation patterns can have on the area and perimeter of the Interior (White) and Edge (Grey) of patches.

(English Nature, 1993)

CHAPTER 3

THE EFFECTS OF FRAGMENTATION

Fragmentation through whatever however it is caused has the potential for effecting the environment and habitat in several ways. This chapter explores what impact habitat fragmentation has upon Barriers, Edges, Disturbance, Community interactions, Dispersal and Connectivity, Landscapes and lastly Populations. This last section acts as an overview as ultimately each effect has an effect upon the population status of the individuals and species involved.

3.1 BARRIER EFFECTS

When a habitat is fragmented there is an associated barrier effect that reduces the flow of species, individuals, genes, nutrients and energy across the landscape (English nature, 1993). Barriers can take two forms, Physical and Behavioural (English Nature, 1993). A physical barrier could be a road or an unsuitable habitat. A behavioural barrier could be open ground which makes the individual more vulnerable if it chose to cross it. In the case of a road it is suggested that a four lane divided highway may be as effective a barrier to the dispersal of small mammals as a river twice as wide (Oxley, 1974).

It is important to note that a barrier to one species may not be so for another, a key determining factor for this is the elasticity of the eco-system (English Nature, 1993). Hedgerows form good corridors for small mammals and birds but create impenetrable barriers for some butterfly species. Work by Thomas (1993) illustrated that reduced recolonisation probabilities were observed in the North Downs as a result of Barriers.

When a barrier is created and the flows changed, there are several consequences. Populations become restricted to their remnant patch. This increases isolation and intra-specific competition pressures will rise, especially in species, which rely on their offspring dispersing over long distances (English Nature, 1993). Barriers also inhibit the probability of a patch being recolonised following a species extinction.

3.2 EDGE EFFECTS

The boundaries between two habitat types are never abrupt, there is always a gradient of one vegetation type to the other. These zones of gradation are populated by edge species, some of which can be very specialist. The balance between edge and interior species can be severely disrupted by habitat fragmentation.

The reduction in the size of a habitat increases the ratio of perimeter to area and thus the number of edge species. The same is true of a change from a regular to an irregular shaped patch (Kirby, 1995). Such changes in edge quantity can have very varied effects upon the interior habitat. The key effects are changes in light, humidity, windthrow, shade, predation, pollution, disturbance, competition and invasion by open-ground species (Kirby, 1995). In woods it is noted that an increase in the edge can result in an increase in pollution, noise and spray drift effects upon the wood (Kirby, 1996).

Assessing the effect on edges is difficult, as there are no strict boundaries between edge and interior. Webb (1984), who studied fragmentation on heathlands believed that area was a poor way of assessing the importance of edge effects, instead he viewed the shape of the heath and the composition of the surrounding vegetation to influence diversity to a greater degree.

Edge effects are not necessarily disbeneficial to all species. Generalist species that use both the patch interior and edge decline only in relation to habitat loss and not fragmentation (Bender, 1998). For interior species, populations decline as a result of fragmentation to a greater extent than habitat loss (Bender, 1998). Kirby (1995) questions whether there are any true interior mammal species left in the UK (Kirby, 1995) suggesting that edge effects do not adversely affect them. For edge species; the loss of species or reduction in population size is less than would be predicted from pure habitat loss alone (Bender, 1998) in fact fragmentation increases their abundance.

3.3 DISTURBANCE

When fragmentation occurs, both the process and the final state create disturbance problems for populations. For example when a wood is bisected by a road project the destruction of the forest and the construction of the road constitute disturbance. Once the road is finished disturbance to the environment continues through its use. Disturbance is not just the effect of noise it can include, smell, dust, smoke, wind or vibration. Evidence form Australian eucalyptus forests have shown that animals appeared to be virtually absent where heavy machinery had disturbed, destroyed or damaged parts of the forest (Lindenmayer, 1999).

In the case of roads, extensive work by Reijnen and Foppen (1994) on Willow Warbler breeding habitats along Dutch roads have illustrated significant impacts. Their work showed that in a zone of 0-200m from the road the density of territorial males was considerably reduced and that the total output of males per hectare was 40% lower than average. Noise disturbance is particularly a problem for vocal organisms, such as birds. Vibration disturbances will effect a variety of mammals and reptiles, whilst dust presents a problem for plants, when leaves can become covered in a fine layer affecting photosynthesis and respiration. Changes in wind disturbance as a result of landscape change can additionally have large impacts on flying insects and aerially dispersed plants.

3.4 COMMUNITY INTERACTIONS

When a habitat is fragmented it is not just the numbers of organisms which are affected but the interactions between them. Predator/Prey interactions can be destabilised by fragmentation and new interactions can be introduced (Fahrig, 1996). Populations of herbivores fluctuate in cycles these cycles can disappear as a consequence of fragmentation. Fragmentation increases prey species density and diversity and therefore an increase in generalist predators and an increased predation pressure (Andren, 1985).

Within a fragment, generalist predators from the surrounding habitat penetrate patches and can prevent prey populations from building up (Andren *et al*, 1988). The increased perimeter created by fragmentation increases the predation rate along the edge which can result in a lower reproductive success of patch interior species (Andren *et al*, 1988). Other than the changes in predation, fragmentation could have an effect upon any commensal or mutalistic relationships in the patch species (Fahrig, 1996). By altering the species composition of a patch, competition interactions (Intra and inter- specific) can be significantly altered. Competition for resources by patch residents would be increased by fragmentation potentially forcing extinctions or dispersal amongst the occupants.

3.5 DISPERSAL AND CONNECTIVITY

A key element in the functioning of any habitat is the ease to which individuals can move between patches, this is termed Connectivity (Fry, 1994). The dispersal of organisms of organisms is vital to the survival of all species to varying degrees, and integral to the theoretical models explored in Chapter Five. The mode of dispersal varies from taxa to taxa, but corridors are considered very important for a whole variety of species. Corridors can, however, create barriers as well as facilitate dispersal.

There are a variety of factors, which need to be considered when assessing dispersal. Firstly, what causes dispersal? Boudjemadi (1999) highlights 2 prompts, Genetic and Environmental. Genetically it is important for all species to maintain a pure gene pool and avoid detrimental mutations through inbreeding. In terms of plants this concept is termed the optimum outbreeding distance (Hansson, 1991). Environmentally, dispersal reacts in response to habitat heterogeneity changes in time and space, and the make-up of the social environment (Boudjemadi, 1999).

Hansson (1991) breaks the influencing factors in to 3 common causative factors. Economic thresholds are the first consideration, where an individual disperses when one of its resources falls below a critical level.

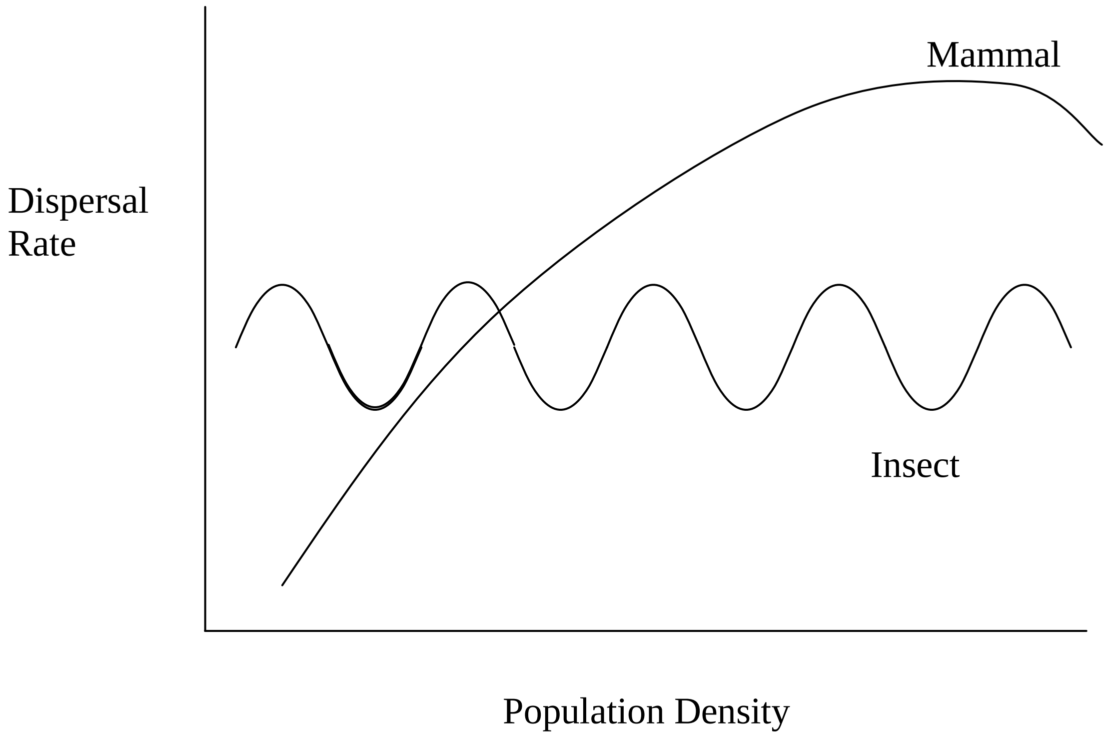
Secondly, conflict over resources prompts dispersal. There are several forms this conflict can take. The obvious conflicts are over resources such as food and shelter, however, competition for mates, parent/offspring competition and inferior/superior social hierarchy's can all promote dispersal. (Hansson, 1991).

The third is this concept of genetic preservation. The avoidance of inbreeding that in mammals usually results in male dispersal and in birds, female dispersal.

Fragmentation's effect on dispersal is related mainly to the change in the distance required for successful dispersal, this is the inter-patch distance. When a patch is reduced in size and fragmented populations become crowded in the patch, increasing competition pressures are increased and consequently dispersal pressures mount.

The reduced size of the patch means that there is a greater distance to travel before a 'safe' habitat is reached. This distance may not be suitable for the organism and could present a barrier.

FIGURE 4 Dispersal Patterns



Graph illustrating two dispersal responses to rising population density. Larger organisms are more affected than smaller ones whose response is cyclic in the short term. The dispersal threshold is much lower than for mammals

The success of any dispersal depends upon species mobility. There are 3 classes of mobility; Highly mobile species, such as most mammals and birds, Highly immobile species, like plants and lastly, species which have varying abilities to disperse across gaps or through corridors (Kirby, 1995). Figure 4 shows two different taxas response in dispersal to population density

Fragmentation effects can be felt not just at the source patch but at the receiving patch. For example a development forces a clan of badgers to travel to a new piece of woodland where a clan already exists. The receiving patch is subject to intense competition and social interaction pressure. Fahrig (1985), however, believes that receiving patches are only affected when large populations are involved at the source patch..

Corridors can allow recolonisation. Size thresholds cause individuals to locate to the necessary minimum area requirements; corridors form a conduit for this dispersal. Corridors are often used by migratory organisms and can provide an avenue to escape environmental change; they also facilitate the flow of genes across the landscape (Dawson, 1994).

All-purpose corridors do not exist and requirements vary from species to species. Continuity is a particular important factor in corridor suitability particularly for migratory freshwater animals (Dawson, 1994).

The usefulness of corridors is often debated, it is the view of Dawson (1994) that rare and threatened species are unlikely to benefit from corridors unless they are of a made up of rare habitat type. He also noted that most species do not actually depend solely on corridors for recolonisation or extinction prevention (Dawson, 1994).

Corridors and the connectivity of the landscape significantly affects the dispersal of organisms, for example Dormice will only travel from one wood to another if they are connected by hedges (Bright *et al*, 1993).

Patch connectivity is a landscape function that expresses the degree to which sub-populations are inter-connected into a functional demographic unit (Fry, 1994). Connectivity is measured as the probability of an individual from a habitat patch with species A reaching another patch (Fry, 1994).

Linear features represent corridors through which organisms may diffuse more easily, if the matrix is hostile to them. Thus the nature of the matrix effects the connectivity and the ease of dispersal (Harrison *et al*, 1995). Corridors have been found in medium sized fragments to reduce the rate of species loss from a patch allowing a healthy population to survive, and giving access for reintroduction if extinctions occur (Collinge, 1998). Here it is clear that if during fragmentation connections are maintained the populations in question are less affected by the factors which would force populations into extinction in unconnected patches.

3.6 LANDSCAPE EFFECTS

As mentioned earlier, habitats can be described in terms of their place and influence upon the landscape and eco-system at large. Fragmentation produces a series of patches of remnant vegetation, this has two primary effects, the alteration of the microclimate and the isolation of the patch from others (Saunders, 1991).

There are 3 microclimate parameters that can change with increased fragmentation, these changes are Radiation flux, Wind flow and Water flux (Saunders, 1991).

Radiation Flux

The energy balance of any landscape is determined by its native vegetation and the extent of coverage of that vegetation over the landscape. Different vegetation types and substrates absorb solar radiation to different degrees. For example the change of a native vegetation type to a crop species increases the quantity of radiation reaching the ground thereby increasing daytime ground temperature and lowering it at night.

Changes in patch size and shape increase the quantity of solar radiation at the edge of patches encouraging different species to colonise. Shade-tolerant species are more and more restricted to the interior the smaller a patch becomes. Solar radiation doesn’t just effect vegetation, work by Saunders (1991) indicates that increased soil heating as a result of increased radiation can affect the nutrient cycling processes within the landscape. This is due to the change that increased soil temperature has upon soil micro-organisms, the number and activity of invertebrates the soil moisture retention and lastly the rate of litter decomposition (Saunders, 1991).

Wind flow

A change in any landscape element will effect the flow of air through the landscape. According to Saunders (1991) the 'fetch' or effect of wind as a result of a patch is 100-200 times the height of the vegetation of the patch. Therefore a wood with 20m tall trees would need to be at least 2-4 km wide before the wind profiles would resemble those in an unfragmented situation.

Patches within a fragmented landscape are subject to an increased exposure to the wind. When a patch is reduced in size the edge acts as a buffer against windpruning or wind throw. When the edge is removed the remaining vegetation is subject to damage, increased evapotranspiration, reduced humidity and increased desiccation (Saunders, 1991). Windspeeds which are increased as a result of the change in landscape pattern result in the increase in the transfer of dust and seeds from the matrix (Saunders, 1991). Saunders (1991) quotes that particulate matter deposition at the edge of a forest patch increased by 40% compared to the open.

Changes in wind profiles can significantly affect the dispersal of plant propagules and insects.

Water Flux

The last microclimatic factor is water flux. The removal or change in vegetation alters the rate of rainfall interception and evapotranspiration which affects the soil moisture content (Saunders, 1991). Where vegetation is removed, increased surface flow leads to increased soil erosion and the transport of particulate matter. Changes in water flow alters nutrient transport, surface salt concentration, and water storage. These affects are landscape wide and can have consequences not only for the patch but the surrounding matrix as well.

Isolation

The second effect on landscape, isolation, has four components, Time, distance, connectivity and changes in the matrix.

The time since a patch was isolated is crucial to the scale of the effect, which is observed. When a patch is first isolated it will have greater species extinction followed by a period of relaxation. Specialist species, those needing large territories and low-density populations rapidly go extinct (Saunders, 1991). The distance from other patches is vital if a fragment is to survive. The ability of species to colonise a patch depends on inter-patch distance. Distance and the third factor, connectivity have been explored in earlier sections. Isolation as a result of fragmentation changes the surrounding matrix it can affect or alter the intra and inter-specific interactions, competition, predation and resource availability (Saunders, 1991). There are three forms of isolation Within-Site where a road may cut through a wood, Loss of links and the restriction of the ease to which a species can move about freely (Kirby, 1996).

3.7 POPULATION EFFECTS

Population changes are the end result of any change in the previously addressed Barrier, Edge, Dispersal and Landscape effects. The primary result of fragmentation on populations is the risk of local or regional extinction through decreased population size (Fahrig, 1996, 1997; Harrison *et al*, 1995; Rolstad, 1991; Taylor, 1991). Habitat loss decreases the number of local populations and therefore the overall population is also reduced (Fahrig, 1996). Low populations result in a decreased number of dispersers for recolonisation and the patch becomes increasingly isolated (Fahrig, 1996).

When a patch is fragmented a population can be affected in 2 different ways. Firstly the physical sub-division of a continuous habitat decreases the patch area and increases insularisation, these two parameters dictate the viability or probability that an individual or species is present in a patch (Andren, 1994). The relationship between these two parameters the 'distance-area' component, influences the dispersal rate and population size by directly reducing the immigration rate and increasing the extinction rate (Rolstad, 1991).

Work by Rolstad (1991) on the effects of fragmentation on birds showed that a local population might become extinct if the size of the patch falls below a threshold value set by the minimum territory size. Subdivision is a population level effect. Inter-patch distance, patch density and the density of the corridor network influence the strength of the effect, which is observed. Secondly the reduced area and the altered spatial configuration effects the habitat composition of both the patch fragment and the surrounding matrix. This effect includes the patch/matrix and interior/edge ratios and the heterogeneity of both the patch and the matrix.

Heterogeneity and edge ratios as described earlier indirectly affect mortality and productivity through the increased pressure from the matrix. This pressure could be abiotic landscape pressure or biotic such as predator or competition relations, This second effect is therefore a community level. The different effects of the community effects can be viewed diagrammatically in Figure 5.

Rolstad's (1991) investigations of forest birds shows that where a forest fragment is reduced leaving non-forest habitats, the carrying capacity of generalist predators, open field competitors or nest parasites able to infringe upon the forest interior species is increased. Figure 6 shows the increase in the extinction probability during the fragmentation of breeding habitats compared to other habitats showing the different effects fragmentation can have.

