November 2010

Safer, more permeable roads

Learning from the European approach

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The problem of fragmentation and its solutions are universal. The key to success is the adoption of a holistic approach that allows the whole range of ecological factors operating across the landscape to be integrated within the planning process.

JG de Vries & T Damarad (2002) *The European Review*

Executive Summary

Recognition of the impact of transportation infrastucture on ecosystems and biodiversity is transforming the planning, design and construction of roads throughout the world. Although much of the research and influential reviews associated with the new field of road ecology appear to originate in North America, this perception is partly due to a focus on English language sources. In reality, the development of responses to the impact of roads on natural systems in the European Union has led to a remarkably mature approach across Europe, as evidenced by the high standards or practice and the sheer scale of the measures in place and planned. Given the general lack of readily accessible information on what can be called the European Approach to the ecological impact of roads, and the rapidly growing need for knowledge that may aid the development of the field in Australia, this review aims to address the following questions:

(i) *Why has European road ecology evolved to its current state?*

(ii) *What are the key approaches to addressing the impacts?*

(iii) *How can this information be applied in Australia?*

Contemporary European policies and practices have had a long history of development, originating in the environmental positions present in the early European Community. Especially influential have been Directives of the European Commission which oblige European Union Member States to comply and enshrine the policies in national legislation. In particular, the 'Birds' (1979) and 'Habitats' (1992) Directives have been instrumental in ensuring international responses to the protection of sensitive species and sites from the impacts of developments. Critically, the designation of a large number (over 20,000) of sites distributed throughout Europe and known as the *Natura 2000* network posed a major challenge to the expansion of transportation infrastructure. The key response to this challenge was via the formation of the Infar Eco Network Europe (IENE), an international group of road planners, researchers, policy developers and NGOs. Using funds from the European Commission, IENE undertook a hugely ambitious cooperative project (COST Action 341: *Habitat Fragmentation due to Transportation Infrastructure*) involving 16 countries over six years. This project synthesised all existing information and practice, producing a series of products the most significant of which were *The European Review* (2002) and *The European Handbook* (2003).

The 'Handbook' has proved to be the single-most important influence on the responses of the diverse range of countries, providing both clearly stated concepts as well as detailed technical details and recommendations which are capable of straight-forward translocation into road design. This has enabled the crucial outcome of the implications and mitigation of impacts to be considered at all stages of project development and implementation. That is, full integration into the road design process.

The efficacy of the European approach can be seen in its practical responses to the three-stage process of minimising impact: first, **avoid** (sensitive sites or local

disturbances); then **mitigate** (any impacts, usually through the construction of fauns passages); and, as a last resort, **compensate** (unavoidable impacts by careful off-setting or financial recompense).

Avoidance of sensitive sites can be attempted at both the route alignment phase and at the local scale, the latter involving a range of design options that ensure that impacts on sensitive sites (especially watercourses) are entirely eliminated (such as through broad avoidance bridging). The most effective and impressive of all such structures are undoubtedly the new-generation viaducts. Although the primary driver for the installation of these extremely expensive structures has been the necessity for very flat roads, carefully considered pillar-centric construction techniques have dramatically reduced disturbance to the land below. The extensive use of tunnelling has also had many biodiversity benefits.

The mitigation of impacts has certainly become the most active area of development and innovation, with many engineering solutions being employed with the overall aim of de-fragmentation by enabling the safe movement of animals across roads. Underpasses are now routinely designed to fit specific target species, and are increasingly placed in relatively high densities (every 300m is recommended). Various raised platforms – either included in the design or retro-fitted - are also commonplace now.

The most conspicuous manifestation of the European approach to reducing fragmentation is the many and varied overpass designs now present in hundreds throughout the region. From the earliest structures designed simply to allow deer movements (due to pressures from the still powerful hunting lobbies), overpasses are now broader (50m is the recommended minimum width), often longer (the largest are over 1km in length) and increasingly planted to attract a wider range of species. Barriers to reduce traffic sound and noise are important elements of current underpass design.

The last and least defined measure is that of compensation. Considerable debate continues at what may be regarded as suitable or adequate off-set provisions, although important approaches to this vexed area have been recently developed.

Finally, the issue of monitoring must be regarded as an essential element of the overall approach. Only by intentional and carefully formulated assessments can improvements and adaptations continue to lead to better fulfilment of the aims of the de-fragmentation. In particular, attention must be direct toward evaluation of the effectiveness of mitigation plans at the population level.

In conclusion, Australian agencies and road engineers have much to learn from the processes and practices now well established across Europe. In particular, consideration of measures that aim to ameliorate the impacts associated with roads must start to be included at all phases of the development of a project, and especially at the earliest strategic scoping stages.

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1 Introduction

Roads have always been a feature of human activities. They provide essential and inevitable linkages for the movement of people and goods as well as enabling efficient communication and contact between communities and businesses. Daily life for most people would be inconceivable without the ability to travel along the roads that connect homes with work places, schools, shops and entertainment areas.

For much of human history these networks have criss-crossed the landscape, with relatively little impact on the surrounding environment. While roads were mainly narrow tracks through bushland or pastures, most animals – both wildlife and domesticated - could cross easily, without risk of exposure to predators or collision with a vehicle. The level of traffic was typically patchy and relatively slow, and usually infrequent or non-existent at night.

This situation still exists in more remote parts of the world but has altered beyond recognition in most towns and cities. Increasing levels of population growth and car ownership has lead to an acceleration of traffic densities, especially in and around cities, with a continuing expansion of the road network. New constructions and the up-grading of roads is proceeding at unprecedented rates throughout the world as civil transport authorities attempt to address traffic congestion and improve transit rates. As well as the burgeoning road works near urban areas, increased traffic levels on intercity motorways, has lead to continual up-grading activities of existing highways and the construction of new routes and bypasses. While the number of such projects may seem impressive in Australia, the scale of road building in China, South America and even Eastern Europe, for example, is simply staggering.

While the impact of many human activities on natural environments and biodiversity has been thoroughly appreciated and addressed for a long time (consider controls on the use of agricultural chemicals, the mitigation of pollution sources or the protection of most native wildlife species, for instance), the influence of roads has only recently been considered seriously. Perhaps the simple ubiquity and familiarity of the road network has habituated us to its pervasiveness. Nonetheless, roads are now widely regarded as one the most important driving factors of environmental degradation and especially biodiversity loss (Millennium Ecosystem Assessment 2005).

The initial motivation for concern over the interaction of roads and wildlife was that of public safety. As soon as private vehicles were capable of a certain level of speed, the implications of a collision with any larger animal attempting to cross the road became a significant concern. This issue increases in importance with the number of vehicles and their speed, with a collision with a single deer, moose or kangaroo on a high-speed motorway representing a major risk of loss of life and serious injury. For these reasons, road authorities in many locations have been forced to consider measure that prevent or limit access of wildlife to roads. Some form of fencing has been the usual response, and such barriers are now ubiquitous features of many motorways in Europe and parts of North America.

