HIGHWAYS: THE ECOLOGICAL RESOURCE NET

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1. INTRODUCTION AND BACKGROUND

In March 1999, Halcrow Group Ltd (Halcrow) was appointed by the Highways Agency to lead the 'Managing Integration Commission' for their Traffic Safety and Environment Division. There were fourteen sub-projects within the overall commission including sub-project DE4 'Community, Landscape and Habitat Fragmentation' (abbreviated to 'Minimising Fragmentation'). The aim of this sub-project was to assist the Highways Agency in gaining a greater understanding of that fragmentation and severance which may be inherent to its network and to examine the potential to overcome or reduce such impacts, thereby achieving greater integration of the Agency's responsibilities to transport and the environment.

The work upon which this paper is based formed a part of the 'minimising fragmentation' sub-project and addressed issues relating to ecological fragmentation and severance in relation to the trunk road network. The present paper seeks to present some of the practical conclusions of that project (see Halcrow July 2001) and to raise the profile of two issues which arose from the study. These are firstly that a vast amount of scientific data and speculation is now gathering regarding the positive and negative effects that the transportation network has upon wildlife and secondly, and as a result of this, that a nomenclature is now needed under which this data can be stored, augmented and considered.

It may be accepted intuitively that road networks fragment habitats. The division of areas of landscape by engineered surfaces utilised by moving traffic will inevitably have some effect on wildlife and some of these impacts are well documented (see Ecological Impacts of Highways Relating to Habitat Fragmentation - Below). This raises the need to develop objective protocols for assessing the significance of habitat fragmentation due to transportation infrastructure and the first part of this paper examines this issue and provides some early steps towards developing this theme. Leading on from this, the wealth of information regarding the ecology of highways is briefly examined in support of the case for recognition of a transport-derived habitat category.

Approximately 380,000 km of tarmacked roads traverse the British Countryside (see Beebee 2001), linking, dividing and anastomosing to form a complex reticulum. Each road corridor encompasses its central reservations, verges, planting areas and hedges which collectively form the 'soft estate'. For the English trunk road and motorway network alone, this currently represents approximately 30,000 hectares of land, supporting a wide range of habitats (see Highways Agency 2002). In 1999/2000, the Highways Agency carried out an audit of the existing biodiversity on the soft estate, and published the information in the Stage 1 Report (Cresswell Associates 2000). The report identified that about 40% of priority habitats and 53% of priority species identified in the UK Biodiversity Action Plan are known, or are likely to occur in the soft estate (Highways Agency 2002). However this is viewed, it is clear that the 'soft estate' is not merely an ecological residue pushed to the edge of a functional transport system, it is a significant biodiversity resource.

Objective knowledge of the ecology of road margins is increasing rapidly. The fact that road verges have a value to wildlife is not a new perception (e.g. see Dowdeswell 1987) and the view that the ecology of the 'soft estate' network has a recognisable and definable reality comparable to the complex habitat mosaic of a well-managed heathland is supported by the Highways Agency's audit and many other examples in the literature, some of which are discussed below. It may be argued that the exigencies of highway management, mowing, earthmoving, planting and drainage have acted over time to create an anthropogenic vegetation climax which has become refuge, foraging area and habitat to a wide range of animal and plant species, including many of those entities displaced from bordering agricultural and urban land.

It is important to the understanding of the significance of this concept that an appreciation is gained of the ambiguous role road networks may play in the fragmentation, severance, linking and provision of habitats. For this reason the significance of transportation infrastructure with regard to these phenomena is discussed below. As data accrues however regarding the ecological effects of roads and the ecology of their attendant soft-estate, the need for a habitat nomenclature under which such information can be stored, and under which research can be carried out, is growing and a suitable taxon is subsequently proposed.

2. DEFINITIONS OF USE IN ASSESSING THE ECOLOGICAL IMPACTS OF LINEAR INFRASTRUCTURE

If an objective understanding of the significance of habitat fragmentation due to linear transportation infrastructure is to be gained, a number of terms must be clearly defined. The definitions below are offered as simple, workable and appropriate options with regard to the issues under consideration.

2.1 Ecological Severance and Habitat Fragmentation

Fragmentation occurs when a large expanse of habitat is transformed into a number of smaller patches of smaller total area, isolated from each other by a matrix of habitats unlike the original (Wilcove *et alia* 1986). In summary, fragmentation is understood to mean: the break-up of ecosystems and/or habitats of plant and animal populations into smaller, more isolated units (Rijkswaterstaat, 1997). There is a decline in the aggregate area of habitat suitable for species and an increase in the distance between the remaining habitats. Ultimately, fewer species will be able to survive in the remaining fragments (Bekker 1998). Despite being a feature of forests before man became a predominant influence e.g. through treefall gaps, grazing areas and regeneration (Warren & Key, 1991), fragmentation (and loss of contiguous habitat) is now considered one of the most important factors worldwide in accelerating reduction in biodiversity (Wilson, 1992). In ecological terms **'severance'** is an integral part of the process known as 'habitat fragmentation'

By their very nature, linear developments (such as roads, railways and inland waterways) are such that they may engender habitat fragmentation. The intrusion into the landscape of man-made elements which have the potential to function as barriers and bisect ecosystems may be readily perceived to impose such effects. The objective assessment of the significance of this is however not simple, will vary for different species (see Barrier Effects of Highways – below) and depends on an appreciation of minimum viable population size and metapopulation biology for the species concerned. The latter issue is not dealt with in detail here though, as Morrison *et alia* (1992) have pointed out, metapopulations are typically conceived as pockets or sub-populations that interchange genetic material at a significantly higher rate within the sub-population than with other subpopulations. Populations of amphibians separated by a carriageway but able to interbreed to a limited extent due to the provision of an amphibian underpass may be acting as a metapopulation.