FIGURE 5 Diagram of Fragmentation Interactions

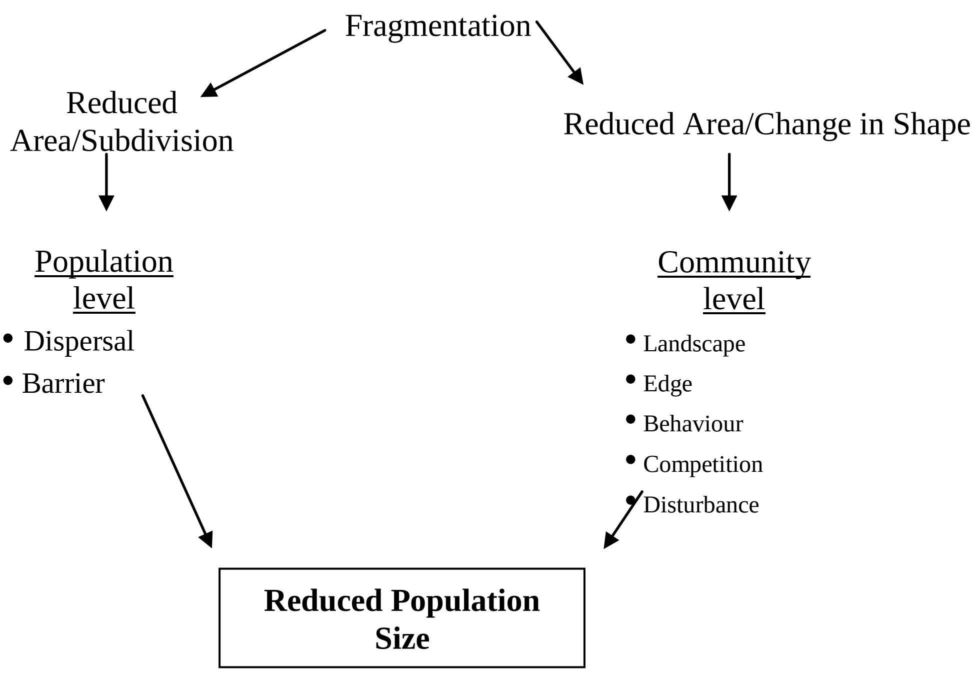
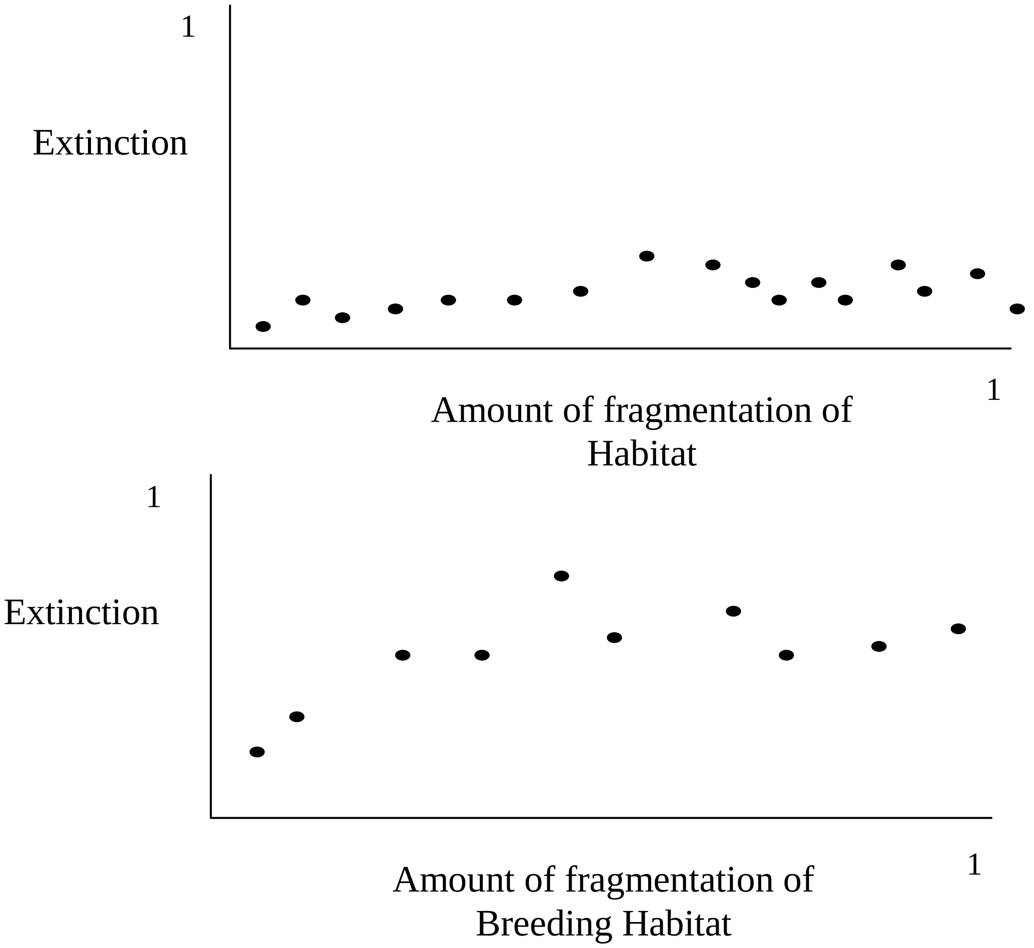


Illustration of the different levels on which fragmentation can occur. The Population and the Community.

FIGURE 6 Extinction Probabilities as a result of Fragmentation



(Fahrig, 1996)

CHAPTER 4

THE SCALE AND PATTERN OF FRAGMENTATION

One of the most important questions in assessing fragmentation is the scale which is used (Rolstad, 1991). The incorrect scale can misrepresent risk and overlook major fragmentation effects.

There are several levels at which an area can be assessed, the population or metapopulation level, Community level or the Landscape level. Quite often the scale is determined by the technique used to explore it. Hanski (1991) identified three scales Local, Metapopulation and Geographical. Table 1 shows the level at which most effects are expressed.

TABLE 1 Levels of Fragmentation

EFFECT	LEVEL
Insularisation	Population/Metapopulation
Connnectivity	Population/Metapopulation
Fragment size	Population/Metapopulation
Interior/Edge ratio	Community/Landscape
Heterogeneity Changes	Community/Landscape
Barrier	Community/Landscape

(Krebs, 1994)

4.1 LOCAL VERSUS REGIONAL SCALE

The extinction of local populations is often preceded by its isolation from larger regional populations. Local populations are therefore dependant upon the regional framework for survival (Rolstad, 1991).

Local or regional scales are useful for assessing or quantifying the rarity of a species or habitat within the landscape.

4.2 INDIVIDUAL VERSUS POPULATION SCALE

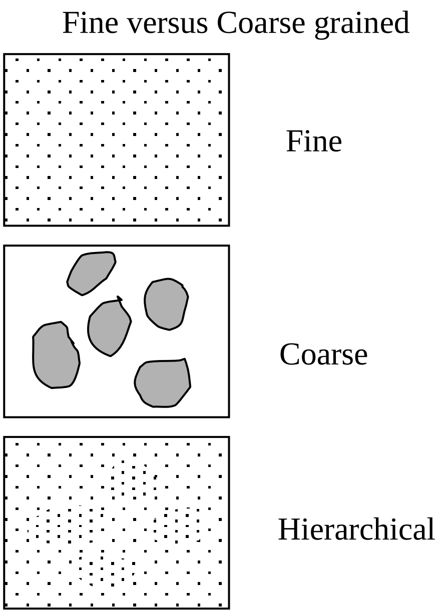
Fragmentation on the individual scale is directly related and defined by the area requirements and movement patterns of the species in question (Andren, 1994). Population scale, however, is defined by the isolation of local populations and the exchange of individuals between generations and populations (Andren, 1994). Both Metapopulation and Island Biogeography theories operate on the population level, whereas some computer models (Cui and Chen, 1999) operate on the individual scale.

4.3 FRAGMENTATION PATTERN

The overall pattern of fragmentation is heavily affected by scale. Rolstad showed in 1991 that there are three main patterns as shown in Figure 7. Fine-grained landscapes are formed by the sub-division of the habitat into patches smaller than the home ranges of the individual. Coarse-grained landscapes are where each patch contains several individuals. Lastly, Hierachal patterns are formed as a result of highly specific fragmentation combining the pattern of fine-grained and coarse-grained.

The question of scale can be seen by looking at the Hierachal pattern. For example if one were to assess the fragmentation of one of the clusters in the hierarchical pattern one could easily be observing a fine-grained pattern and miss the wider effects and impacts.

FIGURE 7 Patterns of Fragmentation



(Rolstad, 1991)

CHAPTER 5
THEORIES USED TO ASSESS FRAGMENTATION

As the awareness of the issues of habitat fragmentation increase so do the number of spatial models, available to describe it.
Here 5 spatial theories and 1 computer model are explored in relation to their possible, practical use in developing assessment guidelines.
The spatial models appear in two forms, Spatially Implicit and Spatially Explicit. Spatially implicit models relate purely to the destruction of habitat and not the isolation of the remnant patches (Bascompte, 1996); whilst spatially explicit ones are usually map orientated which incorporate isolation and fragmentation into the factor of straight habitat loss (Bascompte, 1996).

5.1 COMPUTER MODELS

In 1999 Cui and Chen developed a computer model to assess the effect of habitat fragmentation and ecological invasion upon populations (Cui and Chen, 1999).
The model works from the single population perspective in a mosaic where patches are connected by the discrete diffusion of individuals. The model is:

$$X_i = X_i\,[b_i(t)-a_i(t)] + \quad D_{ij}(t)(X_j - X_i), \quad (i= 1,2,\ldots.n) \qquad \textbf{Eqn. 1.1}$$

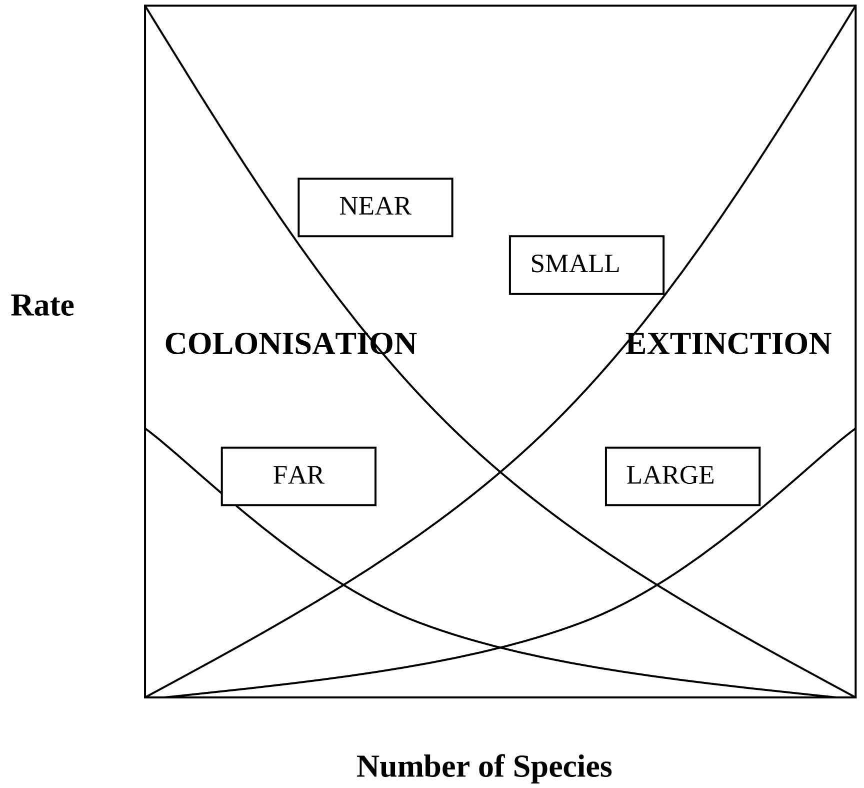
Where $b_i(t)$ is the intrinsic growth rate for species x in patch i, $a_i(t)$ is the self inhibition coefficient of the species, $D_{ij}(t)$ is the diffusion coefficient of species x from patch j to
patch i and X_i is the concentration of species x in patch i.

Experiments using the model showed that fragmentation was a major factor on the extinction of endangered species.
The Cui and Chen model relies on specific complex population data which could hinder its use as a practical tool in everyday fragmentation studies.

5.2 ISLAND BIOGEOGRAPHY

The dynamic theory of Island Biogeography is a spatially implicit model developed by MacArthur and Wilson (1967), it explores the dynamics of colonisation and extinction within the survival of populations and deals with ecologically uniform areas (Dawson, 1994). The theory focuses on populations of a single island or habitat patch. Factors are studied as a function of area and isolation from the mainland (Hanski, 1991).

FIGURE 8 Graph illustrating the Theory of Island Biogeography



MacArthur -Wilson Model of equilibrium insular biogeography, which shows extinction and colonisation rates as functions of island size and isolation.
(Brown and Kodric-Brown, 1977)

Figure 8 shows graphically that colonisation's and extinction's create a dynamic equilibrium in which the number of species remain constant whilst the identity of the species varies over time (Brown and Kodric-Brown, 1977). The model predicts that the rate of species replacement of an island is inversely related to both the size of the island and the distance to a source of colonists, be that another island or a mainland (Brown and Kodric-Brown, 1977).

In terms of its relation to habitat fragmentation, islands are analogous to patches, which act as sinks and mainlands as larger patches, which respond as sources. The model therefore represents the extinction rate of the species as a function of island or patch size and colonisation as a function of insular isolation.
This insular isolation is also a component of fragmentation. Where populations of species are concerned the model can be expressed as:

$$\frac{dp}{dt} = (c_m + cP)(1-P)-eP$$ **Eqn. 2.1**

Where c_m is the colonisation rate per empty patch from the mainland, c=0 , e equals the extinction rate. The equilibrium value of P is given by:

$$\frac{c_m}{c_m + e}$$ **Eqn. 2.2**

This form of MacArthur and Wilson's Model is often termed the Mainland-Island Metapopulation structure. Metapopulation theory is explained in greater detail later in this chapter.
Work by Brown and Kodric-Brown (1977) introduced the modification of the rescue effect to the original model. The rescue effect increases the population

size, which lowers the risk of extinction in relation to the increased rate of immigration. This concept incorporates a species or populations ability to adapt and rescue failing numbers in fragmented patches. This ability of course is a direct function of the connectivity of the mosaic and the species mobility.

The term mainland-island belies the problem with the MacArthur and Wilson Model for the purposes of the preparation of guidelines. The MacArthur and Wilson model assumes that the patches in question are islands embedded in a matrix which is essentially hostile to the species in question, that is to say that the connectivity value of the mosaic is zero. Realistically, in actual landscapes this does not happen, a hostile habitat is not always impermeable to the species. A species quite often is not stopped by a hostile matrix but merely impinged. Another shortfall is the models dependence upon specialised species information such as the measures of colonisation and extinction.

5.3 CELLULAR AUTOMATA MODELS

Cellular Automata models were explored by Dytham (1995) and are spatially explicit. They operate by representing a set of habitat patches as a regular lattice (Hanski, 1999). The model measures the colonisation probabilities of vacant cells by occupied neighbouring ones (Hanski, 1999). The landscape in the form of the lattice is represented as a black or white square dependant on occupancy. The degree of fragmentation can be expressed as a fraction of the suitable sites occupied when plotted as a function of those sites which were destroyed (Bascompte, 1996).
The model, although map based does rely on the MacArthur and Wilson theory shown in equation 2.1 and is therefore subject to the same limitations as the ones listed in the previous section.

5.4 PERCOLATION THEORY

Percolation Theory works on a similar level to Cellular Automata and is also spatially explicit. Like the Cellular Automata model the theory operates on a grid or lattice of cells or sites; which are given specific co-ordinates and a randomly scattered fraction of destroyed patches (Bascompte, 1996). Each point represents a spatial unit so that when a patch is destroyed it is possible to examine the direct effect strictly within the spatial context.

In a theoretical landscape an unfragmented area can be slowly fragmented and snapshots be taken at each crucial stage (Bascompte, 1996). As the fragmentation increases the effects alter. Initially the destruction of patches has only a quantitative impact upon the landscape, a physical reduction in the number of spatial units. Eventually a qualitative change is seen as the survivability of each decrease with the increased isolation (Bascompte, 1996).

Andren (1994) explored the concept of percolation theory. He showed that a populations response can only be explained by habitat loss alone when a valid random placement hypothesis is used. Simulations showed that until 60-80% of the habitat had been lost, isolation effects were minimal (Andren, 1994).

Studies by Andren (1994) using artificial maps and mean patch sizes showed that a continuous patch only fragments when 40% of the original habitat had been lost.

Percolation Theory keeps separate habitat loss and isolation, which can be done by using order parameters.

An order parameter is:

$$\Omega = \frac{S_{max}}{i \;\; j \; \theta(i,j)}$$ **Eqn. 3.1**

Where S_{max} is the size of the largest patch and $\theta(i,j)$ =) if the site (i,j) is destroyed or 0(i,j) = 1 if it survives. This order parameter can then be plotted as a function of D or destruction (Bascompte, 1996). Explorations of this model have shown some agreement with experimental tests of habitat fragmentation, which seem to demonstrate that there is no single population response to fragmentation (Bascompte, 1996). Like other models before it the Percolation theory does not incorporate any species characteristics such as mobility, sensitivity or colonisation and extinction rates.

5.5 METAPOPULATION THEORY

Metapopulations were first described in detail by Levins (1969). A metapopulation is defined as a population of populations, which interact with each other (Hanski and Gilpin, 1991; Bright, 1993).
Levins work closely mirrored earlier work by MacArthur and Wilson (1967) and even earlier works, which explored but didn't name the precepts of metapopulation theory (Hanski and Gilpin, 1991). Metapopulation models are built up of separate populations whose survivorship is reliant upon themselves and the connections between them, As a result the matrix resistance and connectivity is particularly important in the model (Van Apeldoorn, 1992).

Hansson in 1991 highlighted the importance of dispersal in metapopulations. He showed that the spatial arrangement of patches and corridors was important for populations of corridor-dependant species (Hansson, 1991). Many small mammals exist as a mainland of a large population and outlying habitat islands with several small local populations (Hansson, 1991) The metapopulation theory can be explored in two forms, Levins original equations and work by Hanski (1999) which extend that work.

The Levins Rule

Levins (1969) first coined the concept of metapopulations and developed the first model to measure the dynamics involved. The rate of change of a metapopulation is measured by the fraction of patches which are occupied at time t (Hanski, 1999).

$$\frac{dp}{dt} = cP(1-P)-ep$$ **Eqn. 4.1**

Where c is the colonisation rate, e is the extinction rate and P is the population. This equation is a simpler form of equation 2.1 of Island Biogeography developed two years previously MacArthur and Wilson, 1967).

The model is a phenomenological model (Hanski, 1985) that takes the assumption that there are an infinite number of habitat patches and that the value of 'c' is not affected by inter-patch distance. The model conforms to the mean-field assumption, which assumes that all the patches are equally connected. This in practice is not so, in fact patch distance and connectivity are vital to the survival of most metapopulations (Hanski, 1999).

To resolve the inherent problems in not accounting for inter-patch distance and population distribution the model can be rewritten to incorporate species population characteristics:

$$\frac{dp}{dt} = (c-e)P\left(1-\frac{P}{1-e/c}\right) \qquad \textbf{Eqn. 4.2}$$

Where c-e is the intrinsic rate of the increase in metapopulations. The local carrying capacity is expressed by 1-e/c. The result of this model is that P cannot exceed 1.

The Levins model shows that where a patch network is modified by removing a proportion of the patches without affecting the remaining populations (i.e. Habitat loss) the extinction rate of a population is not affected, however, colonisation is. This is due to the lower level of patch connectivity and the reduced population size (Hanski, 1999).

If no patches are lost but their size is reduced (i.e. Isolation) there can be an increase in the extinction rate and a reduction in the colonisation rate per empty patch (Hanski, 1999).

The Model can give a measure of a populations response to the two facets of fragmentation. it highlights that with an increase in fragmentation the patch density decreases. In the long term, before all the suitable habitat is lost or fragmented the colonisation rate would drop below the critical threshold necessary to support the populations rising extinction rate.

The Levins Rule can be seen when the model is modified to incorporate patch occupancy (P_{tot}):

$$\frac{dP_{tot}}{dt} = cP_{tot}(h - P_{tot}) - eP_{tot}$$ **Eqn. 4.3**

Where h is the equilibrium of patches given by:

$$h = P_{tot} = e/c$$ **Eqn. 4.4**

Hanski describes that this model represents the Levins Rule where a sufficient condition for metapopulation survival is that the remaining number of habitat patches following a reduction in patch number exceeds the number of empty suitable patches before patch destruction (Hanski, 1999).

On the face of it the Levins Rule and model appear to be a very useful tool in assessing population changes as a result of fragmentation. The rule can give an estimate of the minimum amount of suitable habitat for the long-term survival of a metapopulation. Hanski (1999), however, warns that the Levins Rule is not robust enough for practical use. In practice the minimum quantity of suitable habitat can be significantly affected by parameters outside of those incorporated in the model. The Levins Rule additionally does not account for population clumping, it is only effective for a large number of patches and it assumes metapopulation fragmentation is only achievable in recently fragmented landscapes.

The Hanski Modification

The limitations of Levins' (1969) approach to metapopulation theory can be overcome by using work conducted by Hanski (1999). Hanski saw that there was a relationship between the connectivity of a metapopulation and the degree to which it is affected by habitat fragmentation (Hanski, 1999). He noted that with increasing habitat destruction the resulting impact through habitat loss is amplified by the combination with isolation effects. To measure the degree of fragmentation, Hanski (1999) came up with a practical measure of the accessibility of the habitat to the individual, this value he termed the Neighbourhood Habitat Area.