These structures are, however, of limited use in areas, typical of Australia, where fencing the vast lengths of roads would be utterly impractical. Furthermore, fences greatly exacerbate the capacity of the road to act as a barrier to the movement of animals, leading to the process of fragmentation of habitats, one of the fundamental impacts of roads in the landscape.

Figure 1.1. View of a section of the C37 motorway in northern Catalonia, Spain taken from the top of a 500m width 'landscape ecoduct' and looking toward another cut-and-cover style overpass. Part of Europe's most permeable road (see Box 2)

Once the scale and fragmenting impact of roads present in the landscape was added to the direct impacts such as habitat loss and road-kill, the importance of the influence of roads began to be appreciated. Over the past two decades the new field of research now known as 'road ecology' has developed from an obscure special interest concern to one of international significance (Forman & Alexander 1998, Forman *et al.* 2003). Today, road engineers and designers, as well as their government and private clients, are increasingly seeking the latest advice and news on what is a rapidly advancing and changing scene. This increased involvement from those engaged in developing and constructing roads is the result of compliance and legal pressure from a wide range of sources including government agencies, political pressure and community activism, as well as genuine motivation by road construction companies to be at the forefront of international best practice. A major challenge, however, remains the difficulty in accessing reliable and relevant information, both conceptual and technical, which can be applied to a specific situation. This is especially acute in Australia where many of the environmental and ecological conditions we face – as well as the legislative and contractual frameworks – differ markedly from countries where practice is relatively more mature.

Although Australian governments, road authorities and construction companies are beginning to address these complex issues, and a wide range of crossing structures and innovative approaches have been installed throughout the country, the field is very much in its infancy here. Nonetheless, remarkable progress has been made over the preceding decade, with the construction of the first wildlife overpasses, the installation of canopy ladders and glider poles, and the first detailed studies of the use of these structures (see e.g., van der Ree *et al.* 2007). Moreover, several state transport agencies have completed comprehensive guidelines to environmental best practice (e.g., QDTMR 2009) while the Federal Department of Environment, Water, Heritage and the Arts commissioned a major review of the effectiveness of mitigation measures for linear infrastructure (van der Ree *et al*. 2009). In addition, the first national symposium on roads and biodiversity – *Breaking the Barriers* – was held in Brisbane, an event attended by local and state government agencies, road construction engineers, researchers, consultants, community groups and the public (http://www.eianz.org/aboutus/breaking-the-barriers/).

While being thoroughly successful in terms of sharing ideas and establishing networks, one of the most pertinent outcomes of the *Breaking the Barriers* symposium was identifying the critical need for more relevant information. The unexpectedly rapid 'agenda entry' (identified as such by Outram 2009) of these issues into the decision-making framework in Australia, despite an absence of specific legislation, was of considerable concern for many stakeholders – road engineers, advising consultants, local governments, transport agencies, environmental officers - engaged in planning roads. Each of these groups requires access to design plans, specific guidelines, technical specifications and reliable advice that often do not yet exist in this country. Although the situation is rapidly improving with a proliferation of mitigation measures being implemented in all states, the level of adequate or appropriate assessment remains extremely mixed. More importantly, access to such information and findings is often difficult.

An apparently obvious source of information is that available from the Northern Hemisphere. The construction of road mitigation structures, and the associated legislative and decision-making frameworks are certainly well advanced in these regions. While there are many important legal, jurisdictional and even ecological differences between Australia and the Northern Hemisphere, there are also many issues and challenges that are shared by all countries and solutions can often be readily adapted to local conditions. Thus, seeking information from these regions can be invaluable and is already occurring.

Figure 1.2. Fauna overpass designed mainly for roe deer on motorway M7 in southern Hungary

There are, however, some key differences between North America and Europe in what we can be accessed from outside these regions. For example, road-related publications in English are dominated by authors and studies from the United States and Canada, with the most influential overviews (e.g., Forman *et al.* 2003) and the recently released book *Safe Passages* (Beckman *et al.* 2010)), as well as by far the largest proportion of research papers in road ecology coming from North America. Furthermore, government agencies such as the U.S. Federal Highway Administration (see www.fhwa.dot.gov) and the biennial meetings of the International Conference on Ecology and Transportation (ICOET) have been very successful in facilitating cooperation and an exchange of ideas. Nonetheless, and despite the regular attendance of researchers from numerous countries other than Canada and the U.S. (including Australia) at ICOET, the focus of these activities remains predominantly and undeniably North American.

In contrast, gaining easy access to European information - research findings and technical details of plans, approaches and concepts associated with crossing structures - *in English* remains distinctly limited. While important studies and reviews of European work do appear in the English literature, the relative paucity of these means that it is quite possible to form the opinion that, compared to North America, this field is somewhat modest in scale in Europe with relatively little activity and innovation being evident. The reality is, in fact, quite the opposite.

Primarily because much of the information is not available in English and in only limited forms, road ecologists and others may be surprised to learn that European nations have been actively engaged in mitigating the impacts of roads for many decades, that the legal and policy frameworks are thoroughly embedded in national administrations and that, as a result, the number of major crossing structures both existing and planned is astounding. If we consider only the largest and most expensive structures – fauna overpasses - France alone has more than 125, while some of the 'landscape ecoducts' constructed in Switzerland and Spain are over 800m in width (Holzgang *et al.* 2001, Colatti *et al*. 2008). Combined with those from other mainly Western European countries, the total number of these massive structures is certainly in the hundreds. Purpose-designed underpasses occur throughout the continent and must number thousands, not including the many smaller amphibian tunnels. Vast numbers of crossing structures are also being incorporated into the massive expansion of new roads being constructed in a range of newer European Union Member States as part of development and modernisation efforts.

Beyond the sheer scale of these construction activities, understanding the legislative and planning frameworks that have resulted in what is an attempt at 'de-fragmentation' at a continental level would be greatly instructive. Some obvious questions include: Where does the pressure to comply come from? Is it local, national, regional or European in origin? Has the EU been able to influence what are national decisions on the manner is which roads are planned and designed? Has EU membership resulted in uniformity among the vastly different states?

Figure 1.3. Typical open fauna ecoduct from eastern Austria (photo: Fabrice Ottburg)

The aims of this review: Learning from the European approach

It is my conviction that environment-sensitive road design in Australia – and elsewhere - has much to learn from the policies and practices of our European colleagues. Unfortunately, while the number of projects and associated published material is considerable, relatively little is available in English. Despite this, individual researchers, consultants and road designers have been more than willing to share their considerable knowledge and experience. Indeed, such people are justifiably proud of their achievements in what have often been groundbreaking innovations.