2.2 The Importance of Minimum Viable Population Size in Habitat Fragmentation

The effect of fragmentation on population size is important as a result of the phenomenon of minimum viable population size (MVP). Soulé (1987) argued that one of the most difficult and challenging intellectual problems in conservation biology is determining what the minimum conditions for the long term persistence and adaptation of a species or population in a given place actually are. The severance of a 'large' breeding group of a certain species into two 'smaller' groups can engender greater vulnerability for the entire population.

Considering the fragmentation of nature and the landscape by transportation infrastructure, Bekker (1998) pointed out that small populations face a high risk of extinction and that re-colonisation from elsewhere is only feasible if there is adequate access to the area in question. The extinction of small populations can be the result of natural causes (stochastic extinction events) or as a result of human developments. Essentially, however smaller, more isolated populations are at greater risk from catastrophes, demographic stochasticity, genetic deterioration or social dysfunction (see Wilcove 1987).

2.3 Patches, interiors and edges

Morrison *et alia* (1992) discussed the concept of patches with regard to severance. The patch is defined as an area which has more or less homogeneous environmental conditions. In reference to linear infrastructure, the concept is important with regard to 'edge' effects which arise where habitat margins are influenced by a bordering development or change in land use.

Soulé (1986) has considered the importance of edge, size and size-edge ratios in habitat fragmentation. In general, the smaller the ratio of a patch's periphery to its area, the better protected the patch will be from external threats. It is important to recognise that some of the edge and size-edge effects feed upon themselves autocatalytically resulting in a creeping-edge that can eventually reach the core of even a relatively large habitat. Janzen (in Soulé 1986) describes fire and the rain of seeds from secondary edge species as two such positive feedback processes. The accumulation of litter and changes in air quality may be regarded as edge effects particularly associated with highways.

In some cases, small fragments of habitat may become entirely edge where their width is less than twice that of the zone where edge effects occur (Kirby 1995). Given the complex network of highways, railways and canals which embrace England it is arguable that there are few habitats left with large areas which might be described as interior as opposed to edge.

The relation of edge effects and habitat fragmentation with regard to highways is portrayed in Figure 1. It is important to consider the two phenomena together in the ecological assessment of new route lines but more research is needed with a view to understanding the width of 'edges' with regard to specific habitat types.

3. ECOLOGICAL IMPACTS OF HIGHWAYS RELATING TO HABITAT FRAGMENTATION

In the context of highway infrastructure, Bekker (1998) distinguishes four impacts which may impinge on the natural environment. First of all the destruction of habitats: a certain area of nature simply disappears under the tarmac. Secondly, the ensuing traffic flow disturbs the area adjacent to the road, causing quantitative and qualitative changes to the area that influence a variety of population variables. Disturbance by noise and edge effects are examples of these changes. Thirdly, the barrier effect means that parts of a habitat are cut off, reducing the exchange of individuals within and among populations. And lastly, many animals end their lives as traffic casualties.

All of the above may engender habitat fragmentation and ecological severance to varying degrees and may lead to a change in the species composition of the area in question. This holds true for the vegetation (Angold, 1997), for small animal species (Grutke, 1997) and for large animal species (Groot Bruinderink & Hazebroek, 1996). Traffic casualties are the most conspicuous consequence. These are described, *inter alia*, by Bekker (1997) for the badger, by Van der Tempel (1993) for birds and by Groot Buinderink & Hazebroek (1996) for larger mammals. Reptiles and amphibians may be particularly affected by fragmentation of their habitats particularly where a road divides the breeding and terrestrial habitat of amphibians (Markham 1996). The viability problem caused by fragmentation effects is particularly apparent in low flying species of butterfly and has also been observed in carabid beetles and woodmice (SNH 1994).

Against the backdrop of these negative effects however is the fact that modern highway systems incorporate equally extensive tracts of linear, marginal habitat which is exploited by many animal and plant species in recognisable and, apparently persistent, communities. For example, Referring to the distribution of NVC grassland type MG1 *Arrenatheretum elatioris*, Rodwell (1992) points out that road verges …'represent one of the main reserves of permanent stands'…and the 'gradual maturation of motorway verges is increasing the potential extent of the community'.

The fact that these phenomena are observed is testament to the fact that wildlife is active on the edges of highways. As parts of the English highway network were laid down by Roman engineers (approximately 2000 years ago) it is hardly surprising that some areas of ecological stability may have developed along its margins.

3.1 Highways As Migration Corridors

Severance implies a restriction to movement and geneflow and the isolation of populations from one another. Dawson (1994) has reviewed the scientific evidence relating to whether habitat corridors can function as conduits for animals and plants in a fragmented landscape.

Dawson (1994) points out that these purposes require corridors at a variety of spatial scales but emphasises that while most definitions of the word 'corridor' require them to be both narrow and to connect habitat patches, a corridor can lead animals and plants into its length even where there is no larger patch at its end (see Henderson *et alia* 1985).