The model re-expresses Levins (Equation 4.1) as:

$$\frac{dP_i}{dt} = C_i(t)\,[1-P_i] - e_iP_i \qquad \textbf{Eqn. 4.5}$$

The equation explores the rate of change in the probability the patch i is occupied by a population (P_i). $C_i(t)$ is the colonisation rate of patch i, e_i is the extinction rate which can be expresses a $1/A_i$ where A_i is the area of patch i (Hanski, 1999). Hanski simplifies the model by using connectivity as the main component as opposed to the equilibrium of colonisation and extinction rates or probabilities of patch occupancy.

The connectivity of patch i (Γi) is expressed as:

$$\Gamma i = \Sigma \exp(-\alpha d_{ij})A_j \qquad \textbf{Eqn. 4.6}$$

Where d_{ij} equals the distance between patch i and j; A_j is the area of patch j and α is a measure of the migration range or mobility of the species in question. Connectivity was looked at by Fahrig in 1985, she proposed a matrix approach involving the birth rate, death rate and number of patches alongside age classes

This connectivity value can illustrate the isolation of the patch and can be fed in to the following equation to calculate Neighbourhood Habitat Area (Hanski, 1999).

$$H_n = \frac{\Sigma\,(A_i^2 + A_i\Gamma_i)}{\Sigma A_i} \qquad \textbf{Eqn. 4.7}$$

This equation factors in the area of the patch. The H_n of a patch network increases with an increase in average patch area and average connectivity, therefore the lower value of H_n the greater the degree of fragmentation. This value gives a practical useable figure, which can be used to explore changes in the fragmentation of a landscape.

5.6 INCIDENCE FUNCTION THEORY

Incidence function theory is a spatially explicit theory involving larger number of islands and species (Hanski,1991), which Hanski (1999) explored to expand the power of the Neighbourhood Habitat Area shown in equation 4.7.
The model uses more complex species level census data:

$$J_i = \frac{C_i}{C_i + E_i}$$ **Eqn. 5.1**

Where J_i is the stationary probability of patch i being occupied and C_i and E_i represent the colonisation and extinction rate respectively. Ei was derived by:

$$Ei = \min \frac{e}{A_i^x}, 1 \quad ,$$ **Eqn. 5.2**

Where e and x are two parameters and A_i is the area of patch i (Hanski, 1999). Colonisation was given by an increasing function of the numbers of immigrants (M_i) as:

$$C_i = \beta \exp(-\alpha d_i),$$ **Eqn. 5.3**

Where d_i is the distance of patch i from a mainland and α and β are the two parameters. Taking in to account how patch areas and isolation effect extinctions and colonisation's within the landscape, the following equation for the incidence of patch i is:

$$J_i = \frac{1}{1 + ey/S_i^2 A_i^2}$$ **Eqn. 5.4**

Where S_i is the sum of the connectivity from equation 4.6 as:

$$\beta S_i = \beta \Sigma \exp(-\alpha d_{ij})\, p_j A_j$$ **Eqn. 5.5**

The incidence function model incorporates the elements of colonisation and extinction with species level characteristic and physical patch parameters. The incidence function model is useful as it is simplistic and allows available data to be parameterised. Hanski (1999) suggests the model is useful in six situations.

1- Where the suitable habitat occurs in discrete patches which in total equally less than 20% of the total.
2- Where there is substantial variation in patches and/or isolation.
3- Where patches are occupied by local breeding populations which persist for a few generations after the cessation of migration.
4- Where at least one survey of patch occupancy has been conducted of all the large patches and their areas and spatial co-ordinates are measured.
5- Where a survey includes 30 or more patches of which 10 or more are occupied and 10 or more are unoccupied.
6- Where the metapopulation used for the parameter estimation is at a stochastic extinction-colonisation quasi-equilibrium.

The incidence function model is an incredibly powerful and precise tool; it is very applicable to highly fragmented landscapes. The model has been used to successfully examine the effects of fragmentation on Glanville Fritillary metapopulations, among other species (Hanski, 1999).

The problem perhaps for inclusion in strategic or practical planning guidelines is the complexity of the ecological information, which is required to maximise the power of this model.

CHAPTER 6
THE CURRENT STATUS OF HABITAT FRAGMENTATION IN THE BRITISH LEGAL SYSTEM

The awareness of the issues of Habitat Fragmentation is not enough to ensure that change for the better is forthcoming; action in response to a problem is not usually addressed until it is legislated for. This section examines current planning procedures and environmental protection in regard to reducing the impact of fragmentation.

6.1 ENVIRONMENTAL IMPACT ASSESSMENT

Environmental Impact Assessment (EIA) is the cornerstone of planning law control of construction and development in the natural environment. EIA facilitates development in tandem with safeguarding the environment.
EIA legislation in Britain is as a result of the European Union directive on The Assessment of the Environmental Effects of certain Private and Public Projects on the Environment (Directive 85/337/EEC, Amended by Directive 97/11/EC).
The Directive was translated in to English law in the Town and Country Planning (Assessment of Environmental Effects) Regulations 1988, and later the Town and Country Planning (EIA) Regulations 1999 (DETR, 1999).
The EIA legislation ensures that habitats and species are taken in to account in development. The Act states that where there are significant effects upon:

> "human beings, flora, fauna, soil, water, air, climate, landscape, material assets, including architectural and archaeological heritage and the interaction between any of the foregoing" (DETR, 1999)

that a planning decision is consulted and its impact assessed. Although not mentioned specifically, habitat fragmentation is addressed through the combined study of flora, fauna and landscape.

The main focus and in fact quite often the key output of an EIA process is the Environmental Impact Statement (EIS). This document should ideally cover all the aspects discussed during scoping exercises within the aforementioned quoted parameters above.
In 1996 Jones investigated 18 Environmental Impact Statements to assess their coverage of ecological and in particular fragmentation effects. She specifically chose statements of projects, which would be expected to cause significant fragmentation effects, such as roads, pipelines, runways and tram lines.
The results were quite disturbing. Jones found that 83% of the statements included sections on ecology, however, only 28% made reference to fragmentation issues (Jones, 1996). Where statements did consider fragmentation effects, they were very poorly addressed (Jones, 1996).

Several of the statements acknowledged responsibility under the law for highly protected species but there was little coverage of the types of habitat to be affected or its relationship on regional, national or international scales (Jones, 1996).

6.2 WILDLIFE LAW

The critical piece of United Kingdom species protection is the Wildlife and Countryside Act 1981 (WCA). This act and its 1985 amendment provide the bulk of the protection for individual animal and plant species (Bell, 1997). There are extra provisions for certain species in the Conservation (Natural Habitats etc) Regulations 1994 (CNH), Conservation of Seals Act 1970, Protection of Badgers Act 1992 and the Wild Mammals (Protection) Act 1996 (Bell, 1997). The concept of the WCA is to provide a list of protected species. Birds are listed in schedule 1, Mammals in Schedule 5 and Plants in Schedule 8. These lists are updated every 5 years (DOE, 1994). For animals there are 5 parts of protection. In relation to the issues of fragmentation Parts 1 to 4 are most relevant, and cover; the killing, injuring or taking of animals; damage to, destruction of, obstruction of access to any structure or place used by a scheduled animal and disturbance of any animal occupying such a place. For plants, Part 1 is most applicable and includes the intentional picking, uprooting or destruction of species on Schedule 8.

The WCA additionally provides a framework for the protection of habitats (With the National Parks and Access to the Countryside Act 1949) through the establishment of National Nature Reserves (NNR's) and Sites of Special Scientific Interest (SSSI's) (Bell, 1997).
SSSI's form the representative sample of British habitats determined on the basis of naturalness, diversity, typicalness and size. SSSI's are designed to maintain the present (1981) diversity of wild animals and plants. The designation affords a site some level of protection from development. Permission is needed from English Nature under a General Development Order for planning permission to be granted (DOE, 1994). The law governing SSSI's has been updated and reviewed by the Countryside and Rights of Way Act 2000 (DETR, 2000).

One particular habitat, namely Hedgerows have recently been afforded greater protection under the Hedgerows Regulations 1997 (SI No.1160). The regulations mean that planning permission is needed for the removal of any hedgerow (DoE, 1997).

Table 2 shows the extent of site protection designation and they're enforcing laws in the UK.

There are two very important EU directives concerning habitat protection, these are the EC Wild Birds Directive 79/409 and EC Habitats Directive 92/93 (Ball and Bell, 1997). Both directives are translated into UK law in the Conservation (Natural Habitats etc) Regulations 1994 (CNH). The Birds Directive establishes protection for breeding and feeding grounds in the form of Special Protection Areas (SPA's). The Habitats Directive creates Special Areas of Conservation (SAC's) for habitats in danger of disappearing from their natural range.

Article 10 of the Directive states that:

> "Any plan or project not directly connected with the management of the site which is likely to have a significant effect on it must be subject to an appropriate assessment of the implications"
> (EU 2000)

This statement safeguards areas from development. More importantly the Directives first Annex list a series of priority habitats. 75 of these habitats occur in the UK and can be seen in Appendix A.

TABLE 2 Conservation Legislation

Designation	Details/Legislation
National Nature Reserve	Areas of high national or international importance for Nature Conservation. S19 National Parks and Access to the Countryside Act 1949. S35 Wildlife and Countryside Act 1981.
Site of Special Scientific Interest	Sites of particular value to nature conservation to represent the range of

	British eco-systems National Parks and Access to the Countryside Act 1949. S28 Wildlife and Countryside Act 1981
Ramsar Site	1971 Convention on Wetlands of International Importance. Ramsar, Iran.
Special Area of Conservation	Conservation of Natural Habitats and Wild Fauna and Flora EC Directive 92/43/EEC In the UK: Conservation (Natural Habitats, etc) Regulations 1994.
Special Protection Area	Conservation of Wild Birds EC Directive 79/409/EEC. In the UK: Conservation (Natural Habitats, etc) Regulations 1994.
Limestone Pavement Order	Conservation (Natural Habitats, etc) Regulations 1994. S34 (6) Wildlife and Countryside Act 1981
Sites of Important Nature Conservation	County Councils, Wildlife Trusts, Farming and Wildlife Advisory Group.
Biogenetic Reserve	Bern Convention

CHAPTER 7
CURRENT GUIDELINES AND ORGANISATIONS

There have been several attempts to develop guidelines or practical models for use in the assessment of fragmentation in the workplace. In this chapter some of the more important ones are examined along with organisations which are investigating the issues of Habitat Fragmentation.

The development of any set of guidelines or model, need to cover five important aspects. The model must be cost-effective if it is to be readily used. The model needs both spatial and temporal resolution when dealing with landscapes and any changes occurring over time. The model and the data that is inputted need a degree of accuracy to gain valid results and the whole package must be repeatable and yield results within an acceptable margin of error (Firbank *et al*, 1996).

7.1 GUIDELINES AND MODELS

Wathern in 1999 proposed a procedure for the evaluation of the effect of site removal on Metapopulations (See Box 1). The Model is qualitative in nature and operates on the landscape scale. The model expressed in Box 1 is very simple and doesn't illustrate the techniques required to assess the various aspects. It does, however, provide a strong, logical framework for assessing impact and makes clear the need for data to be plotted on maps of an appropriate scale.

Box 1 Wathern's (1999) Assessment of Metapopulations
- For the species of concern, Identify critical fragmentation phenomena, such as migration, connectivity or patch distribution. - Determine scale at which fragmentation phenomenon is likely to operate for the species. - Look at the distribution data plotted on a map at an appropriate scale. - Determine the nature of change, compare with other landscapes or known critical factors from field studies or literature. - Identify remedial and mitigation measures, including habitat creation. - Establish monitoring to see what happens. - Identify any positive implications of development or change in land management.

Jones, a student of Professor Wathern's in 1996 specifically examined habitat fragmentation within the E.I.A process. She outlined a potential framework for fragmentation guidelines, which were the basis for the more comprehensive ones proposed in Chapter 9.

Box 2 shows Jones' (1996) systematic approach that again lacks the specific detail to make it any more than a rough guide. Jones believed that guidelines need to be drawn up to fully collate ecological information on an area and to fully assess the significance of fragmentation in a scientific, methodical way (Jones, 1996)

Box 2 Jones' approach to Fragmentation assessment (1996)
- Gather available Information.

- Generate original information: Phase 1, 2/3 surveys where necessary.
- Assess methods for use in assessing the impact of habitat fragmentation.

1. National Vegetation Classification (NVC)
2. Species Database
3. Species range and availability
4. Scale

- Plot Information on Maps.

Analyse fragmentation through:-

1. Connectivity
2. Patch distribution
3. Migration Paths
4. Geographical Range of Species
5. Patch Heterogeneity

- Identify remedial and mitigation measures
- Establish monitoring

Jan Kalkhoven also in 1996 explored the problem of integrating models in to the planning arena. He saw three major steps in addressing fragmentation.

1. Detection of the problem with the help of Standards and Directives.
2. Appointing the Aim or Determining the Priorities
3. Determining the rules and Directives to enable a solution appropriate to the planning situation.

(Kalkhoven, 1996)

Kalkhoven proposed the guidelines which can be seen in Box 3 known as the Landscape Archipelago Rules for the Configuration of Habitats (LARCH) model. LARCH is a computer model and contains both quantitative and qualitative expert knowledge.

Box 3 Jan Kalkhoven's (LANDECONET) LARCH Model (1996)

- Delineate the Planning Area.
- Identify the relationships between habitat quality, area and connectivity.
- Derive standards for area, connectivity, and number of patches in relation to survival probability.
- Determine Solutions.
- Assess sensitivity of species in the landscape.
- Assess the survival probability of metapopulations.
- Assess and Calculate Minimum Area Requirements.
- Assess Connectivity.
- Evaluate solutions in light of standards.

The model is interfaced with databases, GIS and Metapopulation models, such as LOGIT, WINK and METAPHOR (Kalkhoven, 1996). The model enables estimates of survival probabilities, shows spatial processes and tests a wider range of landscape situations.

LOGIT regression models are used for detecting relationships in empirical data sets and relating the species dynamics to the landscape. Its major disadvantage is that it is purely descriptive and extrapolates outside the range of values (Kalkhoven, 1996). WINK is a mechanistic model of metapopulations based on the theory shown in Chapter 5. This model is fully parameterised with field data but simplifies the extinction and colonisation rates to logistic dependence on area and connectedness (Kalkhoven, 1996)
METAPHOR, the last model, is a mechanistic individual based metapopulation model. It takes in to account the population dynamics of real species traits giving it clear biological meaning. It is however, a laborious process and has rather a large number of parameters (Verboom, 1996). LARCH incorporates all the aspects of these three models making it a highly valuable fragmentation assessment tool.

7.2 ORGANISATIONS

Several organisations provide guidance on habitat fragmentation. The work by Kalkhoven (1996) and Verboom (1996) were presented at the Connect Meeting on Biodiversity in Changing Agricultural Landscapes on the 22nd November 1996. The two ecologists were working on an EC funded project called the Landscape Ecological Network (LANDECONET). The network studies how the landscape generates biodiversity (Opdam, 1996). LANDECONET aims to develop tools which will allow planners to assess the impact of different land uses (Firbank *et al,* 1996) Their approach includes Pattern and Process studies, the development of models and making the results applicable in the planning process (Firbank *et al,* 1996).

Another European level organisation investigating fragmentation is the Co-Operation in the field of Scientific and Technical Research (COST) program 341. COST 341 researches habitat fragmentation due to transportation infrastructure. The research aims to produce a 'European Handbook on Habitat Fragmentation due to linear transportation infrastructure', indicators, recommendations and its place in E.I.A and S.I.A as well as providing an on-line database of experts, existing literature and glossaries (European Union, 2000).

In the United Kingdom guidance and research can be found with English Nature (CCW and SNH). English Natures Habitat Fragmentation Group was set up in 1992 and concentrates on the species, habitats and landscape effects in England. In 1995 they produced a very valuable report called 'Rebuilding the English Countryside: Habitat Fragmentation and Wildlife Corridors as issues in practical conservation' which is readily available from their offices (Kirby, 1995). English Nature and any of the Statutory Consultation bodies will have resources concerning fragmentation and their services are available all year round.

CHAPTER 8

THE HABITAT ASSESSMENT MODEL

The Habitat Assessment Model (H.A.M) is a model that is designed to facilitate the better understanding of habitat loss and fragmentation in the planning process. The model consists of six stages which can be either incorporated in to existing Environmental Impact Assessment (EIA) and Strategic Environmental Assessment (SEA) practices or used on its own. The process itself can be seen in Figure 9. Figure 10 shows how the model can be fitted in to these existing processes.

The Model involves a phase of Information gathering, akin to the baseline requirements of a standard EIA. The second step is a Mapping phase followed by an Assessment stage, both of which are vital to the understanding and interpretation of the impacts. The Assessment step includes models discussed in recent literature (See Chapter 5) that enable quantitative measures to be made. The Quantification Phase uses the quantitative and qualitative data to assess the significance of the impact of a development with regards to fragmentation.

The model incorporates the use of scenarios to consider any alternatives or mitigation measures, which are examined in an Options phase, which takes place after the Quantification phase. Lastly, the model has a step of Monitoring. This is designed to constantly improve the robustness and accuracy of the model.

The following Chapter (Chapter 9) looks in detail out how each step is carried out and why each component was chosen.

HAM is designed to be used by those not necessarily of a full scientific background. The model can be used in assessing and quantifying the effect of any development upon the habitat and species at the local, regional and national scale. The model tries to emphasise the balance between development and environmental protection.