During sabbatical leave from my University taken in the latter half of 2010 I began what I hope to be a comprehensive exploration of the European road ecology literature with a view to synthesising what might be useful to an Australian audience. As intimated earlier, while I found plenty of material, much of it Government agency or consultancy reports from a wide range of countries, most of this was not in English. Initially, I felt that this problem could be overcome simply through translation. However, it soon became clear that an understanding of the procedural and historical context in which these reports were written was essential. Moreover, being written largely for internal consumption within a specific organisation (for example, explaining the principles of impact assessments to field workers), a thorough understanding of the national legal and compliance background was assumed in most cases. Attempting to understand and appreciate such contexts was crucial to a better appreciation of the information, yet was essentially impossible from outside the country itself.

Figure 1.4. Modern fauna overpass on A66 motorway in north-west Spain (Photo: Cristina Mata)

The obvious answer to this dilemma was to obtain information and views directly from appropriate people working in the field in some of the main European countries. Given a strictly limited opportunity for travel (approximately one month, September 2010), it was obviously not possible to visit more than a few key countries, and, based on the availability of suitable people, these were selected to be The Netherlands, France and Spain. However, my access to knowledgeable experts from a far greater range of countries was unexpectedly expanded when I was invited to attend a symposium of the Infra Eco Network of Europe being held in Velence, Hungary in late September 2010.

The general aim of this report is to provide a brief guide to the range of approaches being undertaken in European countries in terms of the procedures for planning roads, mitigating impacts and recent advances in monitoring. Overall, my intention is to explore whatever aspects of European road ecology may be beneficial to the Australian scene as we move rapidly into a more mature approach to these critical areas. As a framework to these aims I posed the following three questions; the bulk of the content of the report that follows represent my attempt to address these questions:

(i) *Why has European road ecology evolved to its current state?*

(ii) *What are the key approaches to addressing the impacts?*

(iii) *How can this information be applied in Australia?*

The structure of this review is as follows:

1 **Roads in the landscape**. This section provides a brief overview of the main issues as a concise background to the more detailed sections that follow. This is provided as a simple introduction to the field for those less familiar with the issues.
2 **Europe in context**. Any attempt to understand Europe requires a brief resume of the European Union and the implications for countries within.
3 **The influence of the European Directives**. The legislative influence of the EU in requiring Member States to comply to its ruling has proven to be fundamental to the current state of play.
4 **Responses to the Directives.** The significant challenge posed by the EU rulings lead directly to a remarkable level of international cooperation, leading eventually a common approach: the Handbook.
5 **Avoiding ecological impacts**. The best way to reduce impact is to avoid, either within the landscape or at the locality level.
6 **Mitigating ecological impacts**. Describes current practices and innovations in the design and construction of underpasses and overpasses, with the aim of addressing fragmentation.
7 **Ecological compensation**. A brief summary of some of the issues associated with this 'last resort' measure, and some comments of new approaches.
8 **Monitoring.** Often downplayed, systematic and reliable assessment is essential for improvements.
9 **Conclusions**. Finally, some general principals that can be usefully considered in the Australian context, and a plea for integration of these considerations as just one of the issues considered by planners.

Acknowledgements

The Grand Tour on which this review is based would never have been possible without the remarkable efforts, suggestions, encouragement and finally personal tour guiding by Edgar van der Grift (Alterra, Wageningen, Netherlands). Edgar also pulled some strings to ensure I got a spot at the IENE conference in Hungary. In France, my invaluable guide was Eric Guinard (Développement durable et de la Mer, Ministére de l'Ecologie, de l'Energie, Cedex, Bordeaux). I was also honoured to have David Maucour (Eiffage, France) and Cyrille Beaux (conseils en Environnement, France) provide a personal tour of many of the structures on the soon-to-be opened A65 in southern France. In Madrid, Cristina Mata and Juan Malo of the Universidad Autonoma de Madrid selflessly took several days out of their busy schedules to show me around the new overpasses in the district and even more importantly to share their experiences of the decision-making processes. In Catalonia I was again provided with a personalised tour of the remarkable new C37 mountain motorway and the Park Natural dels Aiguamells de l'Emordá with Carme Rosell, Marc Bou and Ferran Farré from Minuartia, Barcelona. Finally, at the IENE conference in Valence, Hungary I am sincerely grateful for discussions with Hans Bekker and Fabrice Ottburg (The Netherlands), Paul Wagner (USA), Lenore Fahrig (Canada), JO Heliden (Sweden), Isobel Abbott (Ireland), Miklós Puky (Hungary), Helena Marques (Portugal) and Marguerite Trocmé (Switzerland).

I am grateful to Cristina Mata and Fabrice Ottburg for the use of several of their photographs; all others are by Darryl Jones.

Road ecology tour guides extraordinaire, long-lunch exponents and experts in the(ir) field(s) (from left): Edgar van der Grift, Cristina Mata and Juan Malo, Carme Rosell, *and* Eric Guinard.

2 Roads in the landscape

While any attempt to understand the full influence of roads on natural systems and the biodiversity present would be impossibly complex, the key impacts can be categorised as follows. (Note also that while this discussion relates primarily to roads, many of the same issues are associated with other linear infrastructure elements including railways, powerlines, pipelines, seismic lines and hydroelectric developments). These types of infrastructure will not be described in any detail here but see Forman *et a*l. (2003). Further details on road impacts can be found in Fahrig & Rytwinski (2009) and Taylor & Goldingay (2010).

1 Habitat loss and the road effect zone

The most obvious environmental consequence of the construction of a road is the necessity to remove existing vegetation from the route. The actual impact is far greater than the extent of the road surface of course; most roads are bound by a verge of varying width which consists of gravel or mown grass. In addition, many significant influences associated with the road can extend well beyond the road and verge, with noise, pollution and light being the most important. Considered together, these impacts result in an area known as the 'road effect zone'.

2 Edge effects

The 'road effect zone' concept emphasises that the influence of the road may extend well into the landscape on either side, even were the verge abuts against a forest. Because of the abrupt change in habitat structure from cover to fully exposed, the edge of the habitat may be penetrated by light, noise, fumes, rubbish, weeds and predators which use the road as a means of gaining access to food resources.

3 Barrier and filter effects

Because roads dissect so much of the landscape, animals attempting to move across the roads face obvious risk of mortality. Some species may attempt to cross anyway; others avoid the area entirely. Certain small mammals appear not to cross even small roads, while many frogs attempt to move over busy highways, with the expected massive mortality. There is also good evidence for individual differences in the reactions of certain species to crossing behaviour. We also now know that many small forest birds are highly unlikely to venture across multi-lane roads, while other bird species show no obvious avoidance. Thus, roads can represent a compete barrier, a partial filter or may be ignored altogether.