It seems reasonable to conclude that the destruction of such corridors may lead to severance and the creation of such features may achieve defragmentation. The incidental creation of species-exploitable corridors by man is ongoing with new examples including the halophyte corridor which is developing along the central reservations of major highways (see Life-form Specific Details, below). The extensive reticular green network of the soft estate has the potential to act as a national system of green corridors for those species able to exploit it.

3.2 Barrier Effects of Highways

Contrary to acting as corridors, to engender severance and fragment habitats, highways must function as barriers to geneflow between populations. In the case of animals, this usually means acting as a restriction to free animal movement, in the case of plants this means functioning as a barrier to the dispersal of pollen, seeds or vegetative propagules. The development of practical de-fragmentation measures therefore requires an understanding of precisely what constitutes a barrier from the perception of many different species.

Some species of bird (e.g. great spotted woodpecker, *Dendrocopos major*) readily cross gaps and may meet their area requirements by using groups of small woods (Hinsley *et al*, 1994). As Markham (1996) points out however, the ability to cross gaps varies with species and those less able to do so become isolated more readily by fragmentation.

English Nature (1994) has stated that the busier and wider the road, the more it is effective as a barrier to movements. Some species cannot, or rarely, cross such obstacles whilst others venturing onto the road risk vehicle collision. Other species will not settle even within several hundred metres of a road.

Fragmentation resulting from the construction of highway infrastructure is not readily defined. The reality of fragmentation resulting from any physical barrier will vary according to species and the communities or habitats in which they occur. It will also be determined by what has been referred to as *Niche Gestalt* (Morrison *et alia* 1992) i.e. what an animal perceives as its environment. This concept is important in understanding the effects of habitat fragmentation on animal species.

With regard to plants, fungi and lichens, the relative efficacy of dispersal mechanisms of seeds, spores and vegetative propagules is significant in the definition of what is, and what is not, a barrier to dispersal for different different species and plant forms.

Potential aspects of highway infrastructure which may create barriers and fragment habitats include;

Physical Barriers

- The construction and installation of new carriageways
- The construction and installation of fences, walls and drainage ditches
- Changes to drainage patterns

Air Turbulence

The Destruction of Habitat

- The generation of discontinuities in hedges, woodlands, wetlands and other forms of habitat

Physiological Barriers

- Lighting Effects (including modification of shading regimes)
- Air Quality Effects
- Humidity changes
- Disturbance of chemical gradients

Ethological Barriers

- Fear
- Noise Effects
- Modifications to predator density patterns

The construction and installation of a new highway inevitably requires habitat clearance and the installation of man-made surfaces into a landscape. Even in the absence of traffic, this will represent a barrier to the movement of some species and reduce the areas of some habitats below the minimum habitat area requirements of some organisms. As a part of this, fences, walls and drainage ditches all represent physical barriers which restrict the movement of certain species. The generation of habitat discontinuities may represent insurmountable barriers to the movement of some living things.

Road drainage will alter local hydrological patterns in terms of the direction and speed of drainage, storage capacity and water quality. Air currents may be affected by transport infrastructure in terms of changes to natural air flow patterns (wind) across a landscape (cuttings, for example, may create 'canyon effects' channelling air currents in particular directions). The turbulence and vortices caused by the passage of high-speed vehicles may limit the ability of some species to cross carriageways and therefore engender severance. For instance, an early study suggested that the M56 is a barrier to the dispersal of the normally mobile orange tip butterfly (*Anthocharis cardamines*) (Dennis (1986 – cited in Halcrow Report December 2001). Conversely, such air movements may encourage the spread of species with wind-borne seeds. Changes in air quality in the vicinity of roads may restrict, or potentially encourage, the movement of certain animal and plant species in the road corridor by modifying the mineral content of the bordering soil profiles. It has been suggested that the combined effects of potentially high soil levels of sodium chloride (from winter salting) and sulphur compounds (from exhaust, tyre rubber, fuel and concrete leaching) may modify road network floras (Cook 1998). Such changes can open corridors to the movement of some species and close them to others. This is further complicated by the localised changes in drainage and humidity regimes which may concentrate or dilute pollutants. Humidity regimes in themselves are important to the survival of many species, especially invertebrates and lower plants. Minor physical changes to a structure can affect isolated colonies of humidity sensitive species (e.g. see UK Species Action Plan for the lichen *Calicium corynellum*, UK Biodiversity Group 1999).

The high intensity lighting associated with roads may pose a barrier to the movement of nocturnal species or their predators (e.g. see Markham 1996). The attraction of some insect species to lights may affect the behaviour of prey species such as bats (see DMRB Volume 10 Section 1 Part 8). This may lead to severance due to behaviour modification and/or modification of predator/prey relationships. Traffic noise has been shown to reduce the breeding density of bird species in adjacent woodland (Reijnen *et alia* 1995) and may be expected to have similar effects on other aurally sensitive species. It may be postulated that some animals may 'fear' to approach a carriageway due to noise or other impacts.

Many species navigate through the environment by the use of naturally occurring physico-chemical gradients (e.g. pH, oxygen, carbon dioxide, salinity, conductivity, pheromones, sugars, scents). This includes mammals using scents to hunt prey, mark territory or attract mates (e.g. see Bang and Dahlstrom 1972), insects responding to the chemical attractants of flowers (see Proctor and Yeo 1973), and the gametes of algae and fungi and the spermatozoids of certain plants 'swimming' between male and female gametangia (see Strasburger 1965). Transport infrastructure and its inherent changes inevitably disrupt these gradients through concentration, dilution or chemical contamination with a suite of different substances (lead and other heavy metals, oxides of nitrogen, diesel, sodium chloride, urea, carbon monoxide) which may act as chemo-navigational smog.