FIGURE 9 The Habitat Assessment Model

INFORMATION

- **Gather Information**
  - Site Designations
  - Statutory Authorities
  - Biological Records
- **Generate Information**
  - Species Level
  - Habitat

MAPPING

ASSESSMENT

- **Species Level Models**
  - Number
  - Sensitivity
  - Neighbourhood Habitat Area
  - Connectivity
  - Rarity
  - Mobility
- **Habitat Level Models**
  - Patch Distribution

QUANTIFICATION

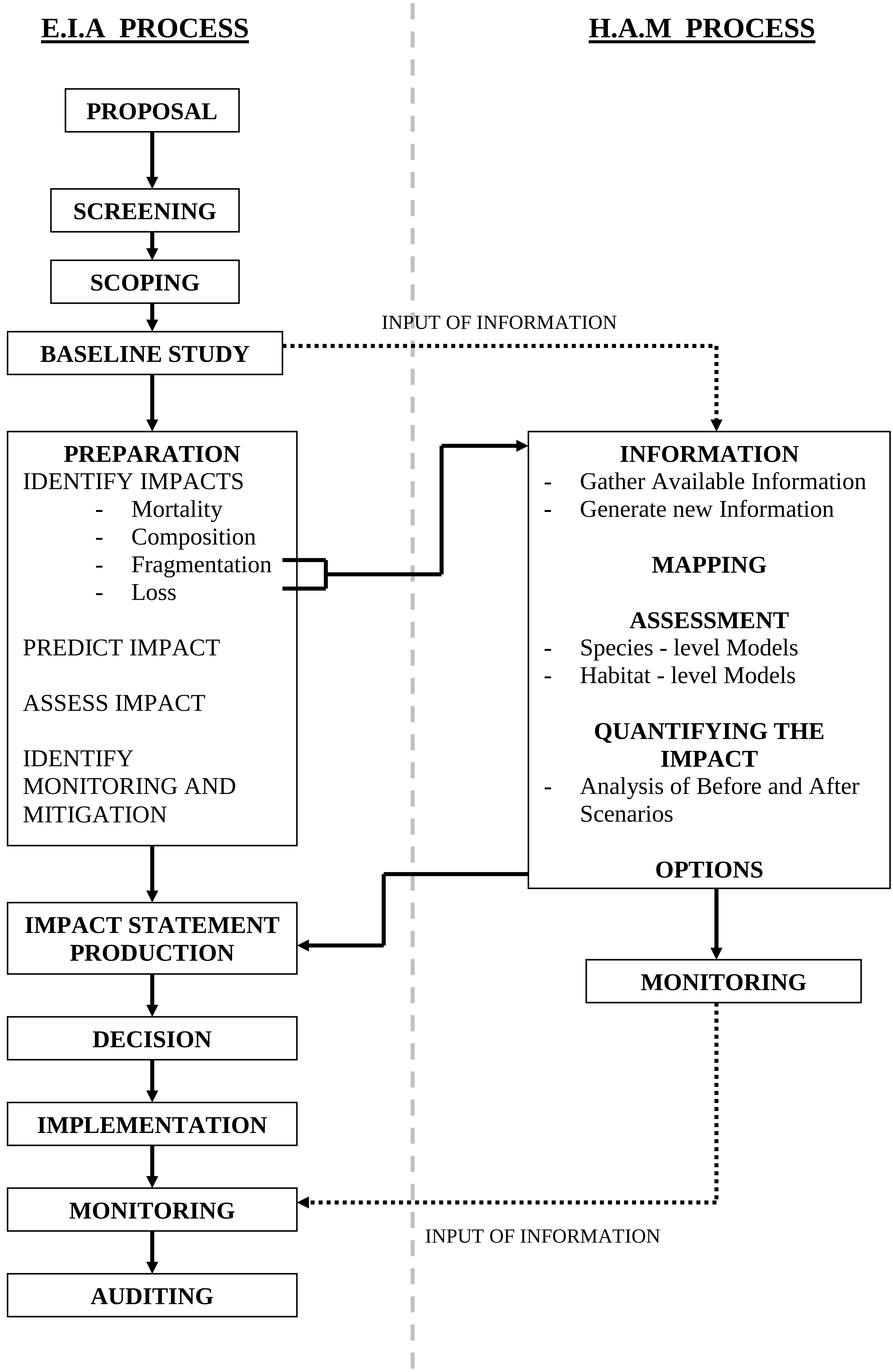
- **Interpreting**
- **Predicting**
- **Magnitude**
  - Loss/Isolation
  - Edge Effect
  - Dispersal/Connectivity effect

OPTIONS

- **Alternatives**
- **Identifying Mitigation Measures**
  - Maintenance of linkages
  - Pipes/Tunnels
  - Translocation
  - Stepping stones

MONITORING

FIGURE 10 The Place of HAM in EIA



CHAPTER 9
EXPLANATION OF THE HABITAT ASSESSMENT MODEL

9.1 THE INFORMATION PHASE

Accurate comprehensive information and data are the main stay of any assessment or subsequent decision making on a project. The gathering of information in many situations can appear overwhelming, and effective planning is required to ensure that all the information necessary is collected without duplication in the initial stages of the assessment. The HAM, like all assessments has a set of core information requirements that are essential for any analysis, these are: -

- Detailed plans and processes of the development in question.
- Map of the area. Covering an area larger than the development itself (See the Mapping Phase.
- Character of the Landscape.
- Area and composition of Habitats.
- Species presence/absence and number data.
- Site protection designations.

These six areas are a mix of both qualitative and quantitative data, the collection of this data can be competed by employing 2 stages, Gathering and Generating. This section explores these two stages.

Gathering Information

Where ever the project is in the country or no matter how obscure a species found is, someone will know something about it and in most cases will have relevant accurate data available.

The principle behind gathering information is to establish first, what data you require and secondly, what data already exists on your subject. Using other sources of information can be very cost effective and save time foe example, maps can be obtained from the County Council or Ordnance Survey without the need for you to draw your own.

The first and most important source of information is the developer themselves. They can provide you with the specifics of a project and may even have commissioned survey work before your involvement. Table 3 shows what information can be found from which organisation.
When dealing with information collected by others it is best to pay special attention to its robustness. Who collected the data? When was the data collected? How was it processed? And what methods were used? By asking these questions one can avoid circumspect data or misinterpretation of the information.

Generating Information

The process of generating information is to fill the gaps, which exist in the gathered information thus rendering the full picture. This section also includes how landscapes should be assessed and the use of metrics in Habitat analysis.

Survey Work

Conducting a baseline survey needs careful planning. There are many different techniques, which can be employed to assess the habitat or species diversity. The HAM operates by assessing the habitat primarily through the use of JNCC Phase 1 surveys with follow up National Vegetation Classification (NVC) where necessary.
At the species level each taxa or for that fact each individual species may have a specific technique applicable to it, ranging from direct counts to intuitive assessments. Below is a list of some of the different methods: -

- Plants - NVC
- Mammals - Signs/Tracking, Hair Tubes, Sherman Traps, Longworth Traps.
- Butterflies - British Butterfly Monitoring Scheme.
- Birds - Ringing, Transect/Area Direct Counts.
- Moths - Illumination Direct Counts.
- Insects - Pitfall Traps.

- Toads - Calling Males, In refugia, Night Counts, Spawn String counts.

(Beebee, 1996; Bright 1996)

Table 3 Sources of Information

Information	Organisation
Site Designations	
Legislative explanation	DETR, IEMA
SSSI's	
- Local Land Charges Register	Borough and District councils
- Statutory Nature Conservation Auths.	EN, CCW, SNH
National Parks	Countryside Commission
NNR's	EN, CCW, SNH
RAMSAR sites	"
Special Protection Areas	"
World Heritage Sites	"
Important Bird Areas	Birdlife International
Ancient Woodlands	EN, CCW, SNH
Habitats	
Biotopes	CORINE Program EC
Land Cover	EUROSTAT. Lux.
	Institute of Terrestrial Ecology
	Institute of Hydrology
	Forestry Commission
Phase 1/2/NVC	Local Planning Authorities
	EN, CCW, SNH
Species	
Distribution	Biological Records Centre
	RSNC - Wildlife Trusts
	Woodland Trust
Protected Species	DETR, IEMA, RSPB, BTO
Land Cover/Use	Ordance Survey
	Institute of Terrestrial Ecology
	EN, SNH, CCW
	MAFF

EN = English Nature, CCW = Countryside Council for Wales, SNH = Scottish Natural Heritage, MAFF = Ministry of Agriculture Food and Fisheries, IEMA = Institute for Environmental Management and Assessment.

(Smith, 1996)

One needs to assess which technique is most applicable given the situation. Any survey work requires two things, competent surveyors and careful timing. A bird survey in November will not cover breeding birds thus it may be necessary that more than one survey be needed in the course of the year. This is of course dependent on the timescale of a project and cost. In such cases where a conflict occurs, a balance should be sought.

Landscape Assessment

The specific assessment of Landscape is particularly useful in the HAM in that it allows one to generally overview the area and can highlight specific components which might be overlooked when examining habitat patches in isolation. Landscape assessment explores the spatial relationships between eco-systems (i.e. Energy, Materials, and Species) and the interactions between these spatial elements among the component eco-systems or functions (Turner, 1989).

Conducting a landscape assessment requires the quantification of landscapes, this on the whole is achieved with the use of landscape indices. Turner (1989) suggests nine possible indices.

- Relative Richness
- Relative Evenness
- Relative Patchiness
- Diversity
- Dominance
- Fractal Dimension
- Nearest Neighbour Probabilities
- Contagion
- Edges

Information on any of these indices constitute part of the picture of the structure and function of a landscape.

Bell in 1994 described a particularly useful technique for analysing landscapes. Originally designed for agricultural landscapes the four steps are an excellent template for assessment. These steps are shown in Box 4.

The end product of this stepwise approach can be presented as a series of maps or descriptions.

The use of Indices or Landscape Metrics

Indices or landscape metrics are potentially useful constructs that allow certain aspects (variables) of landscape character to be discussed in quantitative terms. They are often the basic inputs for LOGIT, WINK and METAPHOR models

Box 4	**Bells Landscape Assessment (1994)**
Step 1 - Describe the landscape structure. - Divides the landscape in to components e.g. Matrix, Patches, Corridors Step 2 - Describe flows in the landscape. - Flows are agents biotic or abiotic that traverse the landscape e.g. Fauna, Water Step 3 - Relate the flows to the different components. e.g. A bird may roost in one component hunt in another and nest in another. Step 4 - Explore Dynamics - Examine the interactions and changes e.g Disturbance factors, Succession	

(Verboom *et al,* 1996). Metrics need three aspects defined, these are Patch, Edge and Matrix (Theobald, 2000) and are usually calculated from digital maps. An index or metric must have a strong relationship between itself and the functional response it represents (Theobald, 2000) The values must be reasonably distributed across the range and discriminate between geographical distributions and amongst landscape type. The information of each index should ideally be independent (O'Neil, 1988).

There are many different landscape metrics that can be calculated, in fact Riiters *et al* (1995) used a total of 55 landscape metrics to analyse 85 maps from the US Geological Survey Land Use Data Analysis Scheme.

On the smaller scale Riitters (1995) has also outlined five major metrics: -

- Mean perimeter-area ratio
- Mean patch area
- Patch perimeter-area scaling (Fractal dimension)
- Image Texture (Contagion)
- Number of attribute classes

Verboom (1996) additionally outlines a series of measures he views as important: -

- Total amount of habitat or habitat density
- Number of patches
- Mean patch area
- Standard Deviation of patch area
- Mean inter-patch distance
- Standard Deviation of inter-patch distance.

There is considerable overlap between just the two metric schemes shown here. O'Neil (1988) developed three indices which capture all the important aspects required in just a few numbers, these three indices were: -

- Dominance Index
- Contagion Index
- Fractal Geometry

The HAM uses a set of metrics, which are designed to examine an area in relation to fragmentation. The full list can be seen in Table 4 and can be calculated from standard mapping and surveying techniques.

9.2 THE MAPPING PHASE

Mapping all the collected data is a very important part of the HAM. Mapping enables a visualisation of a project to be made and can help in identifying patterns within the landscape and data.

This section looks at what should be mapped and will explore the potential of Geographical Information Systems in habitat analysis.

There are four items that need mapping for the assessment of Habitat Fragmentation, these are: -

1. Habitat = Each Habitat within the plot area should be recorded and illustrated and described.
   = The JNCC Phase 1 survey technique with its colour and alphanumeric coding system is particularly useful in portraying habitats.
2. Species = It can be quite difficult to justify mapping highly mobile

species such as most species of bird. However there are a number of species measures that can be mapped with some accuracy: Homerange/Territory, Nest/Burrow Site and Individual stands of isolated plants.

3. Land Use =The current land use needs to be identified for each portion of land in the plot area. (E.g. Arable, Industrial, Livestock, Housing).

4. The Development = The plan and boundaries of the project in full.

TABLE 4 Metrics used in HAM

Metric	Expression
Number of Habitat Types	NH
Proportion of Habitat I of total number of Habitats	P_i
Total area of study	A
Density of Patches	DP (N/A)
Number of Patches	N
Nearest Neighbour/Patch Distribution	Rc
Connectivity	Γ_i
Neighbourhood Habitat Area	Hn
Inter-patch Distance	D_{ij}
Area of Patch I	A_i
Number of species	S
Number of individuals of species x	S_x
Species mobility factor	α
α Diversity	αD
β Diversity	βD
Dominance	D_1

Scale

Scale is a very important consideration in the Mapping Phase, too small and the information can become clouded and too large and the quantity of information becomes unwieldy. The Ordnance Survey are able to provide, at a cost, maps at almost any scale. The best scale from the point of view of readily available shop bought maps is the Pathfinder series, which is at a scale of 1:25000. This map importantly shows field boundaries and all public rights of way. Another useful map is the Definitive Map. The Definitive Map is a map that by law (Wildlife and Countryside Act 1981) has to be prepared and maintained by every County Council (Warwickshire County Council, 1993). The map can be at any scale but is more commonly found at a larger scale of 1:10000. It shows field boundaries and existing buildings far more clearly than the Pathfinder and is the legal document for rights of way (Warwickshire County Council, 1993).

How much should be mapped?

The question of quantity is particularly vital in terms of cost and time allocation for the assessment. In some cases the environment directly surrounding the development is all that is considered during an assessment, when in fact the impacts associated with the development can operate at some distance from the source.

Studies have shown that edge effects in woods can intrude up to 600m from the field edge (English Nature, 1993) and that disturbance can have an effect anything from 500m up to 1000m from a development depending upon its nature (English Nature, 1993).

On the species level work by Andren (1994) on fragmentation suggests that mammals and birds have a critical nearest neighbour distance of between 500m and 1000m. Other organisms such as invertebrates and plants are unlikely to have larger dispersion ranges than 1000m.

Using these figures as a guideline a value can be derived for determining the size of the mapping required. One should map 1000m in every direction from the perimeter of the development; this is the minimum requirement. If however there are no similar patches of those which are lost within that 1000m radius then it is necessary to increase the coverage (within reason) to include the nearest patch of that type. Figure 11 shows a flow chart that can be used to decide the map coverage required.

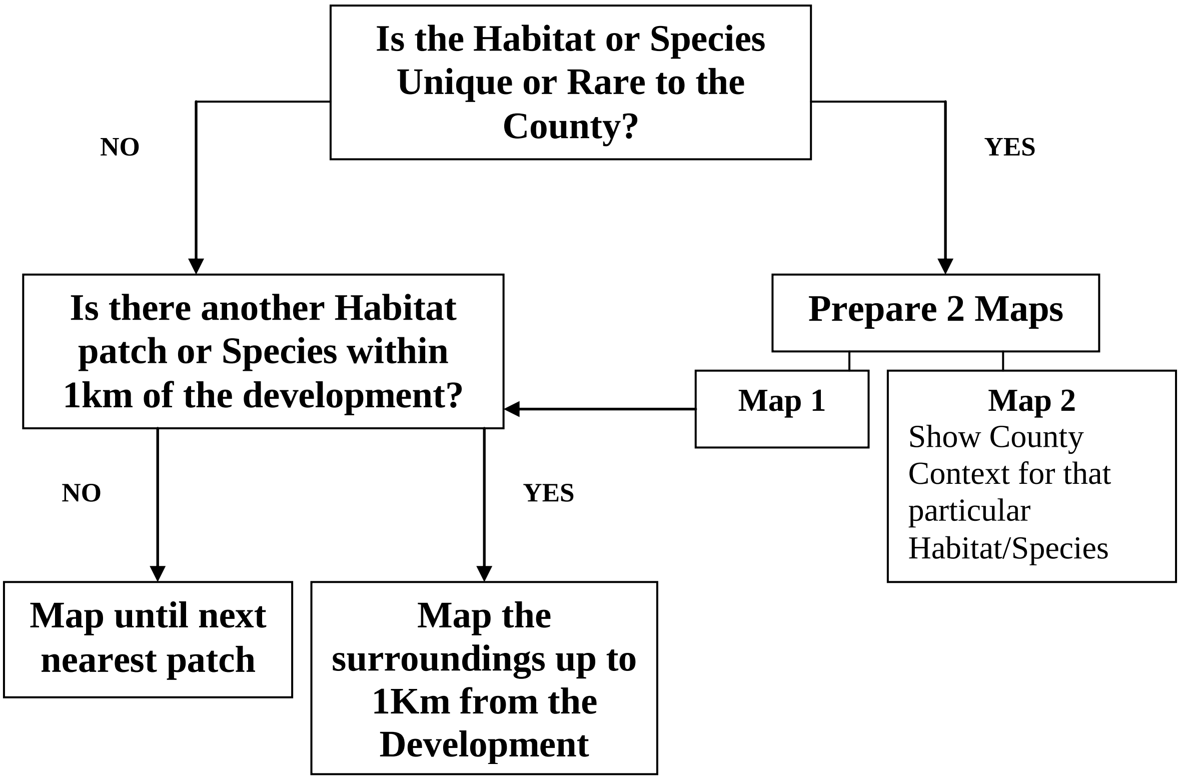
Mapping Techniques

Overlays

The four mapping variables (Habitat, Species, Land Use and Development) can be plotted on a series of separate maps on acetate which can then be overlaid to build up a picture of compounded fragmentation issues.

Overlays have been used since the 1960's, they allow multiple variables to be superimposed upon one another. The information is portrayed by shading the map according to the degree of impact, therefore high impact areas are identified by an intensification of shading (Glasson *et al* 1999). Overlays can be very useful in planning linear projects and can incorporate the consideration of alternatives. It is also easy to prepare and interpret.

Figure 11 Mapping Range Flow Chart



Rare = Less than 3 discreet populations within a county and for habitats, less than 20% coverage of the County Area

Geographical Information Systems

In recent years the technique of Overlaying has been superseded by that of Geographical Information Systems (GIS). GIS is a spatially referenced database that can enable multiple layers of data to be compiled displayed and interpreted (Firbank *et al* 1996). There is no theoretical limit to the number of layers a GIS can handle given a specifically designed programme.

GIS can be used to derive both landscape measures and conduct a variety of spatial analyses, such as area and perimeter calculations (Firbank *et al* 1996). The scale of the GIS assessment is as already alluded to, very important. It is vital that the correct map resolution and pixel size are selected. These two parameters, when employed at the species level must relate to the size and the

mobility of the species in question. For example Fry (1994) points out that at a resolution of 1 metre the scale would be too fine to study Roe Deer, whilst a resolution of 25 metres would be too coarse for insect studies.
The choice of resolution and pixel size will depend on the landscape heterogeneity. In many habitats, heterogeneity increases with resolution, this is because many characteristics can be considered in terms of fractals (Fry, 1994).

GIS requires specialised data. Habitat maps can be converted to digital map files and can be added to base maps. This creates the base for a permeability map which can be used in computer diffusion models (Fry, 1994) (See Chapter 5).

Existing GIS Systems

The programming and equipment required to conduct a GIS for a particular project can be considerably complex. There are currently exists a range of GIS models that are either specific to or can be tailored to the assessment of fragmentation. Table 5 shows what models have been developed and how they can be used.

The Use of GIS

GIS is a complex piece of software that can make fragmentation assessments quickly, accurately and very presentable. GIS allows analysis to be rapidly extended to cover areas greater than that it would be easy to do so with aerial photos or physical maps (Sparks *et al* 1994). The problem with GIS is that the models are only as good as the data available, and due to the specialist needs of the data not every region has suitably compatible resources (Firbank *et al*, 1996). Additionally GIS studies require sophisticated computers and software, and a competent operator to co-ordinate the study.

The HAM is designed to operate on the practical hands approach, whereby every step can by done by hand. However, specialist packages such as FRAGSTATS offer a level and ease of interpretation and handling that means that if GIS were available its use would be extremely beneficial to any study.

9.3 THE ASSESSMENT PHASE

Once all the available baseline information and necessary survey work has been conducted, the data needs to be assessed in order to place it in a fragmentation context.
The HAM assesses the information through two processes, one a species-level approach and the other a habitat-level approach. This section takes you through the two processes explaining each step in turn.