4 Isolation of populations

When the road represents a complete or partial barrier to animal movements, or where crossings result in significant mortality, animals living within a habitat remnant may become entirely isolated from other nearby populations. This greatly increased the chances of local extinction as replacement individuals are unable to recolonise across the barrier and genetic exchange becomes unlikely or impossible.

5 Road mortality

The death of individuals due to collisions with vehicles is the most visible and obvious form of direct impact associated with roads. It is also the single most significant road-related issue for the community, especially were charismatic species (for example, otter *Lutra lutra* or koalas *Phascolarctos cinereus*) are involved. The importance of road mortality depends, however, on the extent to which the populations beside the roads are affected. The deaths of large numbers of locally abundant animals may be of little consequence. Unfortunately, there are now numerous studies that indicate serious population declines in a wide range of species due directly to road-kill rates. Indeed, road mortality leading to local extinction was first demonstrated in Australia (Jones 2000).

Being a relatively new field, research into many of these impact and influences has largely been small in scale and typically focussed on specific examples from single locations or a particular road. More recently, an explosion of studies from around the world has enabled the first large-scale general syntheses of the impacts of roads to be undertaken. These reviews are the first to document the generalised nature of road and traffic influences at an international scale and are summarised very briefly here.

In a review that focussed on the impact of roads on the abundance and distribution of 131 species, Fahrig & Rytwinski (2009) found largely negative effects for most amphibians, birds and large mammal species. Interestingly, the review found small mammals in general to be either neutral of positively affected by roads (these species tended to be those tolerant of the disturbance of traffic but nonetheless avoiding the road itself). Four types of species were identified as being especially impacted by roads: (i) species attracted to roads and unable to avoid vehicles; (ii) species with large movement ranges, low reproductive rates and low natural densities; (iii) species that avoid habitats near roads; and (iv) species that were not deterred by roads but were unable to avoid vehicles.

In the second important review, Benítez-López *et al.* (2010) conducted a statistical meta-analysis of data contained in a large number of studied from four continents, using the relationship between abundance and distance to the road as the key variable. They found clear evidence of a decline in the abundance of both birds and mammals. Specifically, this detailed analysis found reductions of 28-36% within 2.6 km of the road for birds, and 25-38% within 17 km for mammals. Somewhat unexpectedly, these authors found no consistent influence of traffic intensity on either group.

Mitigating the impacts of roads

Both of the two reviews mentioned above conclude by stating strongly that the effects identified clearly strengthen the call for mitigation measures: "We argue that the evidence for population-level effects of roads and traffic is already strong enough to merit routine consideration of mitigation of these effects in all road construction and maintenance projects" (Fahrig & Rytwinski 2009: 1).

Mitigation of the impacts of roads has taken many forms but these can be simply classed as measures that either: reduce road mortality, or allow the safe passage of animal from one side of the road to the other. A separate though related measure is that of providing compensation for situations were some level of impact is unavoidable. These measures form the basic for a huge international effort are will be discussed in considerable detail within this report. Here I provide a simple introductory explanation.

1 Reducing road mortality

Keeping animals away from busy roads is not only important for biodiversity, it is a fundamental element of facilitating the safety of the motorists. Indeed, the provision of fencing and other structures that attempt to exclude animals from gaining access to the road has long been a feature of many larger roads through the world, but especially in areas where larger mammals are present. As a result, exclusion fencing may be regarded as the first widely used structure to be employed as a mitigation measure, although its primary use was and often remains aimed at human safety.

2 Safe crossing structures

While the use of exclusion fences may be highly effective in keeping animals safely away from the traffic, these structures also intentionally prevent the movement of animals across the road. To address this fundamental issue, a wide range of structures is used that allow the safe passage of animals either under or over the road. Critical assessments and appraisals of the design, installation, dimensions, methods of monitoring and refinements represent much of the considerable efforts of international road ecology researchers.

3 Compensation

Where impacts cannot be avoided, compensatory measures are sometimes required as part of an overall road construction project. Although the form of the compensation varied widely, the most common approaches are either the acquisition of suitable habitat in another location or the rehabilitation of a degraded site. This remains the most problematic and unresolved issue in this field.

While fencing to prevent animal's access to roads have been a long-term feature of many roads, and compensation is relatively new and contentious concept, the construction of safe crossing structures has been the main focus on mitigation efforts for several decades.

3 Europe in context

When viewed from elsewhere, the state of play in Europe in relation to addressing road impacts appears to be extensive and also intensive, well established in places and barely embryonic in others. There is, as must be expected from their vastly different histories, levels of economic development and potential for growth, great diversity among the different countries making up modern Europe. As will be seen, membership of the European Union has been a fundamental influence on many Member States though not on all.

3.1 *State of the Union*

Given the historical flux in membership of the EU it is worth summarising the current status of this important international body. At present, the EU is made up of 27 Member States making up most of those found in the continent of Europe (Figure 3.1) although Cyprus, geographically regarded as part of Asia, is also a member. The exceptions are Switzerland, Norway, Russian, Iceland and the Baltic State nations. A further four countries currently have candidate status (Turkey, Croatia, Iceland and Macedonia). Only 16 of the 27 Member States belong to the Euro-zone.

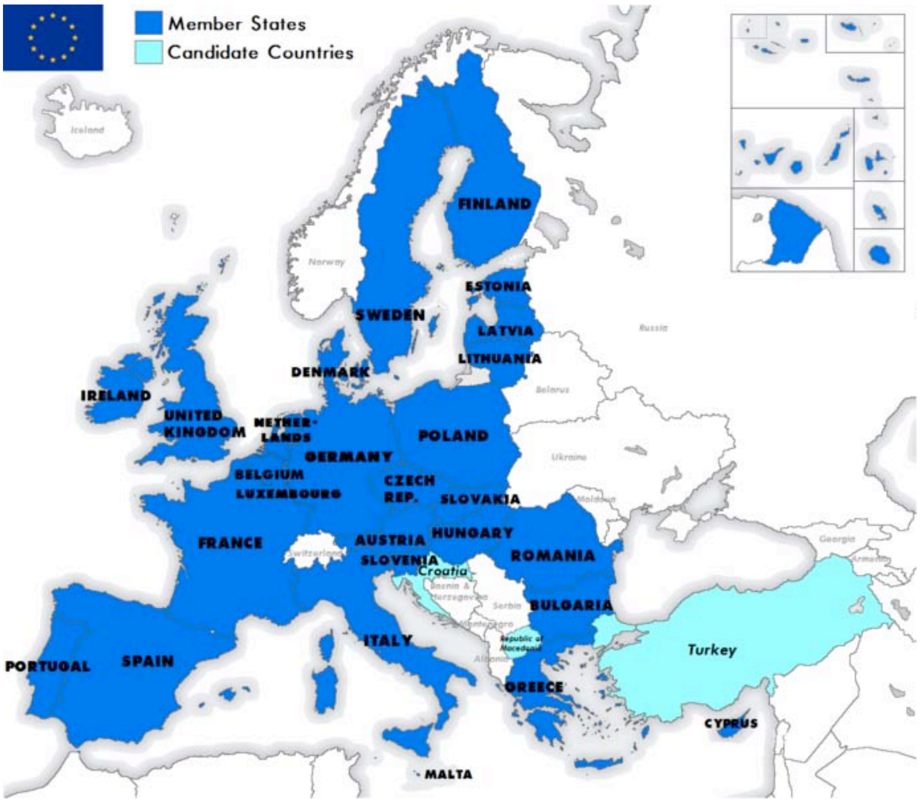


Figure 3.1 Member States of the European Union in 2009, showing full members in dark blue and official candidate states in light blue (source - http://www.eea.europa/maps)