Of the above phenomena, drainage, air turbulence, the generation of habitat discontinuities, lighting, air quality, humidity, disturbance to chemical gradients, fear, noise and modifications to predator/prey density patterns may all be expected to contribute to the definition of Forman's Road-effect Zone (Forman *et alia* 1997 – the outer-limits of the significant ecological effects along, and generated by, a road) for any particular highway or highway network. These factors may act singly or in cumulative or synergistic ways to induce severance.

3.3 Life-form Specific Details

For the purposes of the present paper, a discussion of the fragmentation effect of highways with regard to specific life forms is based upon plants and fungi. Examples from the animal kingdom were also reviewed for the original scoping study (Halcrow 2001).

Lower Plants and Fungi

Hallingbäck and Hodgetts (2000) considered the impact of habitat fragmentation on bryophytes and have pointed out that, in general, those taxa with a large production of small diaspores are considered probably more easily spread (cf. Söderström and Herben 1997) and hence not so vulnerable to isolation through fragmentation of their habitats. Species that produce only small numbers of diaspores (or none at all), or only large ones, are less efficient at long distance dispersal and the subpopulations may be considered more easily isolated if the population has become fragmented.

These considerations may be expected to hold for any species which is dispersed by air-borne spores (or other microscopic propagules) including lichens and fungi. It should be considered also however that air turbulence due to moving vehicles and the canyon effects of cuttings may serve to draw air borne propagules along road routes thus enhancing dispersal along human transport routes. This requires further investigation. Such effects might account for the spread of higher plants with wind-borne seeds in the motorway environment (e.g. *Senecio erucifolius*) which occurs within the M5 corridor (Smith – personal observation). *Senecio squalidus* is reputed to have spread along the Great Western Railway (e.g. White 1912) and this may have been due to the dispersal of seeds in the air vortices of trains.

Changes to natural drainage patterns and water quality through the installation of highway drainage systems and outfalls may be expected to engender adverse effects on aquatic fungi, bryophytes and lichens (and higher plants), thus creating barriers to colonisation. Toxicity studies on stream flora and fauna indicate that major ecological impacts are restricted to run-off from trunk roads and motorways carrying high traffic volumes and principally result from long-tern chronic exposure and bioaccumulation (Markham 1996). The effect of pollutants on aquatic bryophytes and lichens is discussed by Glime (in Bates and Farmer, 1992).

Higher plants

The impact of highway construction on higher plants is usually noted in the form of habitat destruction or the effects of pollution. Gene flow between higher plants and their populations is usually dependent on the transfer of pollen from one specimen to another even in normally self-pollinating species where cross-pollination is rare.

For anemophilous species, the pollen of which is dispersed by air (e.g. grasses), geneflow across a landscape is unlikely to be limited by the construction of a new road. For zoophilous species whose pollination is achieved through an animal vector, it may be considered that if the vector cannot cross the road, then neither can the pollen.

Whether a road can act as a barrier to the dispersal of seed of various plant species is similarly dependent on whether the seed is dispersed by air (anemochory), by animal (zoochory), by water (hydrochory e.g. *Sedum acre* in which the seeds are washed out of the capsules which only open when wet – Strasburger 1965), by man (anthropochory) or specifically by transport (which might be termed Vehiculochory). The latter embraces a series of phenomena including air turbulence and jet streams associated with high speed transport, wheel splash, dispersal in tyre tread, and chemical modification of the environment associated with maintenance and use of transport corridors. A number of plant species, now exploiting the trunk road and motorway corridor, may be regarded as dispersed by transport either by seed dispersal or as a result of conditions created by road use. Table 1 below includes a range of halophytes recorded or reported from the road network by various writers/recorders. The reasons governing the association and spread of these species within the road corridor varies by species but to them, and possibly the animals which feed on them, the road network, its maintenance and operation, represents habitat defragmentation. Smith (personal observation) has observed that *Cochlearia danica* (see Table 1 below) can cross an active carriageway (by undetermined means) in one year. Circumstantial evidence suggests that this may be due to seed transport in road run-off, though this remains to be investigated.

The distribution of maritime species on British Roadsides and their association with the use of de-icing salt is discussed by Scott and Davison (1982). Gilbert (2000) has pointed out that, to date, no maritime lichens have been reported from inland salt burn, possibly because special searches have not been made. The presence of the normally maritime *Solenopsora vulturiensis* on the salt splashed wall of a bridge in Northumberland may be the first example of such an occurrence (Gilbert 2000).

Table 1: Salt-loving Plants (halophytes) associated with the inland road corridor