TABLE 5 Table showing the breadth of GIS systems available

System	Notes	
GRASS	Commercially available system	(Fry, 1994)
IDRISI	- Can calculate histograms of land cover classes. No. of Classes, Mean Patch size and Mean perimeter-area ratios - A Raster based GIS used to integrate remotely sensed data with historical data. Recently used in Fragmentation assessment of the Dorset Heathlands.	(Theobald, 2000) (Veitch *et al*, 1995)
Map II SPANS	Commercially available systems	(Fry, 1994) (Fry, 1994)
ARC/Grid ARCView ARC/Info	Same capabilities as IDRISI	(Fry, 1994) (Fry, 1994) (Fry, 1994)
FRAGSTATS	- Specialised Fragmentation tool. - Calculates metrics form ARC/Info. - Can compute Area, Patch, Edge, Shape, Core-area, Nearest Neighbour, Diversity, and Contagion. - Can use Vector or Raster formats.	(Theobald, 2000)
FRAGSTATS*ARC	- Specialised Fragmentation tool. - Builds on FRAGSTATS, but more fully integrates ARC/Info. - Only uses Vector formats.	(Theobald, 2000)
r.le	- Commercially available system - Specialised Fragmentation tool.	(Theobald, 2000)

Species-level Assessment

This process examines the area of study on a species by species basis and is composed of six steps.

STEP 1 - Establish the number of Species Present.

The result of the baseline work should render a picture of the number of species and individuals (In some cases) present at the site. From this basic image, simple assemblages can be identified such as predator- prey relations or competitive relationships.

STEP 2 - Which are protected by law or are Rare/ Endangered?

In development, developers have many legal obligations to fulfil. It is necessary to cross check the species that are on the site with their level of legal protection. The key body of legislation for species protection is the Wildlife and Countryside Act 1981. The attached HAM Database includes only species on the Wildlife and Countryside Act list and species with specific protection (e.g. Badgers Act 1991). Examining only the species with national legislation protection is the minimum requirement of HAM. However, best practice would incorporate the inclusion of all species that are listed in the Red Data List Books and take in to account regional rarities through the use of local Red Data Books, local Ecologists and County Recorders knowledge.

These rare or protected species are called Key species in the process.

STEP 3 - Assess the Sensitivity of the Key Species.

The sensitivity of an organism can vary from individual to individual as well as from species to species. There are a few guidelines, which can be used to assess which species are sensitive to fragmentation. Migratory species are at particular risk. Badgers and Amphibians are thought to be good examples of sensitive species as they have regular patterns of daily or seasonal movements (Kirby, 1995). Below are some general guidelines:

- Birds - Sensitivity is almost always directly related to the sensitivity of the habitat (Blake and Karr, 1987).
- Mammals - Considerable work has been conducted on mammals. In Box 5 one can see a list of sensitive mammals compiled by Mitchell-Jones in 1993.
- Plants - Plant sensitivity is heavily related to changes in environmental conditions (Wiggington, 1999).

- Butterflies - Butterflies have highly specific requirements for egg laying and larval development (Falk, 1994). They also have low powers of dispersal making them sensitive to any form of isolation (Falk, 1994).
- Other Invertebrates - Invertebrates are particularly sensitive to fragmentation as they have very specialised habitats. Most have annual life cycles that require suitable breeding conditions in every year. Many species have no long term resting stages so can't overcome periods of adversity. Invertebrates are cold-blooded and so require localised 'hot-spots' in all habitats. Most species are limited in dispersal and are therefore poor at colonisation or recolonistation (English Nature, 1998).
- Amphibians and Fish - These organisms are particularly sensitive to the quality and quantity of fresh water.

BOX 5 British Mammal Sensitivity to Fragmentation (Mitchell-Jones, 1993)	
Most Vulnerable	Water Shrew, Greater Horeshoe Bat, Lesser Horsehoe Bat, Whiskered Bat, Natterers Bat, Daubentons Bat, Mountain Hare, Red Squirrel, Water Vole, Dormouse, Pine Marten, Mink, Otter, Wild Cat
↓	Field Vole, Orkney Vole, Yellow-necked Mouse
↓	Serotine Bat, Noctule Bat, Pipistrelle Bat, Common Long-eared Bat, Brown Hare, Grey Squirrel. Polecat, Badger, Red Deer, Sika Deer, Fallow Deer, Roe Deer, Muntjac.
Least Vulnerable	Hedgehog, Mole, Common Shrew, Pygmy Shrew, Rabbit, Bank Vole, Wood Mouse, Harvest Mouse, House Mouse, Brown Rat, Black Rat, Fox, Stoat, Weasel

Generally speaking a species sensitivity can be characterised by: -

- Low populations (Bright, 1993)
- Low dispersal rates (Bright, 1993)
- Short Dispersal distances (Bright, 1993)
- Low Rates of intrinsic population increases (Bright, 1993)
- Vulnerability to extrinsic biotic or abiotic factors (Bright, 1993)
- Large minimum area requirements (Bright, 1993)
- Poor mobility outside the habitat (Kirby, 1995)

- Dependence on habitats which are continuous in time and space (Kirby, 1995)
- Interior preference to exterior or edge habitats (Kirby, 1995)

STEP 4 - Assign each Key species to their spatial relationship

There are four main categories of spatial relationships that organisms fit in to (Opdam, 1996). This step is designed to identify what relationship each of the key species holds.

Archipelago Species	- Species have a habitat choice that restricts them to patches. The matrix is wholly unsuitable. E.g. Woodland Plants
Mosaic Species	- Species that use the landscape as a mosaic. Their homeranges traverse several habitat types. E.g. Badgers and Sparrowhawks.
Shifting Species	- Species that utilise habitats in both the patch and matrix on a seasonal pattern. E.g. Nest in Matrix but winter in the Patch.
Matrix Species	- Species that live almost exclusively in the matrix. E.g. Arable weeds.

STEP 5 - Mapping

This stage requires that where possible one identifies and marks on a map the Critical Species Elements for each of the Key Species. This step of mapping is additional to the general maps required in the Mapping Phase.

The Critical Species Elements are: -

- For Mobile Organisms mark the extent of its Homerange or Territory. This can be derived from field studies or extrapolated from average measures, some of which can be found in the database.
- For Animals, mark the main Habitation sites, such as nests, burrows, holts, dens, setts or roosts.
- Nearest Source of freshwater particularly for aquatic and amphibious organisms.

- For Butterflies, Moths and some Invertebrates the location of larval and adult food-plants.
- For plants indicate significant stands of plants. One could also map soil types and conditions, although this is not specifically required.

STEP 6 For the Key Species Calculate Connectivity and Neighbourhood Habitat Area and Diversity.

The calculations required for these three measures quantitatively represent the organism's sensitivity to fragmentation. Box 6 shows the mathematics necessary for the three calculations and are drawn from the theory outlined in Chapter 5. Connectivity is an expression of the connectedness of the habitat for the species in question. The variable for species is the value of α. α is intended to be an expression of the mobility of an organism. The value therefore could be an index of mobility, minimum nearest neighbour (inter-patch) distance or some factor of dispersal. In most cases the calculation is not applicable to plant species due to their sedentary life strategy.

BOX 6 Calculation for Connectivity, Neighbourhood Habitat Area and Diversity

- Measure the inter-patch distances for all the patches inhabited by the species.
- Calculate Connectivity

$$\Gamma i = \Sigma \exp(-\alpha d_{ij})A_j$$

Where d_{ij} equals the distance between patch i and j; A_j is the area of patch j and α is a measure of the migration range or mobility of the species in question.

One measures the inter-patch distance between all patches in the plot and not just the nearest, this value is dij.

- Calculate Neighbourhood Habitat Area

The value of Hn is calculated by inputting the Γi value of each patch in to the following equation.

$$H_n = \frac{\Sigma (A_i^2 + A_i\Gamma_i)}{\Sigma A_I}$$

The final figure is an arbitrary unit.

(Hanski, 1999)

-Calculate Diversity

Simpson's Index measures how diverse an area. Diversity in a patch is α Diversity and matrix or between habitat diversity is β Diversity.

It is calculated thus:

$$D = 1 - \Sigma(Pi)2$$

Where Pi is the probability of picking two organisms at random that are different species.

A value of 0 = Low Diversity and a value of 1(1-1/s) = High diversity (Where s = number of species)

Whichever variable is decided upon must be used throughout the analysis for that key Species if any comparisons are to be made. The Neighbourhood Habitat Area value gives a measure of the degree to which a Habitat is fragmented for a particular species (Hanski, 1999). Diversity gives a measure of the species make up of the patch and the matrix.

The HAM Database includes suitable α values for species, some of which can be seen in Table 6. One can also find on the HAM CD an Excel Spreadsheet that is designed to automatically calculate connectivity and Neighbourhood Habitat Area and will take up to thirty inhabited patches.

TABLE 6 Some usable α Values

Species	Value	Type
Dormouse	0.061km	Homerange
Badger	0.618km	Homerange
Pine Marten	2.5km	Homerange
Otter	8km	Homerange
Bats	5-8km	Home/Foraging range
Marsh Fritillary	60m	Nearest Neighbour Distance
Great Crested Newt	500m	Nearest Neighbour Distance
Woodlark	400m	Foraging Distance

Summary

These six steps set up a baseline picture of what species are present and how sensitive they are to fragmentation in quantitative terms. In other words this picture shows the 'Do-nothing' Scenario in the decision making process. One then repeats
the steps five and 6 taking in to account the development, this yields a set of information for the 'Project' Scenario which can then be used for comparison with the 'Do-nothing' and allows any number of alternatives to be considered

Habitat- Level Assessment

The habitat-level assessment examines the type, quantity and sensitivity of the habitats found on the site.

STEP 1 - Establish the Number of habitats present.

Baseline JNCC Phase 1 surveys are generally regarded as the best form of habitat survey (Wathern, 1999). They give a good general description of what is present and target more interesting areas to be followed up with a Phase 2 NVC survey.

STEP 2 - Which habitats are protected or are Rare/Endangered?

Many of the habitat designations will overlap with the species ones as most habitat value is determined by species content. The primary piece of habitat protection is the legal designation of; Site of Special Scientific Interest (SSSI). SSSI's are enforced by section 28 of the Wildlife and Countryside Act 1981. They represent the best examples of floral, faunal, geological and physiological features. This part of the act has now been updated by the Countryside and Rights of Way Act 2000 (DETR, 2000). This act improves site protection by increasing penalties, enhanced powers to refuse consent for damage and provide a reasoned structure to compulsory land purchases.

Other specific site based designations include AONB's (Areas of Outstanding Natural Beauty), National Parks, and SPA's (Special Protection Areas) (See Chapter 7). An important piece of habitat legislation is the European Habitats Directive (Directive on the Conservation of natural habitats and wild fauna and flora 92/43/EEC). This directive and its partner UK legislation, the Conservation (Of Natural Habitats e.t.c) Regulations 1994, was designed to:

> "(ensure) biodiversity through the conservation natural habitats and of wild fauna and flora in the European Territory" (EU, 2000).

Annex 1 of the EU directive provides a list of 183 habitats that are rare and in need of protection. Of these 183, 75 occur in the UK, a full list can be found in Appendix A. All the habitats on the list constitute sensitive habitats.

The output of this step is a list of rare (regionally and nationally) habitats (Listed in Appendix A) in the development plot. As with species the bare legal requirements are only habitats with listed designations. Best practice would incorporate the assessment of all the habitat types.

STEP 3 - Assign each landscape component

For each habitat assign it a Landscape attribute. The attributes are:

- Matrix
- Patch: In the matrix
- Patch: Part of Mosaic
- Corridor for species x
- Edge Habitat
- Interior Habitat

A landscape feature can therefore have more than one attribute, for example a piece of woodland in an arable area could be: - A patch in the matrix which is an interior habitat and a corridor for the Wood Mouse.

STEP 4 Calculate the Total Area of the site and the Individual Patch Areas for each element involved.

Include Interior and Edge ratios and record patch shape.

STEP 5 Mapping

The mapping step closely mirrors that for species. The stage identifies and marks on a base map the Critical Habitat Elements.

The Critical Habitat Elements are: -

- Linkages between habitats and networks, such as a series of connected woods.
- Non- species specific Corridors e.g. hedges, connecting patches, Rivers and other linear water features.
- Ponds and bodies of standing water.
- Isolated Patches
- Sensitive habitats (See Step 2)
- For every woodland mark on its category according to Peterken (1977). Box 7 describes each category.

These elements are best placed on a base map that shows the Phase 1 description of the area in question.

Box 7	**Woodland Categories (Peterken, 1977)**
A: Relicts of Medieval wood-pasture system. Has continuity of old trees, relict assemblages of epiphytic lichens and has timber utilising invertebrates. Can often be formerly widespread in Natural Woods. Soils are not directly disturbed by man. **B:** Ancient high Forest; mainly 'native' pinewoods and Highland Birch Woods. They are not positively managed and have similar structure to A but with stronger Vascular plant associations. **C:** Ancient Coppice Woods in which the coppice stratum has not obviously been planted. They have undisturbed soil profiles and a similar structure to A and B. The coppicing alters the older tree structure but not the field layer. They have strong Vascular Plant, Bryophyte, Mollusca and Lepidoptera associations. **D:** Ancient Woods on inaccessible site such as ravines and inland/sea cliffs. None have escaped some modification by man. **E:** Woods formed by a long period of natural development. The structure and distribution of species is critical.	

STEP 6 - For the patches affected, calculate Nearest Neighbour (Distribution) and Dominance Values.

The two calculations in this step are designed to build a picture of the habitat composition in quantitative terms.

Nearest Neighbour Analysis (Patch Distribution) explores the distribution of patches in a landscape. The results can be tested for significance using a Chi-squared test. The value derived can tell you whether the patches are clumped or uniform, regular or random. This can highlight natural and man-made habitats and indicate possible management regimes. It can also help identify if the habitat is sensitive to fragmentation by assessing the degree of isolation in the landscape (Clark, 1954).

The Dominance equation is in essence a measure of the diversity of the number of patches in a given area (O'Neil, 1988). This renders a value that can help distinguish the relationships between patch and matrix landscapes with more mosaic ones. Box 8 shows the calculations necessary to derive these measures.

The HAM CD enclosed contains Excel spreadsheets set up to automatically calculate these values and will handle up to 30 patches of information.

These six steps like the ones for Species set up a baseline 'Do-nothing' Scenario of the habitats. Each step should be repeated taking in to account the proposed project and any alternatives for use in the quantifying phase.

BOX 8 Calculating Nearest Neighbour and Dominance

NEAREST NEIGHBOUR

- This measure explains distributions in a two dimensional space.
- One needs to measure the distance of its patch to its nearest neighbour of the same type.
- The values are used in the following formula:

$$R = \frac{(\Sigma r/n)}{(1/2\sqrt{\rho})}$$

- Where Σ r = Sum of measures of distance to nearest neighbour, N = Number of measurements of distance taken and ρ = the density of the observed distribution. (Clark, 1954)

DOMINANCE

- Dominance is calculated by using percentage cover data.
- The data is inputted in to the following equation:

$$D_1 = \ln n + \Sigma P_i \ln P_I$$

- Where Pi = the proportion of area on the landscape in land-use i. And n = the total number of land-use categories.

(O'Neil, 1988)

9.4 THE QUANTIFYING AND PREDICTING PHASE

The quantifying stage of the process looks specifically at what predictions can be made regarding the impact on habitat fragmentation. The stage draws data from the baseline study and calculations and assessments made in the Assessment Phase to quantify and predict any impacts.

An impact is any change in the status quo of a site or the components of the site. The impact can be positive or negative, large or small, direct or indirect. It can be cumulative, or reversible or irreversible (Smith, 1996)

In terms of species there are four aspects that need to be evaluated to deem the significance and magnitude an impact may have:

- Roles (Dominant, Key or sensitive Species)
- Amenity Value
- Conservation Status

- Rarity

For habitats there are nine aspects:

- Size
- Diversity
- Naturalness
- Rarity
- Fragility/Sensitivity
- Recorded History
- Position
- Potential Value
- Intrinsic/Aesthetic appeal

(Smith, 1996)

We shall return to the question of evaluating the impact later in this section.

Interpreting the Values gained in the calculations from the Assessment Phase

Neighbourhood Habitat Area

The value of Neighbourhood Habitat Area (Hn) represents the degree to which the site is fragmented for species x. The lower the value the greater the fragmentation (Hanski, 1999). Where calculations have been made for the 'Project' Scenario and any alternatives, the value can be expressed as a percentage change from the 'Do-nothing' Scenario.

OUTPUT: A figure representing how fragmented the area is for each of the Key Species for all scenarios.

Connectivity

The value of Connectivity is a measure of how connected a habitat is for species x. The higher the Γ_i value the more isolated or less connected that habitat for species x is (Hanski, 1999).

OUTPUT: A value representing how connected the habitat is for each of the Key Species for all scenarios. Can be expressed as a mean across all the suitable patches.

Nearest Neighbour Analysis (Patch Distribution)

Nearest Neighbour is in essence a measure of patch and habitat distribution. The distribution of a habitat can indicate a number of potentially useful items, whether the habitats are man-made or heavily managed and can identify isolated populations. Table 7 shows what each value indicates.

OUTPUT: A value indicating the distribution of the patches in the landscape.

Table 7 Nearest Neighbour Values

Value	Distribution	Indicates
0 - 0.39	Uniform	- A natural habitat or monoculture. - Matrix Nature
0.4 - 0.79	Clumped	- Natural - Patch - Possibly already under fragmentation pressure. - Sensitive to isolation
0.8 - 1.59	Random	- Natural - Patch - Potentially highly sensitive due to isolation.
1.6 - 2.2	Regular	- Man maintained. - Patch -More robust to fragmentation

(Clark, 1954)

Dominance

The Dominance value is a measure of the diversity of habitats within the study area. A high value indicates that one or a few habitats dominate the landscape, this means that the remaining patches are more susceptible to fragmentation. A small value indicates many habitat types in roughly equal proportions. This suggests that the habitats exist in a very mosaic format, such a distribution is less sensitive to fragmentation (O'Neil, 1988).

OUTPUT: A Value indicating whether there is a dominant vegetation of habitat type, this could be considered the matrix.

Diversity

A high value indicates a wide diversity of species indicating a secure habitat. The higher the diversity the greater the conservation wealth. Beta diversity increases with new patch creation in a continuous habitat as new species are found in these new patches (Andren,1994).

OUTPUT: Two values (Alpha and Beta) that represent the species diversity of the patch and matrix.

Scenarios

The HAM calculations are only fully maximised when the baseline figures a re compared with the values of the 'Project' scenario. Scenarios enable any number of alternatives to be explored and compared on even footings. They can also give a quantitative value to the degree of change as a result of a project.

Predicting the Impact

General Species Responses to Fragmentation.

Different species and taxa respond to fragmentation in different ways depending on their life strategy. There are significant differences in mean patch effects between migratory and residential species between herbivores and carnivores. There are, however, a broad range of responses that are widely applicable.

In the Assessment Phase one assigned each of the Key species to a group (Archipelago, Shifting, Mosaic, Matrix), these groups behave in different ways, a follows: -

ARCHIPELAGO SPECIES	- The percentage of occupied patches will fall. - The percentage occurrence in an average patch is reduced. - The matrix resistance increases - Interpatch- distances can increase to the point where the recolonisation probability reaches zero.
MOSAIC SPECIES	- As these species find their habitat in the mosaic any change may affect the distribution and availability of resources such as nest sites or energy budgets. - There is a distortion of energy budgets and feeding allocations. - Mosaic Species often compensate fragmentation

pressure by increasing their homerange where available.

SHIFTING SPECIES	- If the species reproduce in a patch but reside in the matrix, they become more sensitive to any fragmentation effects, especially barriers.
MATRIX SPECIES	- These species are often only affected by a trend in the landuse that directly effects the matrix habitat.