These countries support 500 million people, or 7.3% of the global population, in just 3% of the land. Although many people still live in villages and rural settings, in 2006 75% of Europe's population lived in large cities, a figure that is continually growing. Moreover, while the average density of persons per square kilometre was 113 overall (in 2006), the range is extreme with very lower densities in the far north but 24,672/km^2 in inner Paris! The entire urban area associated with the French capital is the largest in Europe (9.9 million) with London (9.3 million) a close second. However, official population counts for single cities can be misleading; Europe also has numerous massive conurbations where the urban growth of several cities has merged to form vast metropolitan areas. These include Germany's *Rhine-Ruhr* (Cologne, Düsseldorf, etc.) with 11.5 million, the *Randstad* in the Netherland (Amsterdam, Rotterdam, Utrecht, etc.) with 7 million and the Benelux *Flemish Diamond* (Antwerp, Brussels, etc.) with 5.8 million.

The European Environment Agency (www.eea.europa) is actively engaged in documenting and modelling future environmental changes for the EU as a whole as well for specific countries and regions. The most recent mapping of the dominant land cover types was completed in 2000 (Figure 3.2) and demonstrates clearly the dominance of anthropogenic landscapes throughout the region. While the conspicuousness of urban and industrial areas ('artificial dominance' and 'dispersed urban areas') may be expected, it is important to appreciate that the 'forested landscapes' cannot be regarded as natural habitats. Many forested areas are former agricultural or pastoral lands now rapidly revegetating (see below) following abandonment or, to a far lesser extent, due to intentional restoration. Virtually the whole of Europe, with the exception of the upper levels of the main mountain regions and parts of the extreme north is best understood as a thoroughly humanised or cultural landscape (Emannuelsson 2010).

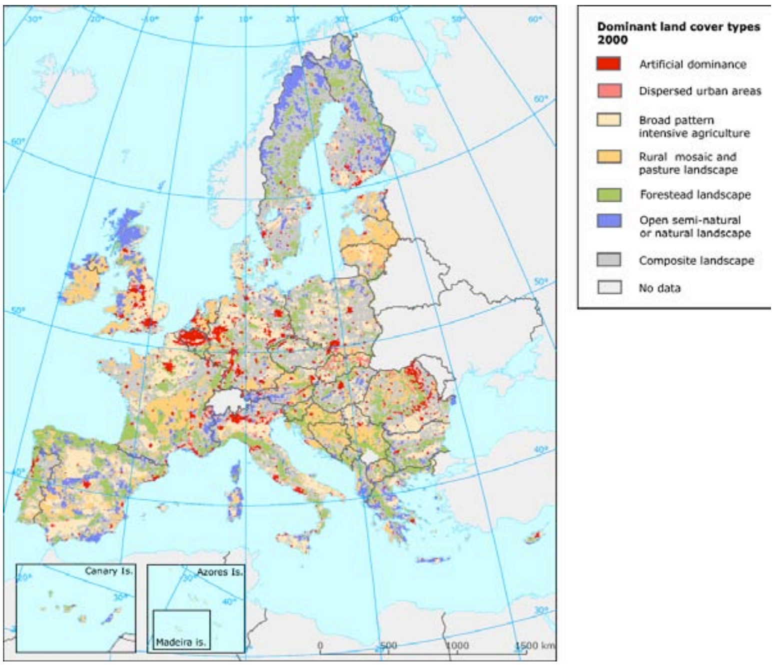


Figure 3.2. Dominant land cover types in Europe 2000 (www.eea.europa.eu/data-and-maps/figures/land-cover-types)

Figure 3.3 indicates the rate of change in the dominant land cover types for 1990-2000, while Figure 3.4 shows clearly the influence of human activities with urban, industrial and agricultural landscape increasing the most (5.3%), followed by land reclamation, primarily in Holland (2.3%) and the largely natural regrowth of forests increasing by 0.5%.