Species	Phenomenon
Armeria maritima	*A38 (Leach, S. 1997), A158 (Weston, I 2000)**
Aster tripolium (sea aster)	*Dowdeswell (1987)*
Atriplex littoralis	*A15 Weston, I (2000)**
Atriplex prostrata	*A158 Weston, I (2000)**
Bassia scoparia	*A16, A140/A143, Cook, P.J.(1998)*, M5 Smith P L 1997*
Bupleurum tenuissimum	*Scott (1985)*
Catapodium marinum	*A338, A35, A380, A38 (Leach S 1997)**
Cochlearia danica	*Dowdeswell (1987)*
Desmazeria marina	*Scott (1985)*
Elymus pycnanthus	*Scott (1985)*
Halimione portulacoides	*Scott (1985)*
Hordeum jubatum	*Scott, N.E. and Davison, A.W. (1982)*
Hordeum marinum	*M5 Green, I , (1998)**
Juncus gerardii	*Scott (1985)*
Parapholis strigosa	*B roads VC 61 Cook, P.J.(2000)**
Phragmites australis	*Gibert, O (1991) M63**
Plantago coronopus	*Scott, N.E. and Davison, A.W. (1982)*
Plantago maritima (Sea plantain)	*Dowdeswell (1987)*
Puccinellia distans (Reflexed meadow-grass)	*Dowdeswell (1987)*
Puccinellia fasciculata	*Scott, N.E. and Davison, A.W. (1982)*
Puccinellia maritima	*Scott, N.E. and Davison, A.W. (1982)*
Spergularia marina (Sea Spurrey)	*Dowdeswell (1987)*
Spergularia media	*Scott, N.E. and Davison, A.W. (1982)*
Spergularia rubra (Sand Spurrey)	*Dowdeswell (1987)*
Suaeda maritima	*Scott, N.E. and Davison, A.W. (1982)*
Triglochin palustre	*A490 (290m) Green, I**

Asterisks indicate records reported in editions of BSBI News Numbers: 59, 75, 78, 79, 83, 84. The fungus, *Agaricus bernardii*, usually associated with salt marshes has also been reported from the A696 (see Scott 1985) .

For plants with light, wind dispersed seeds (e.g. winged samaras of *Acer* spp., parachute types as in many species of Compositae and Onagraceae), it is likely that roads pose little severance. Highways may form more of a barrier for plants whose seeds are transported by animals (invertebrates, mammals and birds), whether in their jaws, intestines, coats or feathers, depending on the animal vector's ability or willingness to cross carriageways. Species reliant on insects for the dispersal of their seeds will be limited by the distance such species can travel through the highway corridor. For example, species which exploit ants for their seed dispersal (e.g. Greater Celandine *Chelidonium majus* – see *Strasburger's (1965*) account of Myrmecochory) may be limited in their ability to cross carriageways unaided.

Provided species produce viable pollen and seed in large quantities, the frequency of earth movement in the UK is probably such that roads do not pose significant barriers to the movement of many plant species, or to geneflow between populations, across the UK even with limitations of the movement of some animal seed vectors. Arguably of greater concern from the perspective of higher plants are pollution and the destruction of habitat.

Quoting Jonathan Spencer, Marren (1990) speculates that Herb Paris (*Paris quadrifolia*) has lost its British seed vector which may have been the wild boar. Poor powers of dispersal make it a good indicator of ancient woodland in Britain while in the Pyrenees (See Marren 1990) it grows in recent scrub by riversides and other pockets of rich moist soil. With appropriate reintroduction of larger animal vectors and suitable defragmentation measures, some of the species presently restricted to ancient woodland in Britain may begin to recolonise new habitats. It is worth speculating that part of the difference between ancient woodland and that of more recent derivation may simply be due to the loss of animal seed vectors or habitat isolation resulting from human development, agriculture and infrastructure which ultimately slows the dispersal of some plant and animal species from one site to another. The age of woodland may be less critical to its biodiversity than its accessibility to immigrant diaspora of animals and plants. If this were shown to be true, then any habitat defragmentation measures which can be designed would be of significant benefit in habitat creation and restoration projects.

4. ASSESSING ECOLOGICAL SEVERANCE

4.1 Incidence Functions

Whitcomb *et alia* (1981) graphically related the size of forest patches in eastern deciduous forests to the probability of occurrence of songbird and other species within them. The resulting probability curves are known as incidence functions. These may provide another objective measure useful in assessing highway fragmentation impacts. As a general rule of thumb, twice the number of species seem to require ten times the area (Darlington 1957).

The situation is complicated by the fact that the presence of other species can greatly influence the basic species-area effect. For example, orb-spiders (Araneae) reach extremely high densities on subtropical islands lacking predators (Schoener and Toft 1983). It is perhaps notable that orb spiders (*Araneus diadematus*, *A*. *quadratus*) appear to reach high densities on some motorway embankments towards the end of the summer in England (Smith - personal observation).

Incidence functions may provide an objective means of assessing the significance of fragmentation events due to linear development. This possibility merits further investigation.

4.2 Historical Evidence

It is essential to consider the historical dimension in assessing habitat fragmentation due to transport corridors. Habitats and landscapes are dynamic and the ecological significance of any fragmentation event is related to, and to some degree relative to, the history of the landscape in which it occurs. The British landscape is criss-crossed by road routes ranging in age from over two millennia to less than a year. The routes intersect and each one imposed some kind of severance, and some connectivity, at the time of its creation. The net of routes imposed on the landscape has resulted in an irregular patchwork of habitats delineated by highways (and other forms of linear infrastructure). This is significant to the present study for the following reasons:

- Since the age of each route varies, the fragmentation events which each engendered will be of varying and in some cases definable, ages. Historical habitat fragmentation events (e.g. the bisection of a woodland by a route of known age) can be used as research sites to examine putative habitat effects. An examination of enclosure maps and early series OS Maps may be used to identify such sites.

- Since almost all UK habitats are, to some extent, fragmented habitats, each new fragmentation event to be assessed must be done so against the backdrop of historical events in the vicinity. The analysis of potential fragmentation of any habitat must be considered against the pattern of historical fragmentation that has already occurred in that region. Severance of a small fragment of woodland, for example, by a new road line may be of relatively small significance in itself but if forming part of a series of fragmentation events affecting the same habitat it may represent the critical event which leads to the loss of one or more species. It should also be considered that with habitat types which may be recognised as edge habitats in themselves, fragmentation may be beneficial in generating more edge.