(Opdam, 1996)

Where a species is capable, it will utilise more marginal patches as more optimum ones are lost (Opdam *et al*, 1993). The decline in population size as a result of fragmentation seems to be linearly related to the proportion of original habitat lost. Once 10-30% of the habitat is lost the size and isolation of the site reinforces the population decline, accelerating it (Andren, 1994)
Nearest Neighbour distances obviously vary between species and mobility types, however, for most species the upper limit appears to be 500-1000m (English Nature, 1993)

Specific Taxa Responses

MAMMALS

Woodland mammals critically respond to fragmentation once the minimum size of a patch falls below 30 hectares. This threshold varies from species to species. Dormice actually prefer woods smaller than 20ha, but for the core woodland species 30ha is deemed the average minimum (Opdam *et al*, 1993)

BIRDS

Fragmentation changes the distribution of birds within a habitat. In woodland the probability of breeding increases rapidly with increased area (Hinsley, *et al*, 1994); for example the probability of breeding success only approaches 100% in woods larger than 10ha (Shelley *et al*, 1996).
Fragmentation significantly decreases the number of interior species whilst increasing the number of edge species (Sparks *et al*, 1994).
Disturbance is a particularly critical factor for birds, 60% of breeding waders can be lost up to 1800m from a road (English Nature, 1993) and work by Reijnen and Foppen (1994) have demonstrated similar impacts on small passerines.

Studies conducted on woodland birds (English Nature, 1995) have shown that small patches of 2-3ha do not support the core species expected, such diversity is only met at patches of 50ha's.

HERPTOREPTILES

Most amphibians and reptiles have exact habitat requirements and already reside in threatened or rare habitats, as such any fragmentation is likely to have a significant impact.

For most species the critical nearest neighbour distance is 500-1000m, if therefore fragmentation increases a patches isolation beyond that, the remaining populations are at considerable risk (Boothby *et al*, 1994).

BUTTERFLIES

Butterflies are very sensitive on the whole to fragmentation (Falk, 1994). Any change can result in almost immediate population loss (Robson, 1996). Any decline in population reduces the ability for populations to withstand any fluctuations in environmental conditions. Species that are weather dependant or have food-plants that are, are more likely to become locally extinct rather that species with wider niches (Robson, 1996).

For the same reason, species with monophagous larvae are very much at risk and depend highly on the range and distance of food-plants. Univoltine species are less likely to recover from any disturbance (Robson, 1996). Mobile species, however, may survive if they can exist as a metapopulation. Sedentary populations can be lost or become very isolated (Robson, 1996).

OTHER INVERTEBRATES

Most invertebrates have small-scale habitat requirements compared to most other organisms, that is not to say however that they are any less vulnerable. Many aquatic invertebrates are particularly sensitive to water quality and composition. Insects as a whole have a critical nearest neighbour distance of 750m.

General Habitat Responses to Fragmentation

A habitat responds in terms of the impact upon primarily the floral composition and structure of the patch.
English Nature has highlighted that non-specific disturbance factors can impact up to 500m from source, and that edge effects can be observed up to 600m (English Nature, 1993). As already mentioned the type of development will affect these figures. For example roads create disturbance up to 500-1800m. In a landscape patches begin to occur at about 40% total loss (Andren, 1994), this value indicates an important critical fragmentation level.
Fragmentation of breeding habitat only affects population survival when the average inter-patch distance is increased by 1-3 times the nearest neighbour distance. The habitat represents less than 20% of the landscape. The habitat is ephemeral. The species has high breeding site fidelity or the mortality in non-breeding areas is higher than in the breeding (Fahrig, 1998).
Below is a list of general responses according to Rolstad(1991):

- Reduced Patch Size - High extinction rate.
- Reduced Connectivity and Insularisation - Low immigration rate.
- Reduced Interior-Edge ratio - Indirect effect on mortality and production. Increased pressure from predators/competitors/parasites/disease.
- Reduced Habitat Heterogeneity in the patch - Indirect effect in reducing the carrying capacity
- Increased Habitat Heterogeneity in the matrix - Indirect effect on mortality and productivity.
- Loss of key species - indirect effect through disruption of mutualistic Guilds or food webs.

Minimum Patch Sizes

The minimum area required for a species is a very difficult value to attribute, many species have areas that incorporate many patch types. There are also different measures that could be used to define it, such as Minimum Area Requirement (MAR), Homerange, Territory and Feeding Territory.
Minimum Patch Size is not useful in all cases, Homerange is a good pointer to the amount of land an organism requires to feed and procreate possibly over a mosaic of habitats. Whereas Minimum Patch Size is a more specific measure of

a single habitat. For example a Newt can have an effective homerange of 50ha as long as at least 2ha of it is open water. Bearing this in mind it is necessary to assess which is most applicable on a case by case basis.

From the HAM database one can draw some average Minimum Patch Sizes for some taxa.

Butterflies	= Small patches of 2ha (Except *Papillo machon*)
Small Mammals	= 10ha
Bats	= 250-300ha. Over a mosaic
Carnivorous Mammals	= 10-100ha, Over a mosaic
Birds of Prey	= 500-5000ha
Small Passerines	= 1.5ha
Waders	= 35ha

Specific Habitat Responses

WOODLAND

A woods response to fragmentation will depend on its type and its management regime. Priority woodland are generally Ancient and Semi-Natural Woodlands (Peterken, 1977).

Peterken (1977) identifies five woodland types that are high priority woods and thus very sensitive to fragmentation (See Box 6). Fragmentation will increase the quantity of edge that in turn increases the interface over which pollution, noise and spray drift can affect the former interior (Kirby, 1996).

PONDS

Ponds are very valuable especially within clusters. The loss of parts of a cluster, can increase isolation and population losses especially if no other ponds exist within 500m (Boothby *et al*, 1994). The optimum pond size is 100-1000m^2 (surface area) with a depth of 1.5-2m.

With water bodies fragmentation of surrounding habitats can impact upon the pond by either altering water height or composition (English Nature, 1993).

HEATH

Heaths are a very sensitive habitat (English nature, 1993) few heaths of over 100ha in size exist in Great Britain. As such any loss of this habitat would have profound impact upon the landscape.

GRASSLANDS

Grasslands are particularly common habitat types. Species-rich grassland is the most sensitive. Responses to fragmentation depend upon the management scheme grass mix, grazing or mowing, rotation or enrichment regimes.

Representing the Information

Before the results can be inputted in to the decision phase, they should be arranged in an easily understandable format. There are several ways of demonstrating the data and the impacts. The process already includes maps. These should be clearly annotated and have an accompanying passage describing what it shows and how the map was prepared.

Where GIS systems have been used the data will be made available in a variety of formats. Again it is necessary to explain the source of the information and its relevance to the site. Other methods include Checklists, Matrices Quantitative Methods and Networks.

The HAM specifically makes use of matrices and checklists. The data can first be represented in a series of three Data Interpretation Matrices. These can be seen in Figures 12 to 15.

The first matrix (Figure 12) is an overall assessment of wider habitat or landscape issues that compares the 'Do-nothing' pre-development state with the predicted Post-development one. The second (Figure 13) explores the habitat in more detail and examines each issue on a habitat by habitat basis. The Matrix is divided in to two halves. The first half of the matrix involves the inputting of values illustrating the percentage increase or decrease from the pre-development to the post-development. The second half is a simple impact matrix where the impact is assessed on a scale of +2 to -2. A score of +2 equals a significant positive impact, -2 equals a significant negative impact and a value of zero represents no discernible impact.

The third matrix (Figure 14) follows the same structure as the habitat matrix but involves impacts on specific species.

The matrices give a visual appraisal of the impacts of a development on fragmentation issues. These matrices can be modified to incorporate different Alternative scenarios, or specific phases of a developments construction, operation and decommission.

The Questionnaire Checklist in Figure 15 is designed to focus the decision-maker on the key criteria of fragmentation and could be used as a more qualitative replacement to the Data Matrices or simply stood alongside them to highlight major concerns.

Figure 12 Habitat and wider Landscape Matrix

	Overall landscape		
	Pre- Development Scenario	Post- Development Scenario	Change
Pattern			
Dominance			
No. Habitat Types			
Mean Connectivity			
Mean Hn			
No. Species present			
Mean Patch Area			

Figure 13 Habitat Impact Matrix

	CHANGE IN							IMPACT ON				
HABITAT	**NUMBER OF PATCHES**	**MEAN PATCH AREA**	**% OF HABITAT AREA**	**MEAN Dij**	**NUMBER SPECIES**	**Species Diversity**	**NUMBER OF LINKAGES**	**RADIATION FLUX**	**WIND FLOW**	**WATER FLUX**	**DISTURBANCE**	**EDGE**
Woodland	**-3**	**-4**	**-10**	**-6**	**-10**	**-3**	**+3**	**-1**	**-1**	**-1**	**0**	**-2**
Grassland												

Figure 14 Species Impact Matrix

	VALUE					IMPACT ON							
SPECIES	**SPECIES TYPE**	**NUMBER OF INDIVIDUALS**	**SPECIES MOBILITY**	**CHANGE IN CONNECTIVITY**	**CHANGE IN FRAGMENTATION (Hn)**	**PHYSICAL**	**BEHAVIOURAL**	**PRED/PREY**	**COMMENSAL**	**MUTUALISM**	**DISTURBANCE**	**CONNECTIVITY**	**NEIGHBOURHOOD HABITAT AREA**
Dormouse	Archipelago	15	Low	-16	-33	-1	-1	0	0	0	-1	-1	-2

Figure 15 Questionnaire Checklist

Checklist of critical fragmentation parameters.

1. How big was the area studied?
2. How many patches are there?
3. Is the density of patches changed as a result of the development?
4. Are the numbers of patches reduced by 40% or more as a result of development?
5. Is the mean inter-patch distance increased as a result of the development?
6. Are mean patch sixes reduced by 40% or more as a result of the development?
7. Is α Diversity decreased by 40% as a result of the development?
8. Is β Diversity changed as a result of the development?
9. Are Nearest Neighbour Values decreased by 40% as a result of the development?
10. Is the degree of fragmentation (Hn) increased by 40% or more as a result of the development?
11. Are Connectivity values decreased by 40% or more as a result of the development?
12. Is the distribution of patches changed?
13. Is the number of different habitats decreased by 40% or more as a result of the development?
14. Are the Dominance values changed as a result of the development?
15. Are Barriers created as a result of the development?
16. Are corridors lost as a result of the development?
17. Are there rare/endangered/protected species on the site?
18. What percentage of species composition do rare/endangered/protected species comprise?

9.5 THE OPTIONS PHASE

The Options phase is designed to focus the decision-making on the optimum solution to the planning issue. The phase illustrates the need to consider Alternatives and demonstrates methods that can be employed to minimise or mitigate the impacts that arise from a chosen development.

Assessment of Alternative Scenarios

The HAM requires by necessity of analysis the consideration of two scenarios, those being the "Do nothing" or "No Action" option and the "Development" or "Project" option

Alternatives are very useful considerations, they encourage analysts to focus on the differences between real choices, and provide a forum for the justification of the specifics of the development (Glasson, 1999). Well thought out Alternatives demonstrate a conscientious approach to planning and allows un-involved people to evaluate the aspects of the project, whilst also providing a rigid framework for decision-makers (Glasson, 1999).

Alternatives are useful after the decision has been made providing a series of possible back-up plans, that can be implemented if problems arise during construction and operation (Glasson, 1999).

There are a variety of Alternatives that could be considered in a development, the main three are the aforementioned "No Action" and "Development" scenarios and thirdly the "Do the minimum required" (Glasson, 1999). The latter two ("Development"/"Do the minimum required") require that five considerations be made regarding the project or potential changes to a project, these are:

- The Location of the Project - E.g. Can the project be sited elsewhere?
- Scale - E.g. Can the project be smaller?

- Processes/Equipment - E.g. Are there different techniques or equipment that can be used?
- Site Layout - E.g. Can the arrangement of buildings be altered?
- Operating Conditions - E.g. Is it feasible to suspend operation in the breeding season?

The five considerations help ensure that all aspects or combinations of project types are assessed and accepted or discarded on merit.

For the assessment of fragmentation in HAM as already stated requires the use of the "No Action" and "Development" scenarios, but it is best practice to consider as many alternatives as are viable according to time and economics. Alternatives are best analysed and displayed in matrices where like can be compared with like (Smith, 1996)

Mitigation

Mitigation is a vital part of an assessment of a project. Mitigation is defined as any

> "measure envisaged in order to reduce and if possible remedy significant adverse effects" (Glasson, 1999).

In effect a mitigated impact is therefore no longer an impact.

In many cases a project can thus be given planning permission where major impacts have been addressed or removed.

Mitigation needs careful planning in an integrated and coherent way to ensure its effectiveness (Glasson, 1999), perhaps more vitally, however it need commitment from the developer to implement them.

In mitigating patch loss there are four factors to consider. Large patches conserve more species than small ones. The same total area will conserve more in one patch than in several small. The same total area will conserve more if the patches are close or are linked. The single patches should be compact rather than elongate (Dawson, 1994).

There are a huge array of different mitigation approaches and techniques available for use. Mitchell in 1997 proposed a hierarchy for the best practice implementation of mitigation measures this was:

- Avoid impact at source
- Reduce impact at source
- Abate impact on site
- Abate impact at receptor
- Compensate in kind
- Compensate by other means
- Enhance

When assessing mitigation measures for the HAM one should work down the viability of each of Mitchell's stages and implement those that are appropriate. Table 8 shows some of the different types of mitigation measures available for mitigating habitat fragmentation impacts. Best practice would involve the mitigation of as many direct, indirect and residual impacts as possible.

TABLE 8 Mitigation Measures

Measure	Notes	Reference
Translocation	- Least desirable. - Additional risks of isolation and disturbance. - Has been used in successfully relocating Toads and Badgers	English Nature, 1993
Habitat Creation	- Includes stepping stones - Natural regeneration is best - Limitations are that it is difficult to recreate habitats and they very rarely adequately replace.	English Nature, 1993
Buffer Creation	- Such as Fences, hedges or strips of vegetation. - Especially useful for protecting wood edges.	English Nature, 1993
Retention	- Retain as much of the natural habitat as possible.	English Nature, 1993
Enrichment/ Enhancements	- Helps improve surroundings - Strengthens linkages	English Nature, 1993
Bridges/Tunnels/ Ecoducts	- Useful for mitigation species movement problems	Van Boheman, 1998
Seasonal Timing	- Regulating action over breeding or migration periods	

Consideration during Development	- Remain sensitive to construction activities - Damp down dust zones to avoid disturbance.	

9.6 ENTRY IN TO THE ENVIRONMENTAL STATEMENT

The format of the HAM information will take will depend on the format of the Environmental Statement in to which it is to be inserted. As such, it should be flexible. If, however, a separate Fragmentation Impact Report (FIR) is required there is a defined structure that should be followed.

The FIR deals only with fragmentation issues and has at least six sections; Box 9 shows these sections.

BOX 9 **Sections required in a Fragmentation Impact Report**
1. Non-technical Summary 2. Description of Project 3. Description of Site. (Baseline Data) 4. Prediction of Impacts 5. Options (Mitigation and Alternatives) 6. Monitoring Potential

The reporting of the predicted impacts must illustrate which species and habitats are affected. The rarity of any of these components at all applicable scales and lastly the degree of fragmentation at both the landscape and species levels.

Every Impact identified needs to be described in text with accompanying maps and photos where necessary. The impacts should be where possible quantified. They should be founded on expert opinion and/or modelling.

The document as a whole should state all methods used with any assumptions made. There should be a minimum of technical jargon and all points made should be concise and specific. Lastly the report, like the EIS should be completely without bias and open to consultation.

9.7 MONITORING

Monitoring is an exercise that is not always employed in all project assessments and is yet a very valuable tool for both the assessor and the developer. Monitoring seeks to provide information on the change in the measured variables during and after a projects development. It particularly concentrates on the occurrence and magnitude of the predicted impacts (Glasson, 1999). Monitoring gives valuable feedback that can help improve the accuracy of future assessments (Smith, 1996). This is done by comparing what was predicted to happen with what actually did. Such evaluation can improve project management and provide a set of data that can be employed when mediating future decisions. It is also useful for effective Environmental Impact Auditing (Glasson, 1999)

Monitoring as a set stage in Environmental Impact Assessment is not a legal mandatory requirement (Glasson, 1999), however it must be stressed how important its role is especially in the analysis and protection from habitat fragmentation. Therefore the HAM includes a monitoring phase that in best practice should be followed.

The phase involves the measuring and recording of all the variables that arise from a developments impact. One should look for impacts that were not identified in the predictions made. The monitoring programme should be linked to a variety of factors to ensure its objectives are achieved. The programmes needs to examine the success of mitigation measures that were implemented (Smith, 1996) and be linked to some form of remedial action that can resolve any problems encountered (Smith, 1996).
Any monitoring scheme should be linked with environmental indicators (Smith, 1996), it should refer to the baseline state and impact predictions. The scheme

should also attempt to incorporate causal underlying factors, opinions and impact equity (Glasson, 1999). The monitoring approach should be stated clearly in the Environmental Impact Statement (EIS) and be given a rigid framework on which to plan where and when different schemes should be employed (Glasson, 1999). In most cases monitoring will involve a balance of short-term and long-term surveys. Each technique and method used must be justified and be published alongside any results gained.

As with mitigation there must be some level of commitment to any programme that is adopted.

9.8 THE HABITAT ASSESSMENT MODEL DATABASE

Attached to this document is a CD containing a database that can be used in the analysis process. Such a database was recommended by Jones in 1996 to compile a list of the species ecological requirements and determine the species vulnerability to fragmentation.

The database includes general habitat and distribution data for 281 species. It also includes the following items:

- Specific habitat requirements
- Minimum Area Values
- Suitable α values
- Foodplant (Larval/Adult)
- Population Size
- Spawning Grounds

The species included in the database represent the minimum legal requirement for species protection. The database includes species listed in the Wildlife and Countryside Act 1981 under schedules 1, 5 and 8.

The list also includes species on the Conservation (Natural Habitats etc) Regulations 1994 and Protection of Badgers Act 1992. Of the species on these lists some have been omitted on the HAM list for reasons of time and practicality (See Chapter 10). The database does not therefore include Cetaceans, Seals, Turtles, Mosses, Liverworts, Fungi or Lichen.

The database assigns each species a general habitat type. The category types can be seen in Table 9. The categories are an amalgam of Phase 1 and those used in the ITE Land Cover Maps (Veitch, 1995 and Riitters, 1995). For distribution, a species range is identified by a presence or absence in each of the counties shown in Figure 16.