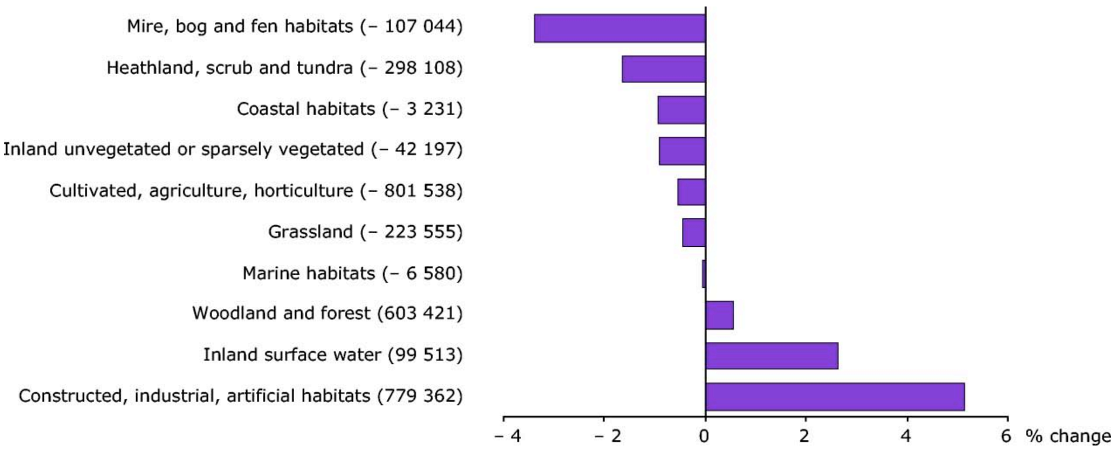
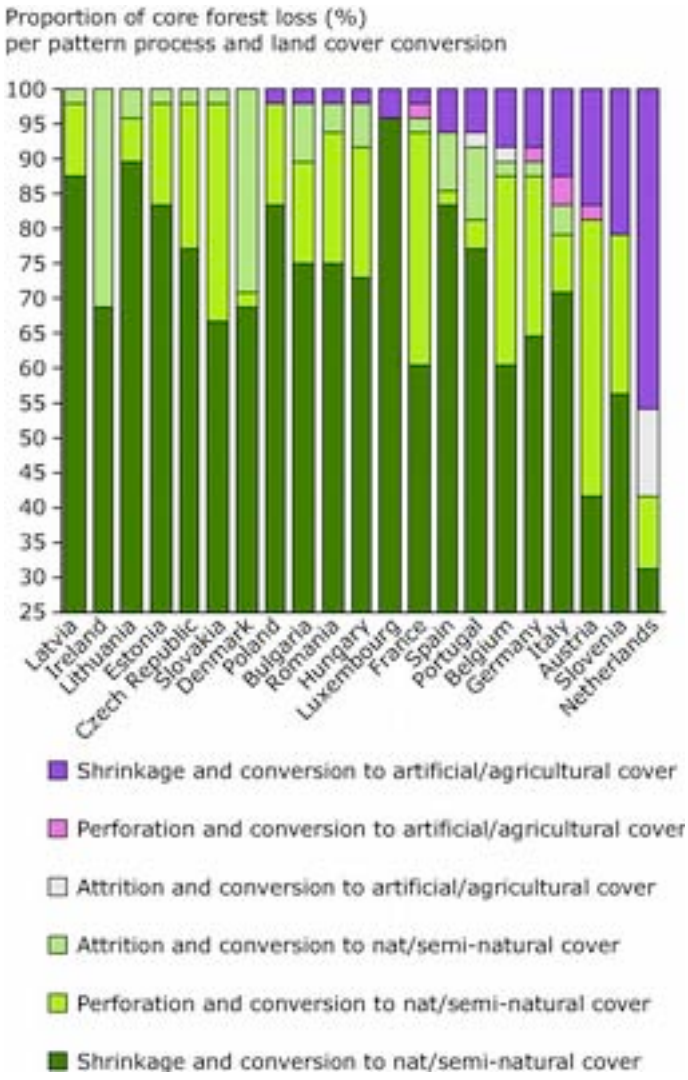


Figure 3.3 Percentage change in dominant land cover types 1900-2000 (source - http://www.eea.europa/data-and-maps/)



All natural cover types were in various levels of retreat, a feature further illustrated by **Figure 3.4** (left) which indicates the manner in which the main natural habitat areas (known as 'core forest areas') had changed. For example, fully 60% of natural areas in the Netherlands had changed due to 'shrinkage and conversion to artificial surfaces'. This was common, though certainly not as extreme, in several of the more industrialised countries, with the main form of conversion being directly attributable to transportation developments. The opposite trend – the change in core forest areas to natural/semi-natural forms of cover, again related to the regrowth of trees, was strongly evident in a majority of EU countries with several (Luxembourg, Lithuania, Latvia, Estonia, Poland and Spain) registering over 85% of the change as forest regrowth. It is worth reiterating for those of us living outside Europe that: “without intervention, the natural vegetation of Europe would consist many of different types of forest, whereas is currently a broad range of ‘cultural landscape’ ” (Farrall *et al*. 2002: 217).

Transportation-related developments throughout the EU over the last two decades (Figure 3.5) have shown some fascinating trends. While the construction of motorways has continued at a relatively steady rate throughout this period, the rate of growth in High Speed Rail networks was particularly dramatic. Predictions of demand for passenger and freight transport (Figure 3.6) point unquestionably to increasing if not accelerating rates of infrastructure development. As will be discussed later, the largest such projects appear likely in the newer Member States such as Poland and Bulgaria, countries with some of the largest and currently least fragmented landscapes (Figure 3.7).

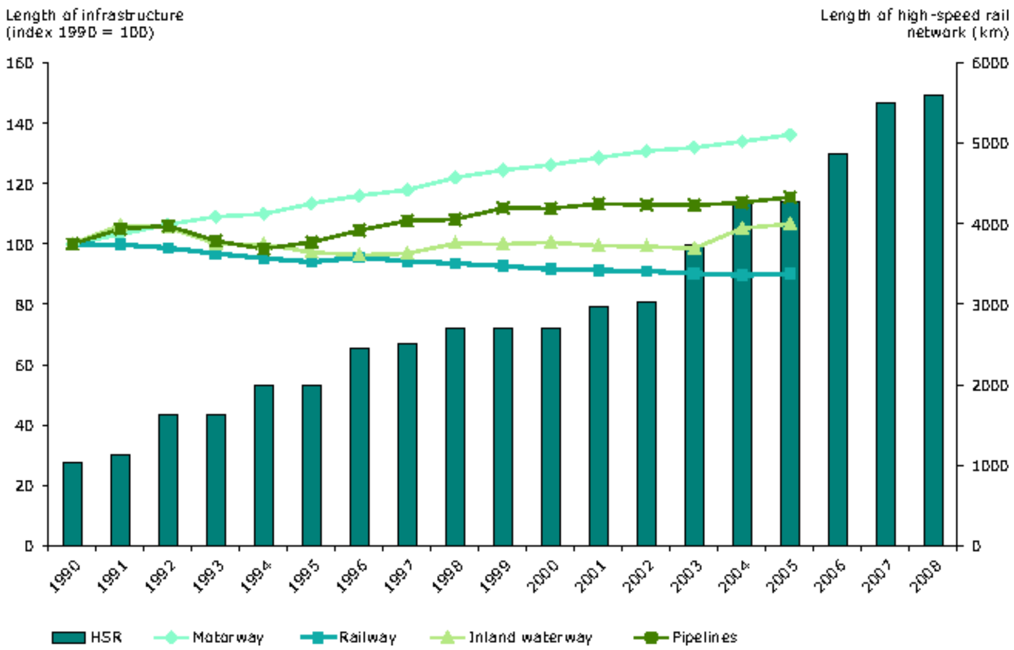


Figure 3.5 Actual construction of new transport infrastructure 1990-2008 (source - http://www.eea.europa/data-and-maps/)