A series of illustrations indicating fragmentation patterns relating to highways are included in Figures 1 and 2. These provide the basis for a developing methodology, for assessing the significance of highway-generated habitat fragmentation events, based upon examination of historical records.

4.3 IUCN Threat Criteria

The Criteria used by the International Union for the Conservation of Nature (IUCN 1994) for the definition of 'critically endangered', 'endangered' or 'vulnerable' with regard to threatened species provide some quantitative comparisons. These are useful in the assessment of the significance of certain habitat fragmentation events.

The IUCN regard a taxon as being Critically Endangered when it is facing an extremely high risk of extinction in the wild, in the immediate future, as defined by a number of criteria.

Adapting these criteria, a population may be regarded as severely fragmented if no sub-population contains more than 10-20 % of the total population.

This may be applied to some degree to situations where a habitat is severed by a new carriageway to derive a comparative measure of disruption to a local population which may be compared against other cases.

5. ALLEVIATION OF SEVERANCE

A range of mitigation methods has been discussed, by various authors, to mitigate the severance or fragmentation effects of highways. These include tunnels and ecoducts (Markham 1996), 'green' bridges (e.g. see Gibeau and Heuer 1996), rope bridges (Scottish Executive (1999) and tree-stump corridors (Van der Linden 1995). These are not subjects of the present paper but, for access to the literature, the reader is referred to the review of Markham (1996) and to Kirby (1995) for the consideration of a range of options which may alleviate barrier effects.

6. CONCLUSIONS

The view gained from review of the available literature is that the concept of habitat fragmentation due to the installation and maintenance of highway infrastructure is still largely intuitive albeit with some established facts relating to certain habitats or species. It might be argued that intuitive appreciation of the phenomenon is confused by the conflict of human perception of 'good' linked and healthy habitats compared to the actuality as experienced by different species. Habitat fragmentation and severance is essentially a species-specific phenomenon and must, to some extent, be viewed on a species by species case basis. It also demands an enhanced understanding of the autecology of a range of species which may be vulnerable to fragmentation.

As is often the case with emotive biological phenomena, it is important to consider the positive aspects of ecological change as well as the negative if a glimpse of reality is to be snatched from the fog of human subjective bias.

Such a line of thinking is adopted with the consideration of lichen migration below and highlights the dangers of relying on the *aesthetic ethic*. What looks good to human eyes is not necessarily good to all species and *vice versa*.

The first evidence that trunk roads can support interesting lichen species came from Germany where it was reported that *Vezdaea leprosa*, well known for its tolerance to heavy metals, regularly occurred in the drip zone below metal crash barriers, where it is part of a community that also includes *V. aestivalis* and *V. acicularis* (Ernst, 1995). Gilbert (2000) found *V. leprosa* on soil and dead vegetation under a crash barrier on the A1(M). Dead, grit-covered leaves bearing the white pycnidia of *Bacidia arnoldiana* were also encountered. The rise in car use since the second world war has been matched by the advance of certain *Stereocaulon* species from the uplands, where they are often present on lead mine spoil, into towns where they are now widespread (Gilbert 2000). The implication, though not proven, is that increased lead levels from car exhausts have shifted the balance of competition in favour of lead-tolerant species, a phenomenon which may be regarded as **defragmentation due to pollution.** As Dawson (1994) pointed out, rare species may require odd corridors. The point to be made is that habitat fragmentation need not be an all or nothing phenomenon. Habitat severance to one species (in this case due to inferred high levels of lead contamination) may be corridor formation for another. The assessment of severance and fragmentation impacts therefore is very much dependent on the species or species assemblages with which an assessment in principally concerned and the nature of the barrier imposed.

Evidence is accruing to indicate that the road network supports a definable assemblage of plant and animal species. Examples may be seen from a drive through the motorway network of England e.g. corvids scavenging for road kill, kestrel and barn owl hunting small rodents in the road verge, the development of MG1 and MG5 plant communities on embankments and junctions, swathes of pyramidal orchid (*Anacamptis pyramidalis*) on motorway cuttings, areas of short turf apparently maintained by rabbit grazing, populations of reptiles on warm embankments, lower plant communities on wayside trees and rock exposures and developing areas of block planting.

The definition of the transport corridor as an anthropogenic habitat should be refined to take account of features such as the maritime influence and national Species Action Plan species which occur there. There is also a need to examine some phenomena which seem to challenge accepted ecological wisdom. For example, large populations of adder's-tongue fern (*Ophioglossum vulgatum*) have developed on 'made ground' at some M5 motorway junctions built in the 1970's (Smith – personal observation). Page (1988) has suggested that the usual habitats of this species are probably mostly those which have persisted over a very long period of human history (citing old, level, low-lying, unploughed, moist, grassy meadows, developed over deep, often heavy and usually markedly basic soils as an example). Page (1988) notes that this species has also appeared in moist base-rich sites of former industrial lime-workings. Perhaps there are similarities between the artificially high soil base status at such sites which may be compared with unusual conditions at motorway junctions where extensive concrete mixing has occurred in the past. It would be of interest to know if such conditions favour rapid development of adder's-tongue fern communities in relatively recently imported soils as this may have valuable implications for the development of translocation methodologies and the creation of natural-type, species rich plant communities in mitigation works.