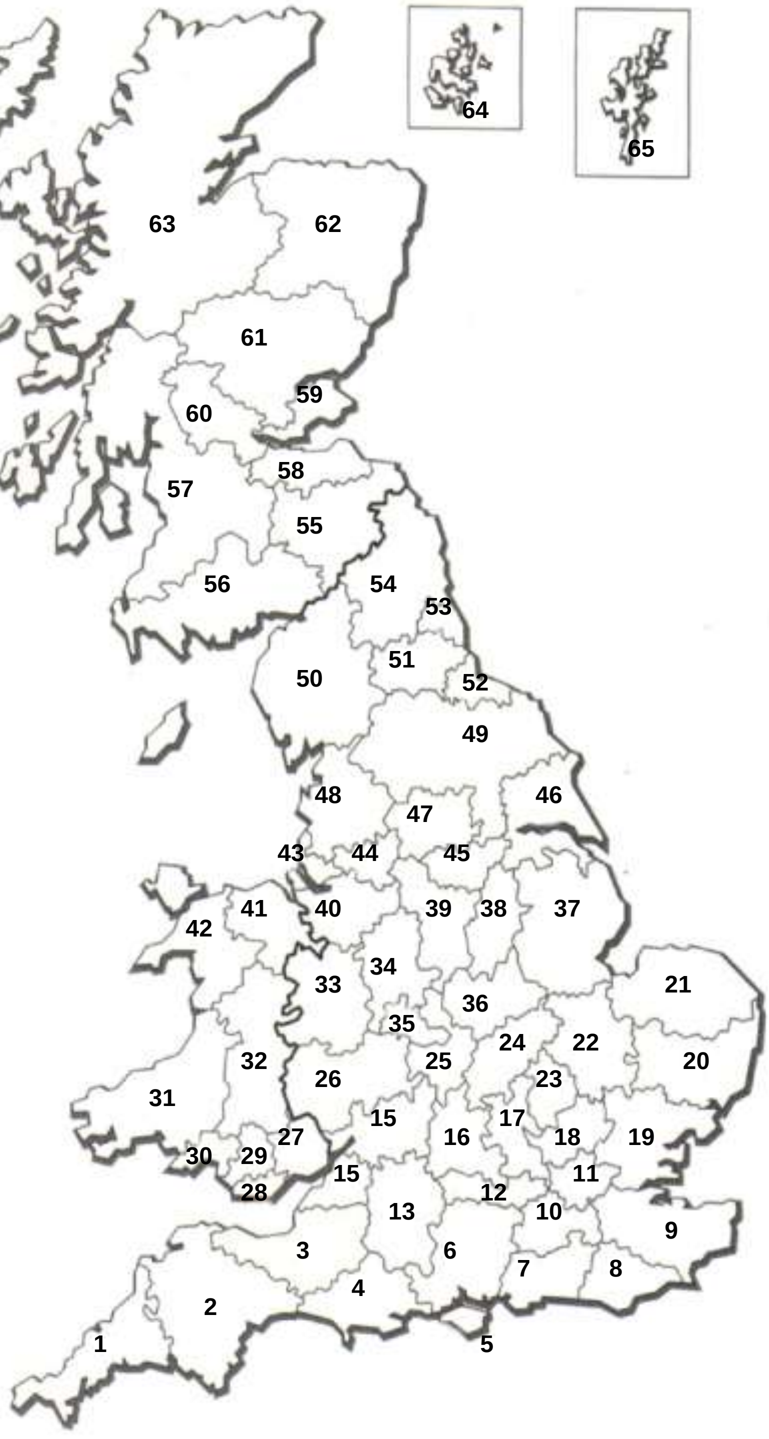
TABLE 9 Habitat Assessment Model Habitat Categories

	Habitat
1	**Mountains/Montane**
2	**Scrub**
3	**Arable Farmland**
4	**Grassland** a) Calcareous b) Acidic c) Neutral
5	**Woodland** a) Deciduous b) Coniferous c) Mixed d) Recently Felled
6	**Wetlands** a) Saltmarsh b) Marsh/Mire c) Reedbeds
7	**Water** a) Standing Water (Ponds/Lakes) b) Running Water (Rivers/Streams)
8	**Verges/Boundaries** a) Hedges b) Walls c) Margins/Verges
9	**Rock Formations** a) Bare Rock b) Chalk Formations c) Limestone Pavement d) Caves
10	**Heathland** a) Dry b) Wet
11	**Coasts** a) Estuaries b) Cliffs

	c) Sand-Dunes d) Beachflats/Intertidal zones
12	**Urban** a) Buildings b) Amenity Turf
13	**Bare Ground**
14	**Wasteland**

FIGURE 16 Habitat Assessment Model County Distribution Map

1 Cornwall
2 Devon
3 Somerset
4 Dorset
5 Isle of Wight
6 Hampshire
7 West Sussex
8 East Sussex
9 Kent
10 Surrey
11 Greater London
12 Berkshire
13 Wiltshire
14 Avon
15 Gloucestershire
16 Oxfordshire
17 Buckinghamshire
18 Hertfordshire
19 Essex
20 Suffolk
21 Norfolk
22 Cambridgeshire
23 Bedfordshire
24 Northamptonshire
25 Warwickshire
26 Hereford & Worcestershire
27 Gwent
28 South Glamorgan
29 Mid Glamorgan
30 West Glamorgan
31 Dyfed
32 Powys
33 Shropshire
34 Staffordshire
35 West Midlands
36 Leicestershire
37 Lincolnshire
38 Nottinghamshire
39 Derbyshire
40 Cheshire
41 Clwyd
42 Gwynedd
43 Merseyside
44 Greater Manchester
45 South Yorkshire
46 Humberside
47 West Yorkshire
48 Lancashire
49 North Yorkshire
50 Cumbria
51 Durham
52 Cleveland
53 Tyne & Wear
54 Northumberland
55 Borders
56 Dumfries & Galloway
57 Strathclyde
58 Lothian
59 Fife
60 Central
61 Tayside



Use of the Database

The database can be searched by Species, County or Habitat. It is intended that it can be used in a variety of roles. Firstly the database can focus baseline studies by giving lists of likely species to be found in the county or habitat in the location of a development, this can help to focus development plans at the strategic level. Secondly once a survey has been conducted the species list obtained from it can be checked against the database highlighting those with specific legal protection, and the individual habitat requirements. This last piece of information can help structure mitigation measures.

The database CD also includes a series of Excel Spreadsheets that are designed to help calculate the measures of Neighbourhood Habitat Area, Patch Distribution and Dominance. The sheets are set up to take information from 30 individual patches and only requires the inputting of the basic raw data derived from map calculations or survey work.

CHAPTER 10
CONCLUSION AND EVALUATION

The natural environment is incredibly complex, for every facet of the interactions between the abiotic and biotic resolved hundreds more are uncovered. Such is the playing field that exists. Within this unknown of ecological and landscape uncertainties developers are encouraged to adopt a sustainable approach to development to ensure that construction is tailored to the needs of the environment.

It is not possible or practical to halt development in Britain in order to safeguard the environment, nor is it practical to allow development to continue unchecked. The post war advent of planning control and subsequent EIA legislation offers a third way, a chance for co-existence.

Its arrival, however, is behind the knowledge to support it. At present the past loss of natural habitats and their fragmentation mean that it is hard to assess how ecologically things should be. For example Kirby (1995) suggests that there may no longer be any true interior species left in the UK, so how can one plan for habitat protection if the species composition has changed to such a degree. Ecologists are faced with trying to assemble a jigsaw puzzle without a picture to guide them and someone removing pieces at the same time.

In recent years the effects of fragmenting habitats have reached greater prominence, this paper illustrated the significant effects on Edges, Corridors, Communities and Landscapes, the creation of disturbance and Barriers as a result of fragmentation. All of these factors can be seen to directly and indirectly affect the populations residing in the patches in question.

The fact that fragmentation creates and effect patches is an indication of the change in landscape continuity. The matrix of the Midlands was once the great forest of Arden, today the forest only remains as scattered, isolated patches embedded in an agricultural landscape.

Ecologists have developed an array of techniques to help quantify and assess this change. It is only through hard numbers and quantitative evidence that developers and planners can be persuaded to change their approach to a more sustainable one, one that allows development not at the expense of the environment.

This paper examined six different models (See Chapter 5), each with their own merits and dismerits.

The theory of Island Biogeography is the very backbone of most landscape and biogeographical studies. It uses specialised information but is restricted by its rather narrow view. It has most importantly provided a basis for further research, from it was spawned Cellular Automata, Percolation and Metapopulation models. The problem with models is that they need to balance the detail of the inputs with their practical applicability.

Cellular Automata models are too heavily theoretical to be of practical day to day use, whilst Percolation theory has too few species variables to make it accurate. The best model needs to balance the use of species characteristics, with the availability of that information and its ease of use, one model comes close to this, the Metapopulation model. Verboom (1996) describe these models as an:

> "indispensable tool for understanding dynamics of fragmented populations"

Metapopulation theory examines the interaction of populations of populations, although it is not widely regarded, all populations exist as metapopulations at some scale, making the model widely applicable.

The Levin's Rule explores the dynamic through colonisation and extinction rates, similar to Island Biogeography, whilst the construct of Neighbourhood Habitat Area developed by Hanski (1999) provides a tool that deals with simple species and landscape variables such as inter-patch distance, mobility and connectivity. The equations for Neighbourhood Habitat Area are essentially quite simple and therefore more accessible to people without an ecological background, such a benefit enables developers to make assessments quicker and with relative accuracy.

The metapopulation model, however, is surpassed by the Incidence Function approach and if ecologists or those with specific knowledge or training were available then it is this model that is the most robust.
The model is more comprehensive and incorporates more complex species characteristics and combines them with colonisation and extinction patterns. The model has been successfully used on Glanville Fritillary metapopulations.
The major limitation of this model, however, is that due to the lack of complete knowledge on the species level much of the information needed to compose the variables aren't known.
This highlights a need for greater research in to the behaviour and responses of all species (at the least Wildlife and Countryside Act scheduled species) a mammoth task for certain.

As illustrated there is a legislative gap in UK law concerning fragmentation. At present developers are obliged to observe the protection of prescribed species and habitats. These are often treated in complete isolation with no consideration of the interactions between them.
Jones (1996) went some way to prove this with her cursory examination of Environmental Impact Statements that highlighted the under representation of fragmentation and wider ecological issues in EIA.
It would be interesting to see if this trend is borne out over a wider range of developments and a larger number of statements. With the development of Strategic Environmental Assessment there is a rising awareness in the need to plan carefully all actions well in advance. Such planning requires focus, especially when dealing with habitat protection.
This study has tried to put forward a technique and methodology for assessing the landscape in terms of its species and habitat interactions, sensitivity and composition.
The Habitat Assessment Models (HAM) greatest strength is the fact that it quickly focuses ecologically untrained developers on the real issues. It allows experienced ecologists to provide information that can be relatively easily digested by others, by breaking down the analysis in to smaller chunks. One must stress, however, that the HAM is very much an infant in terms of its development. It provides the initial framework for a best practice guide that is

based on suggestions be Jones (1996) and other models by Wathern (1999) and Kalkhoven (1996) among others. The model has been placed in the planning context, enabling its incorporation in to EIA by closely mirroring the process of Scoping, Baseline Studies, Predictions, Mitigation and Monitoring.
The model is limited by at least four factors the most important of which is that the model is still theoretical and has not been tested in a real life scenario, because of this its true practical ease of application is not known. The HAM is heavily built on theory and literature review rather than field tests, this could call in to question the applicability of some of the predictions.
The database accompanying the model is limited to only Wildlife and Countryside Act list organisms which are the minimum obliged requirement, it would be much more valuable to cover all Red Data Book List organisms.
Lastly, despite the introduction of several statistical techniques a lot of the predictions are qualitative in nature.

So what needs to be done? Well, the model requires considerable further development. The Database needs expanding and refining, it needs greater species information which is unfortunately restricted by the pace of current research.
Most importantly the model needs rigorous field-testing and application in real scenarios. This means that predictions can be checked and through that the process can be improved. In addition to this, all drafts of the model should be allowed to gain feedback through consultation with researchers and Statutory Conservation Authorities. This should broaden the skill base working on the model allowing experts in each field to contribute or comment.
A key consideration that needs to be addressed in any further expansion of this model, is the greater incorporation of Geographical Information Systems in to the methodology.

Habitat Fragmentation and Habitat Loss are real problems that face all nations but especially ones such as the UK who have a small land mass and a ravenous desire for development. Action at the local and national level is needed to control then degree to which, this necessary development is allowed to impact upon the landscape. Only through the work of Statutory Authorities and Conservation groups in co-operation with the government can this realistically be achieved. Models such as HAM provide the tools or weapons necessary for the fight but it is the need for committed people to wield them that is really necessary.

CHAPTER 11
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CHAPTER 12

APPENDICES

Appendix A

List of sensitive habitats in the UK listed in the Conservation (Natural Habitats e.t.c) Regulations 1994

Coastal and Halophytic Habitats
- Sandbanks (With partial seawater coverage)
- Estuaries
- Mudflats/Sandflats not covered at low tide
- Lagoons
- Large shallow inlets and bays
- Reefs
- Annual vegetation of drift lines
- Perennial vegetation of stony banks
- Vegetated sea cliffs of Atlantic/Baltic coasts
- *Salicornia* and other annuals colonising mud/sand
- *Spartina* swards
- Atlantic salt meadows
- Continental salt meadows
- Mediterranean salt meadows
- Mediterranean and thermo-atlantic halophilous scrubs

Coastal Sand Dunes and Continental Dunes
- Embryonic shifting dunes
- Shifting dunes along shoreline with *Ammophila arenaria*
- Fixed Dunes with herbaceous vegetation
- Decalcified fixed dunes with *Empetrum nigrum*
- Eu-Atlantic decalcifed fixed dunes
- Dunes with *Salix arenaria*
- Humid Dune Slacks
- Machair
- Dune Juniper thickets
- Open grassland with C*oryenephorus* and *Agrostis* of continental dunes

Freshwater Habitats
- Oligotrophic Waters with few minerals of Atlantic sandy plains with amphibious vegetation
- Oligotrophic water in medio-European and perialpine areas with amphibious vegetation, or annual vegetation on exposed banks
- Hard oligo-mesotrophic water with benthic vegetation of *Chara* formations
- Natural eutrophic lakes with *Magnopotamion* or *Hydrocharition*-type vegetation
- Dystrophic lakes
- Mediterranean Temporary Ponds
- Floating vegetation of *Rannunculus* of plain and sub-mountainous rivers

Temperate Heath and Scrub
- Northern Atlantic wet heaths with *Erica tetralix*

- Southern Atlantic wet heaths with *Erica ciliaris* and *Erica tetralix*
- Dry Heaths
- Alpine and sub-alpine heaths
- Sub-Arctic Willow scrub

Sclerophyllous Scrub (Matorral)
- Stable *Buxus sempervirens* formations on calcareous rock slopes
- *Juniperus communis* formations on heaths or calcareous grasslands

Natural and semi-natural grassland formations
- Calaminarian grasslands
- Siliceous alpine and boreal grassland
- Alpine calcareous grasslands
- Semi-natural dry grasslands and scrubland facies on calcareous substrates
- Species-rich *Nardus* grasslands, on siliceous in mountain areas.
- Molinia meadows on Chalk and Clay
- Eutrophic tall herbs
- Lowland hay meadows
- Mountain hay meadows

Raised Bogs and mires and fens
- Active raised bogs
- Degraded raised bogs
- Blanket bogs
- Transition mires and quaking bogs
- Depressions on peat substrates
- Calcareous fens with *Cladium mariscus* and *Carex davalliana*
- Petrifying springs with tufa formation
- Alkaline fens
- Alpine pioneer formations of *Caricion bicoloris-atrfuscae*

Rocky Habitats
- Siliceous scree
- Eutric scree
- Chasmophytic vegetation on rocky slopes - Calcareous sub-types
- Chasmophytic vegetation on rocky slopes - Silicicolous sub-types
- Limestone pavements
- Submerged or partly submerged sea caves

Forests
- Beech forests with *Ilex* and *Taxus*, rich in epiphytes
- *Asperulo-Fagetum* beech forests
- *Stellario-Carpinetum* oak-hornbeam forests
- *Tilio-Acerion* ravine forests
- Old Acidophilous oak woods with *Quercus robur* on sandy plains
- Old oak woods *Ilex* and *Blechnum*
- Caledonian forest
- Bog woodland
- Residual alluvial forests
- *Taxus baccata* woods

APPENDIX B
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APPENDIX C

WORKED EXAMPLE OF THE HABITAT ASSESSMENT MODEL

THE SCENARIO

A local housing contractor wants to build 100 houses on the outskirts of the village of Ufton. The landowner that owns the land Southwest of Ufton is willing to sell his land. He wants, however, to avoid losing any Arable or Grassland if possible.

The Developer wishes to causes as little ecological damage as possible. They plan to build on most of Feldon Wood, aiming to incorporate some of the older trees in to their development.

The developer uses the Habitat Assessment Model to assess the impacts possible from the Development.

1. The Information Phase.

Gathering:
- The Arable land is of little ecological value
- Feldon Wood (W3) was surveyed 2 years ago and found to contain a small population of Dormice.
- The nearest other population of Dormice was in a larger wood to the west, which has been recently felled.
- The site contains a cluster of 5 ponds, some of which contain Greater Crested Newts.
- Ufton Wood to the North is a Local Nature Reserve and SSSI owned and maintained by the local Wildlife Trust

Generating:
- Landscape: The landscape is flat. The area was formerly ancient forest, which is now very heavily fragmented. The fields are a mix of Arable and Grassland, grazed by sheep. The field size is generally small with species-poor hedge and fence boundaries.
- A JNCC Phase 1 survey was conducted (See Map 1
- Summary of Species Survey

Wood 1	Small Population of Dormice and *Argynnis adippe*. Woodland is predominantly Oak and Hazel.
Wood 2	Very small Deciduous Woodland. Badger Sett with a clan estimated at 20 individuals.
Wood 3	Large Population of Dormice, most of whom colonised from the felled wood. Signs of Muntjac and Roe Deer.

Wood 4	Small remnant patch
Pond 1	Population of 26 Greater Crested Newts. A pair of Kingfishers nesting in bank.
Pond 2	Very few species, possible pesticide contamination.
Pond 3	Small number (less than five) of Greater Crested Newts.
Pond 4	Small number (less than five) of Greater Crested Newts.
Pond 5	Small number (less than five) of Greater Crested Newts.
Pond 6	Small number (less than five) of Greater Crested Newts.
Pond 7	Small number (less than five) of Greater Crested Newts.
Pond 8	Recently well stocked fish pond
Pond 9	Recently well stocked fish pond
Pond 10	Recently well stocked fish pond

2. The Mapping Phase

See Map 1 showing study plot, Phase 1 and development.

3. The Assessment Phase

Species Assessment:

- Key Species present on the development site - Dormice, Kingfisher, Greater Crested Newt.
- Rare/Protected ones are - Dormouse, Kingfisher and Great-Crested Newt. Under the Wildlife and Countryside Act 1981 and Conservation (Natural Habitats e.t.c) Regulations 1994.
- Sensitivity and Habitat Requirements-

Dormouse:-	Dormice are very sensitive to disturbance and fragmentation Year-round - Ancient semi-natural woods. Species diverse shrub layer, Coppice of 12-20 years old. Dense regrowth. Hazel and Oak woodlands with honeysuckle for summer nests
Kingfisher:-	Highly sensitive to clean water and breeding sites. Year-round - Slow-moving lowland rivers, lakes and ponds with overhanging trees. Breeding - 1-2m tall banks
Great-Crested Newt:-	Year-round - Poolsize 50-100cm deep with and area of +100m2. Prefers submergeed vegetation,

no fish, still water. Peripheral
layer of trees and scrub around
the water often close to woodland.
Highly sensitive to fragmentation
of pond clusters and changes in
water quality.

- Mapping
  See Map 2 showing location of the Kingfisher burrow and possible corridors for the Dormouse.

- Calculations of Connectivity and Neighbourhood Habitat Area
  Results shown in the Predicting phase.

Habitat Assessment:

- Habitat types present in the development plot are Semi-Natural Woodland, Semi-Improved Grassland, Unimproved Grassland, Arable and Standing Water.

- The Woodland is rare on the county level. Ufton Wood is a SSSI and LNR but there are no protected sites in the development plot.

- Landscape Components: The matrix of the area is agricultural comprised of a mosaic of Arable and grassland. The woods exist as patches in the matrix as do the ponds.

- Total Area of Study = 5.32km^2
  Individual Patch Areas:

	Km^2
Wood 1	0.8
Wood 2	0.02
Wood 3	0.26
Wood 4	0.005
Pond 1	0.005
Pond 2	0.018
Pond 3	0.005
Pond 4	0.002
Pond 5	0.006
Pond 6	0.006
Pond 7	0.025
Pond 8	0.004
Pond 9	0.006
Pond 10	0.006

- Mapping
  See Map 3 showing Critical Habitat Categories, Wood Categories, Ponds and Isolated Patches.

- Calculation of Nearest Neighbour and Dominance
  Results shown in predicting phase.