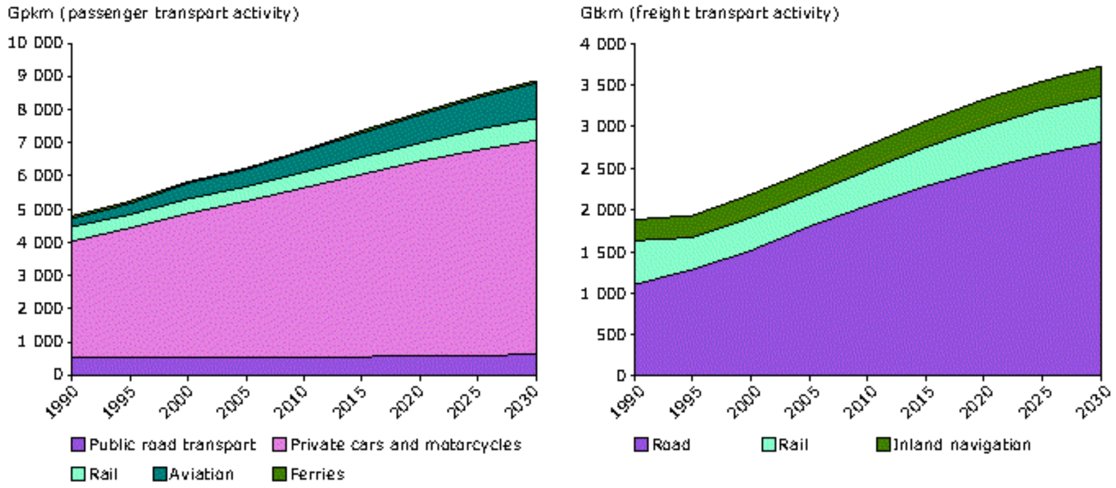


Figure 3.6 Projected growth of passenger and freight transport activity 1990-2030 (source - http://www.eea.europa/data-and-maps/)

This recent EEA spatial survey of the extent of fragmentation of natural and semi-natural landscapes identified urban development and transport infrastructure, in particular, as being the most influential drivers during the period 1990-2000 (Figure 3.7)(EEA 2010). Interestingly, this survey found sections of the Iberian Peninsula and Ireland to have exhibited the most dramatic rates of fragmentation.

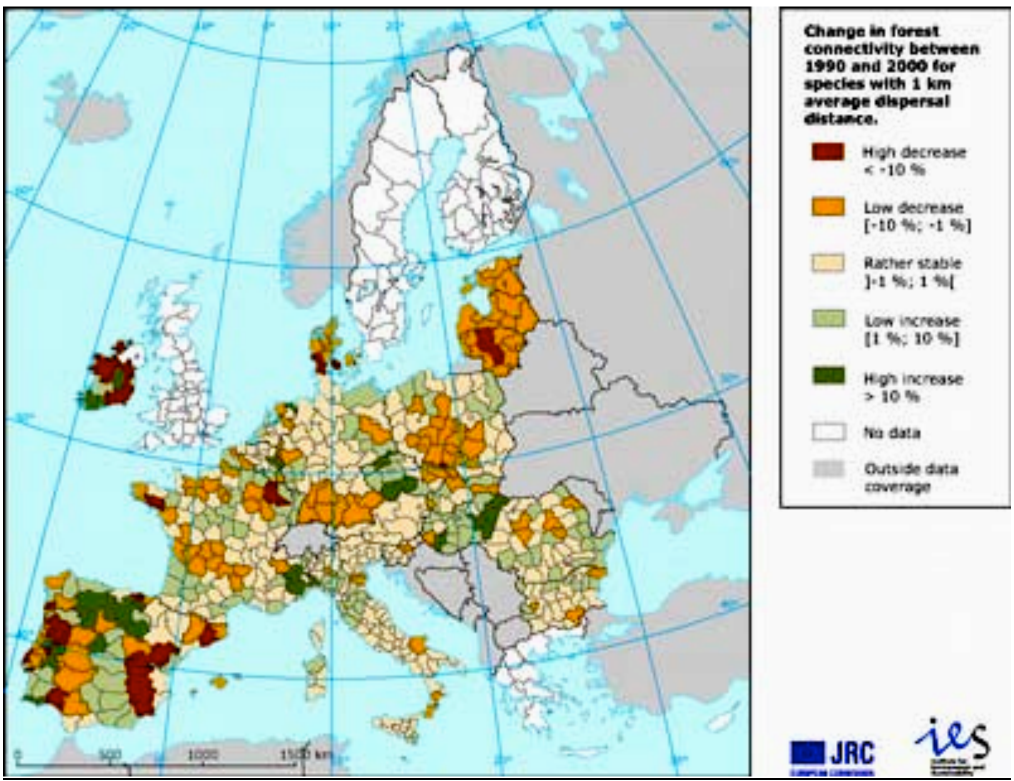


Figure 3.7. Change in forest connectivity for EU Member States 1990-2000 (source - http://www.eea.europa/data-and-maps/)

Obviously, with countries differing dramatically in overall size as well as many other criteria, the impact of the road network will have resulted in greatly varying levels of habitat fragmentation. As a primary measure of the extent to which roads – as well as railways and other forms of linear infrastructure – dissect the landscape, isolating populations and increasing their susceptibility to extinction, a reliable quantitative measure of fragmentation is seem as an essential element needed when considering future infrastructure plans. With this in mind, Jaeger *et al.* (2008) have developed a measure known as 'effective mesh size' (Jaeger 2000) which determines the probability of two random points in a region being disconnected because of a barrier. The more roads in the landscape, the higher the effective mesh size. Figure 3.8 shows clearly the extent to which well-developed, smaller countries (e.g. Luxembourg, Belgium etc.) have become extremely fragmented while wealthy large countries (e.g. Sweden, Norway etc.) remain remarkably intact (Jeager *et al.* (2010)).

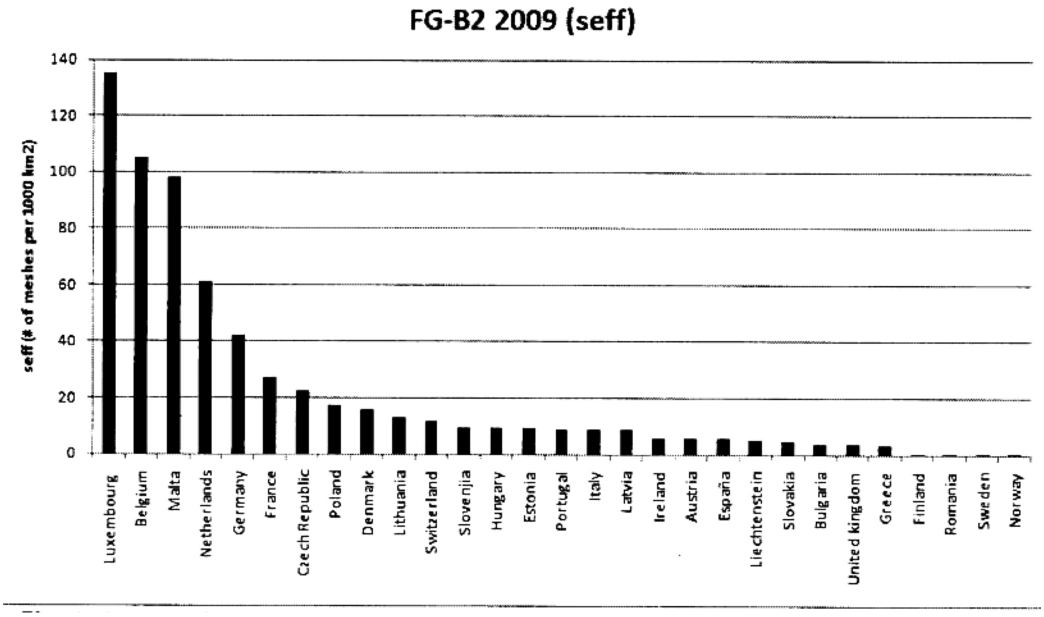


Figure 3.8 Degree of landscape fragmentation (effective mesh density) in 29 European countries in 2009 (from Jaeger *et al.* 2010)