At present, perception of the ecological dynamics of the transport corridor (road, rail and canal) is fragmentary and information for certain groups such as Lichens and bryophytes is poor. Bryophytes and lichens have long been recognised as sensitive indicators of environmental conditions (e.g. see Bates and Farmer 1992). A range of phenomena involving the movement of these species within the transport corridor from one part of the country to another as the network continues to grow, change and mature is yet to be examined. For instance, to minimise the risk of chemical corrosion, urea is used for de-icing purposes on the Forth and Severn Road bridges (its use runs to many tonnes per year). It would be an attractive project to assess its influence on the lichens of walkways and other structures (Gilbert 2000).

The UK Biodiversity Group (1991) has placed actions on the Highways Agency to help protect the Round-leaved feather-moss (*Rhynchostegium rotundifolium*) and the lichen *Bacidia incompta*. Though these are conservation issues relating to network management and development, they highlight the role the Highways Agency has to play in the protection of lower plants and the need to maintain viable habitats for them. *Rhynchostegium rotundifolium* occurs on a tree, hedgebank and wall beside a county road in Gloucestershire. *Bacidia incompta* grows on the trunks of mature trees with basic bark and in Britain it is largely (but not exclusively) confined to elm. The value of boundary walls and wayside trees in providing habitats and potential migration corridors along and through the network for such species is poorly understood but is likely to contribute to the system's 'porosity' for their movement. For such reasons, it is important to view the network as a system of migration corridors in itself and not just a source of fragmentation.

The consideration of severance and fragmentation in the temporal dimension of the diurnal or seasonal cycle is something which has yet to be considered in any detail but it can be reasoned that some barriers (such as artificial lighting or other forms of emission) may only need to be present at certain critical times in a species' activity pattern to render populations isolated.

The Highways Agency's network has fragmented previously existing habitats and created others. As the network grows and evolves it represents a force for ecological change, some of which may be regarded as damaging to national biodiversity and some of which may be regarded as encouraging. The more ecological investigation that is carried out, the clearer it becomes that the niches provided by the Agency's soft-estate are still filling up with living things and assemblages are being selected and defined according to the constituent species tolerance to the particular disturbance patterns inherent to the road network.

An assortment of man-made soil profiles, vehicle and management-derived physical and chemical gradients, specific (and sometimes limited) human interaction, modified predator-prey relationships and artificial light-dark regimes has combined, and is still interacting, to generate a recognisable habitat type which, with local variations, overlays the English Countryside. This reticular ecosystem has a definable reality of its own, in the same sense as a heathland with its mosaic of smaller constituent habitats. It requires management regimes of comparable complexity if its ecological wealth is to be maintained. The fact that much of this management occurs incidentally as a result of the Highways Agency's functional responsibilities has been one of the driving forces for the development of the habitat reticulum in its present form. The publication, and implementation, of the Agency's Biodiversity Action Plan (2002) may be expected to enhance this process.

The definition of this ecosystem and the developing understanding of it argues for its recognition by a specific term under which data may be stored and management regimes proposed. The acronym TIERE (Transport Infrastructure Ecological Reticulum or Resource) is memorable in echoing the Latinate land words *terra*, *tierra* or *terre* and in being the German word for 'animals'. Its flexibility lies in the fact that it may also include rail and canal margins.