4 Quantifying and Predicting

Results from Calculations: -

	No-Action Scenario	Development Scenario	Percentage Change	Result
Dominance	0.23	0.53	+56	Landscape fairly dominated by one feature.
Woodland				
Patch Density	0.75	0.75	0	No Change
Inter-patch distance	0.58	0.58	0	No Change
Nearest Neighbour Value	0.61	0.61	0	Clumped Distribution
Pond				
Patch Density	1.88	0.94	-50	Decreased
Inter-patch distance	0.36	0.52	+48	Distance increased by 48%
Nearest Neighbour Value	0.44	0.59	+25	More clumped distribution.
Dormouse				
Fragmentation	0.93	0.81	-13	Small increase in fragmentation
Connectivity	2.36	2.53	+6	Small increase in isolation of remaining patches
Greater Crested Newt				
Fragmentation	0.05	0.01	-80	Significant fragmentation
Connectivity	0.38	0.09	-76	Less isolation in remaining patches
Kingfisher				
Fragmentation	0.04	0.01	-75	Significant fragmentation
Connectivity	0.29	0.06	-79	Less isolation in remaining patches

Species Responses

All the Key species are Archipelago species and so will respond in the following way:

- The Percentage of occupied patches will fall
- Matrix resistance will increase
- Inter-patch distances become critical factors and increase to the point where recolonisation probabilities reach zero.

Dormouse - The Dormice would be severely affected by any substantial decrease in wood size. The increased population size from the felled wood means that a greater importance is rested on the woods survival. The remnant patch is the preferred optimum size for dormice but is too small to support the whole population currently existing in the wood. The nearest suitable habitat for emigration is Ufton Wood (W1) the matrix in between is essentially hostile. There are several suitable corridor hedges linking W3 and W1, this network however, is broken by a road that constitutes an impenetrable barrier.

Kingfisher - Kingfishers are sensitive to disturbance especially around the breeding period. None of the other ponds have banks high enough for Kingfishers to nest in, therefore the development will render the area unsuitable for Kingfishers breeding.

Great- Crested Newt - The Loss of Ponds 1, 3, 4, 5 and 7 will result in the loss of approximately 50 individuals. Pond 2 is within recolonisation range for Newts, however the road constitutes a significant barrier and the pool is too small for all colonists and of insufficient quality. Ponds 8-10 are a long distance, which would lower the effectiveness of any emigration. The ponds are also stocked by fish that reduce their suitability for Newts.

The development will result in significant loss and impact upon all three key species.

Habitat Responses

General response to Pond and Woodland loss and fragmentation: -

- Increased extinction Rate
- Lower immigration rates
- Reduced Interior-edge ratio
- Increased pressure from Predators, Competitors, Disease, and Parasites.
- Reduction in Carrying Capacity
- Increase in mortality probabilities
- Disruption of food webs and mutualistic guild relationships

Woodland - W3 is Ancient Coppice woodland the reduction in size will increase the Interior-edge ratio so much that the interior composition will be potentially significantly affected.

Ponds - Ponds are most valuable in clusters, with individuals spaced between 500 metres. The loss of ponds as a result of the development disrupts the largest cluster in the region

<u>Questionnaire Checklist of Impacts.</u>

1. **How big was the area studied?**
   5.28km^2

2. **How many patches are there?**

Woodland -	4
Ponds -	10
Arable -	36
Semi-Improved Grassland -	19
Unimproved Grassland -	21
Improved Grassland -	2

3. **Is the density of patches changed as a result of the development?**
   Woodland - No
   Ponds - Yes it is reduced by 50%

4. **Are the numbers of patches reduced by 40% or more as a result of development?**
   Woodland - No
   Ponds - Yes, by 50%

5. **Is the mean inter-patch distance increased as a result of the development?**
   Woodland - No
   Ponds - Yes, They are increased by 25%

6. **Are mean patch sizes reduced by 40% or more as a result of the development?**
   Woodland - No
   Pond - No

7. **Are Nearest Neighbour Values decreased by 40% as a result of the development?**
   Woodland - No
   Pond - No (Increased by 25%)

8. **Is the degree of fragmentation (Hn) increased by 40% or more as a result of the development?**
   Woodland - No
   Pond - Yes, by 80%

9. **Are Connectivity values decreased by 40% or more as a result of the development?**
   Woodland - No
   Pond - No

10. Is the distribution of patches changed?

Woodland - No

Pond - Yes, 25% more clumped

11. Is the number of different habitats decreased by 40% or more as a result of the development?

No

12. Are the Dominance values changed as a result of the development?

Yes, By 50%

13. Are Barriers created as a result of the development?

No

14. Are corridors lost as a result of the development?

No

15. Are there rare/endangered/protected species on the site?

Yes, Dormouse, Kingfisher and Great-Crested Newt

16. Are there rare/endangered/protected habitats on the site?

No

<u>Evaluation of the Project</u>

The assessment of the developments impacts highlights that there are some significant fragmentation and loss effects.

The loss of the woodland affects the local Dormouse population, which would be confined to an unviably small remnant patch in a hostile matrix with no corridors for dispersal.

The development would destroy several ponds that are important in the local area. Their loss would result in the displacement of several Great Crested Newt populations, there is another pond within emigration distance already containing Newt populations, therefore immigrants from the lost ponds would substantially effect the carrying capacity of the pond. The development would also disturb the nesting Kingfishers who are nesting in the only suitable site within the study plot.

Mitigation

1. Enrich the hedges between wood 3 and 1 and provide a rope bridge across the road to facilitate Dormouse dispersal.
2. Relocate Great Crested Newts to new ponds outside the study plot
3. Do not begin the development construction until after the Kingfishers young have fledged and left the burrow.
4. Retain some of the ponds and work them in to the development
5. Protect more trees in the development

Even given these mitigation measures the Developer decides to consider an alternative. They look at relocating the development the develop slightly to the north where only a very small portion of the wood would be lost and all the ponds would be untouched (See Map 4).
This alternative builds on Arable and Semi-Improved Grassland, which would cost more to purchase from the Landowner, however it significantly reduces the impact.
By conducting an assessment on the Alternative a comparison can be made between the two plans.

	No-Action Scenario	Development Scenario	% Change	Alternative Scenario	% Change	Result
Dominance	0.23	0.53	+56	0.46	+23	Alternative is 33% less disruptive
Woodland						
Patch Density	0.75	0.75	0	0.75	0	No Difference
Inter-patch distance	0.58	0.58	0	0.58	0	No Difference
Nearest Neighbour Value	0.61	0.61	0	0.66	8	Alternative increases clumping
Pond						
Patch Density	1.88	0.94	-50	1.88	0	No Difference
Inter-patch distance	0.36	0.52	+48	0.36	0	No Difference
Nearest Neighbour Value	0.44	0.59	+25	0.44	0	No Difference
Dormouse						
Fragmentation	0.93	0.81	-13	0.89	-4	Alternative has smaller impact on fragmentation
Connectivity	2.36	2.53	+6	3.01	+22	Alternative increases isolation of the population
Greater Crested Newt						
Fragmentation	0.05	0.01	-80	0.05	0	No Difference
Connectivity	0.38	0.09	-76	0.38	0	No Difference
Kingfisher						
Fragmentation	0.04	0.01	-75	0.04	0	No Difference
Connectivity	0.29	0.06	-79	0.29	0	No Difference

This alternative removes the fragmentation impact on the ponds, Kingfishers and Great Crested Newts. The Alternative retains a larger piece of woodland for Dormice survival although increases their isolation with the creation of a greater barrier between Wood 3's nearest neighbour, Wood 1, and the loss of some of the hedges that act as corridors for dormouse dispersal.

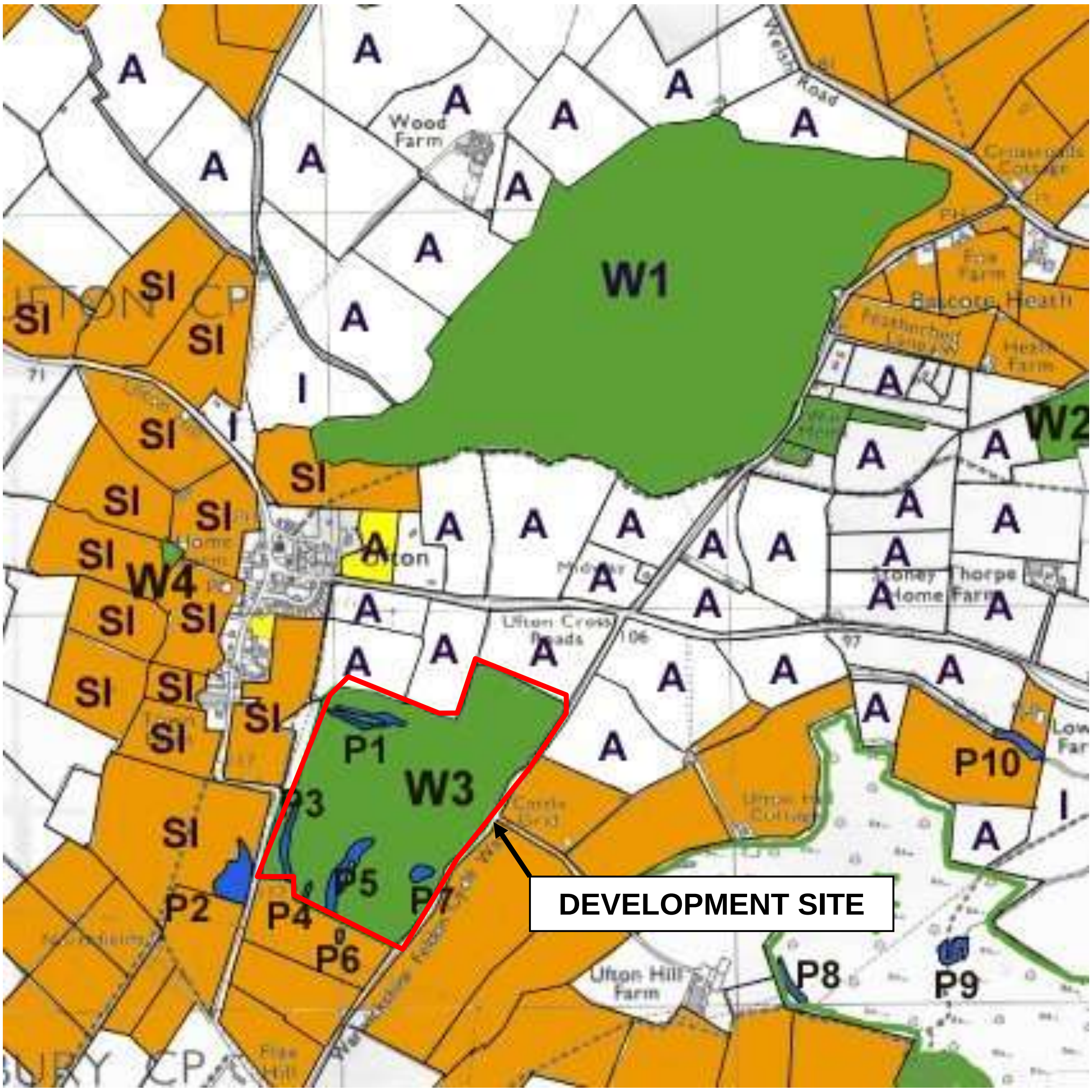
These impacts can be mitigated by: -

1. Retaining as much of the hedgerows and providing a rope bridge across the road
2. Restricting development to outside the breeding season of the Kingfisher to avoid disturbance.

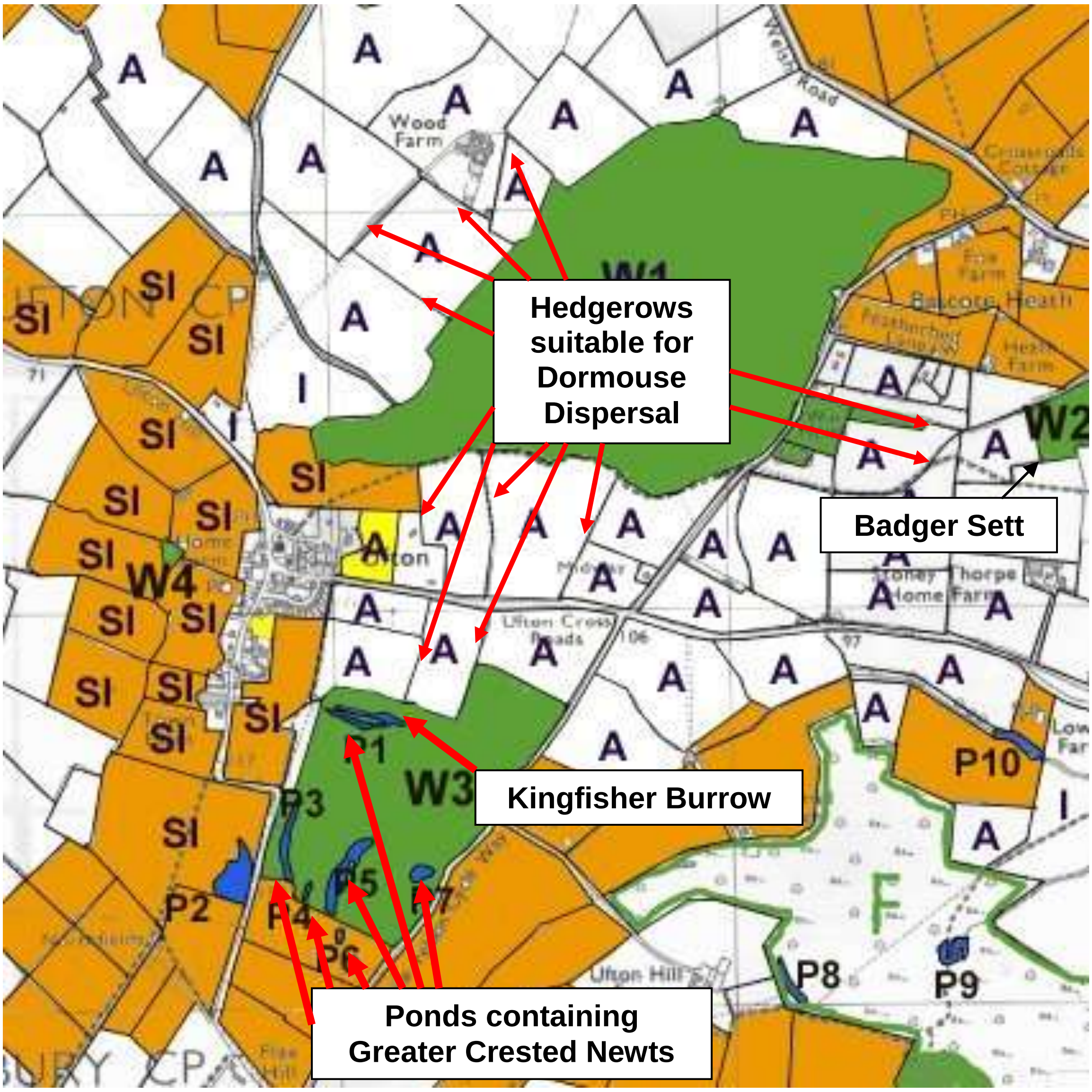
Conclusion

The Habitat Assessment Model in this situation has enabled the developer to realise that the original development plan had significant impact upon the natural environment. The consideration and assessment of the Alternative provides a way in which the development can proceed with fewer fragmentation effects.
It is up to the decision-makers to make the final decision but the model has allowed a more environmentally viable alternative to be considered and highlighted the possible implications of the original development plan. This kind of assessment encourages developers to consider environmental and fragmentation effects in the initial stages of planning, facilitating a more conscientious and sustainable approach to land use allocation.

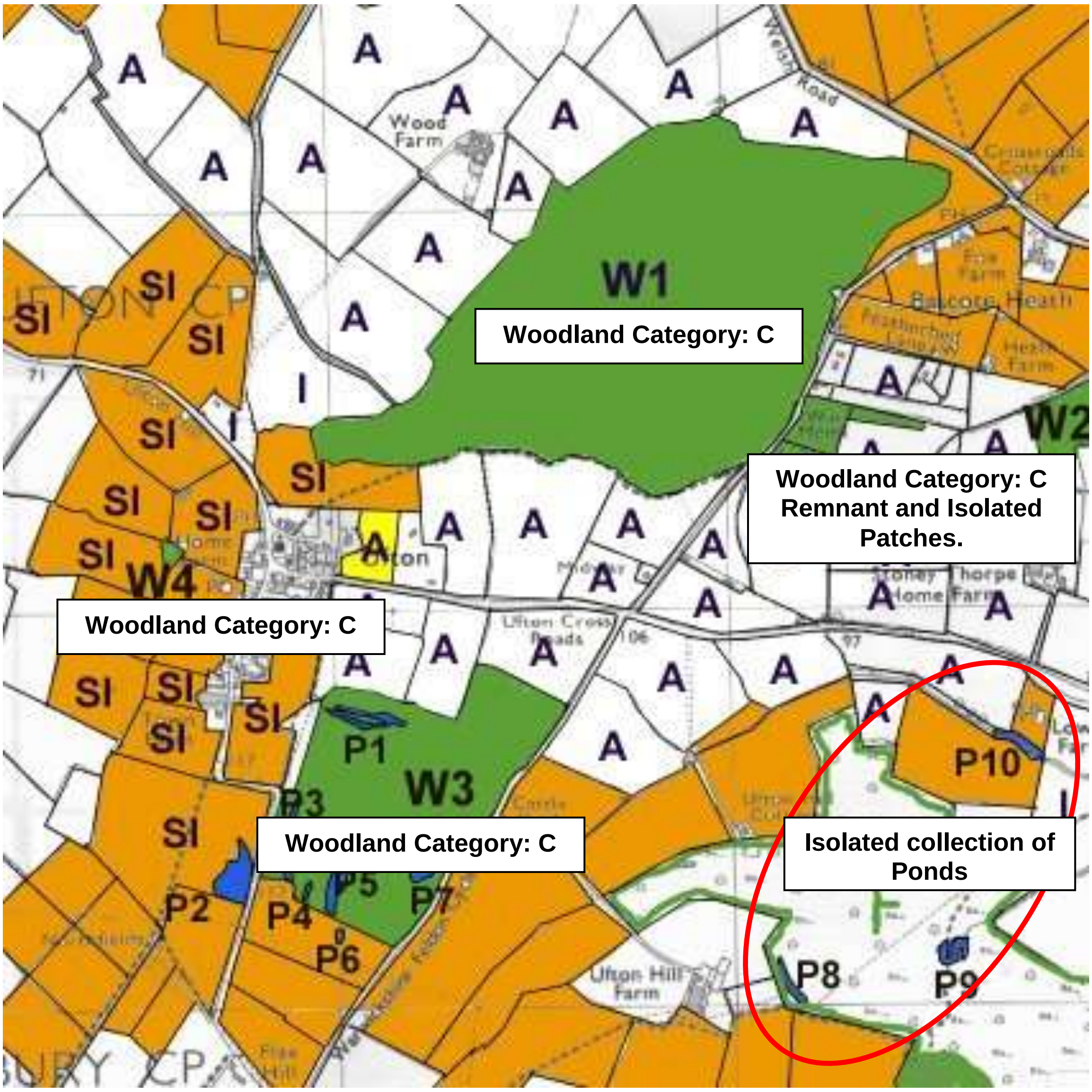
MAP 1 Boundary of the proposed Development and the Habitat of the surrounding area



MAP 2 Illustration of Critical Habitat and Species Elements



MAP 3 Illustration of Woodland Categories, Ponds and Isolated Patches



MAP 4 Illustration of a possible Alternative Site for the proposed development.