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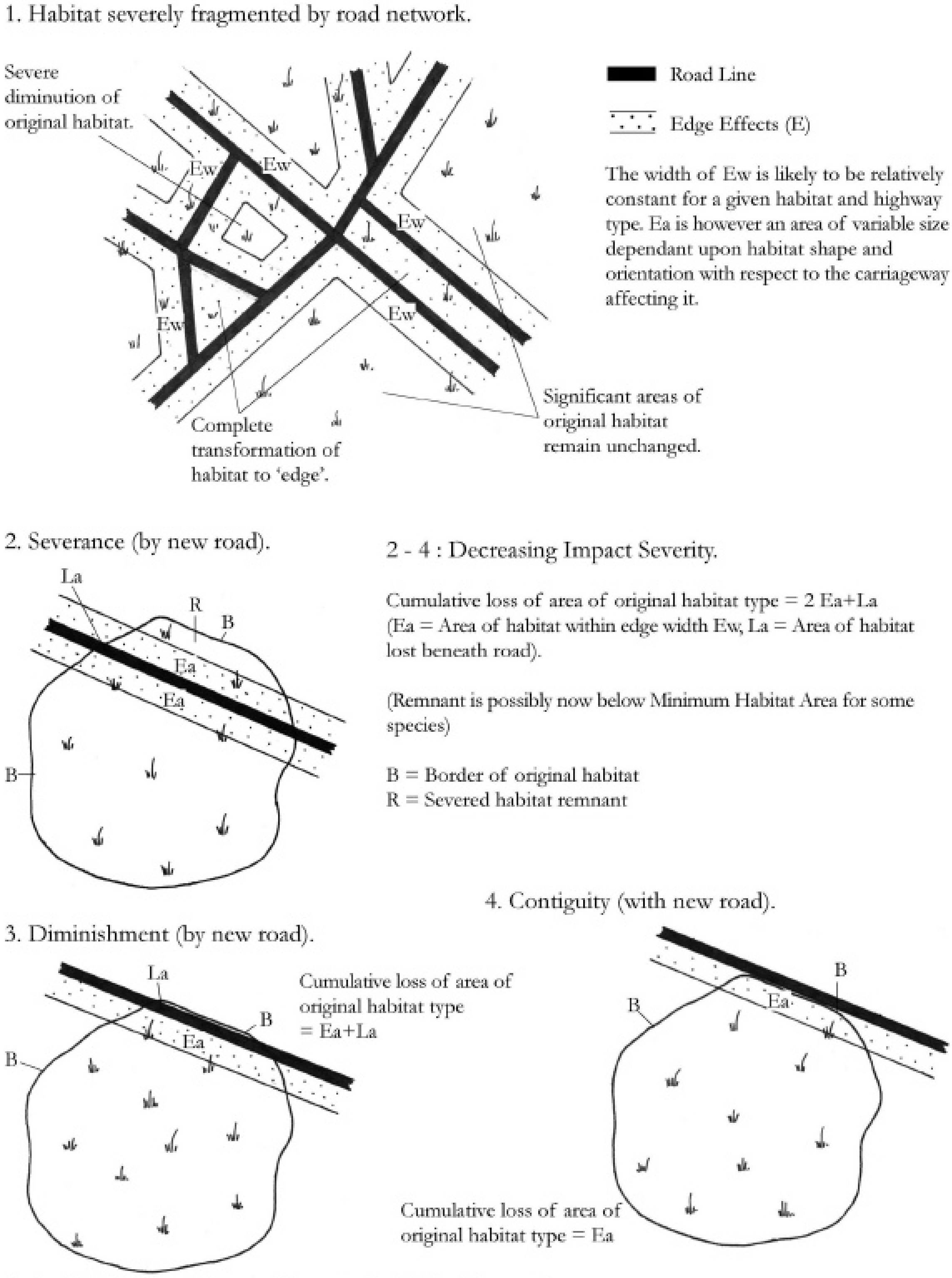
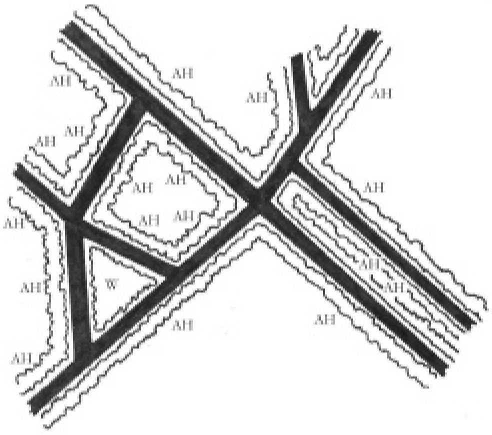
Figure 1 : Habitat Fragmentation and Impact Severity



See also Kirby (1995) for a diagrammatic interpretation of habitat fragmentation.

Figure 2 : Historical Fragmentation Patterns

1. Field Pattern and Road Network of long standing

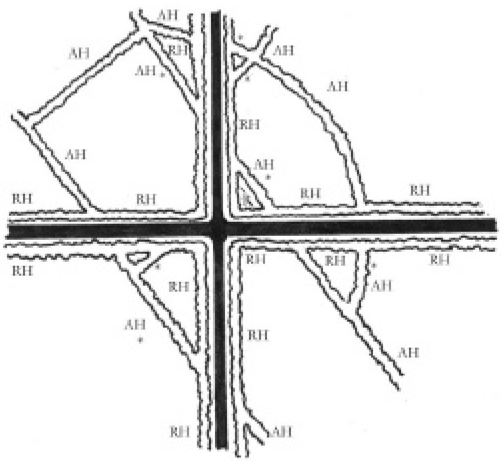


Field patterns have had many years (often centuries in the UK) to harmonise with old road networks

AH : Ancient Hedge
W : Wood

It is important to remember that many ancient roadlines in the UK may be aged in Millenia. E.g. A429 Fosse Way.

2. Ancient Field Pattern and more recent Road Network

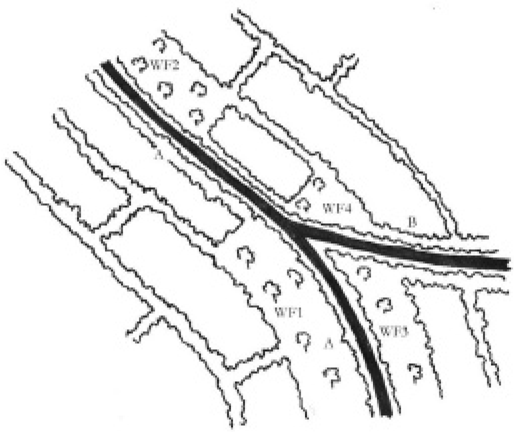


Disharmony between newer road networks and older pre-existing field patterns often leads to planting of new hedges but increased vulnerability of more ancient examples as landowners seek to render fragmented field shapes more utilitarian.

AH : Ancient Hedge
RH : Recent Hedge
* : Vulnerable hedge

Not only are ancient hedge lines severed but resulting fragments become vulnerable to other land use priorities.

3. Network with ancient and recent road lines



Route lines in harmony (A) and disharmony (B) with field pattern. Route B imposes more recent severance and habitat fragmentation.

≠ : Severance
WF : Woodland Fragment
WF1 ≠ WF2 : Possibly Ancient Fragmentation
WF1 ≠ WF3 : Ancient Fragmentation
WF2 ≠ WF4 : Indeterminable from Road Pattern
WF3 ≠ WF4 : Recent Fragmentation Event