At a smaller geographical scale (Figure 3.9), the severity of this measure of fragmentation is evident throughout much of central Western Europe while large portions of northern Scandinavia, Scotland and far eastern Europe are relatively less affected. This approach is already being promoted as a quantitative tool in controlling landscape fragmentation in Germany and beyond (Jaeger *et a*l. 2010)

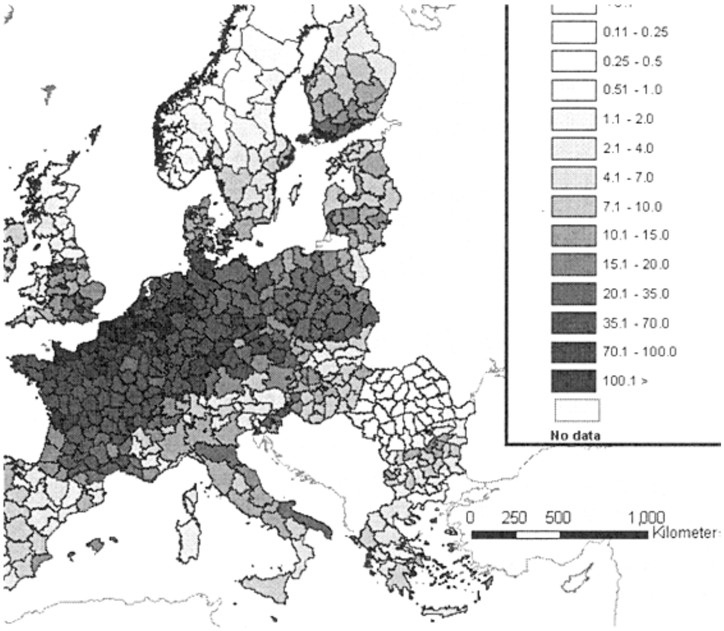


Figure 3.9 Landscape fragmentation in Europe in 2009 for 582 sub-regions using effective mesh density (from Jaeger *et al*. 2010)

Figure 3.10 Landscape fragmentation in Austria; regrowth forest and agricultural landscapes dissected by a small motorway yet permeable through the construction of fauna overpasses (photograph: Fabrice Ottburg)

4 The influence of European Union Directives

Understanding the response of European countries to environmental impacts such as the construction of transportation infrastructure requires some appreciation of the influence of the EU in directing and requiring the compliance of Member States to adhere to certain principles. As we shall see, while countries differ in the level of attention paid to these principles, the conditions associated with EU membership have resulted in an unprecedented degree of international agreement, and even uniformity in approach despite the legal recognition of national 'freedom to respond'.

Globally, the participation by independent countries in most international conventions and policies is voluntary and even becoming a signatory is seen as a moral rather than legal necessity; effective enforcement is difficult and frequently problematic. This is not the case with the EU. Member States are bound to implement European Commission laws and policies, with non-compliance enforceable through the European Court. Thus EU membership is accompanied by significant external jurisdictional influence (Farrell *et al.* 2002).

The legislative framework of the EU consists of three elements: Directives; Regulations; and Decisions, each of which has associated conditions of acknowledgement and compliance. Directives adopted by Member States are required to be transposed into national legislation, typically within a time frame of about two years.

To appreciate the current state of play with respect to controls on development on the environment in the EU three historic articles are of fundamental importance: the European 'Birds' Directive of 1979, the European 'Habitats' Directive of 1992, and the subsequent formation of the 'Natura 2000' network of key sites. These will be discussed below; the foundations, however, of these essential pillars of the current architecture of European de-fragmentation were constructed well prior to these directives.

4.1 The foundational conventions

Concern for integrating environmental considerations into national infrastructure planning was evident in the founding documents of the European Economic Community (1957) with Article 130R directly addressing the necessity for ensuring the pre-eminence of "precautionary measures and preventative action" and the "prioritising of at-source correction [to minimise] environmental damage" (Treaty of Rome, 25th March 1957; reiterated in Treaty of Maastricht, 1993). Of course, these statements were largely intentional rather than prescriptive and the impetus for post-war reconstruction that was underway during the 1950s and 1960s meant relatively little in terms of curbing rates of infrastructure developments.

Community attitudes and activism throughout the Western world in the late 1960s and 1970s had a profound influence on many European governments, and led directly to several important international meetings which in turn resulted in a number of influential conventions. These were:

i) The Ramsar Convention (1971)

'Ramsar' (*Convention on Wetlands of International Importance, especially as Habitat for Waterbirds*; named for the Iranian town in which the convention was signed) was concerned with the conservation and 'rational use' of wetlands internationally, and required signatory states to record sites according to specified criteria associated with their ecological representativeness and unique features. (France alone has 22 such sites.) The convention was a moral rather than statutory instrument, and although the identified sites were intended to be 'untouchable', there are no binding sanctions included.

ii) The Bonn Convention (1979)

'Bonn' (*Convention on Migratory Animal Species* (82/461/CEE)) is a world-wide intergovernmental treaty aimed at the conservation of wild fauna and their habitats which extends and strengthens the conditions of the Ramsar Convention. The convention has lead to many multilateral agreements. Within the EU signatory states undertook to implement swift measures ('immediate full conservation') for the protection of 28 European species threatened by extinction, and to attempt to conclude cross-state agreements for a further 29 species.

iii) The Berne Convention (1979)

The second convention of 1979 (*Convention on Conservation of European Wildlife and Natural Environment* (82/72/CEE)) was by far the more wide-reaching of these instruments and, with a more explicit European focus, has proven to be especially influential. This convention recognises that:

> *Wild flora and fauna constitute a natural heritage of aesthetic, scientific, cultural, recreational, economic and intrinsic value and that there conservation and transmission to future generations is important.*

This convention requires signatory states to establish minimum protection for all wild species of plants and animals, to ensure additional protection for listed species, to safeguard the related habitats, and to pursue cooperative contracts between states to achieve these goals. The convention included a series of addenda listing specific species at varying levels of conservation status. These lists were then approved at the level of the European Council, requiring 'conservation' by member states where necessary.

The convention also included an important and influential statement on preventing impact:

> *In the event of serious or irreversible damage, lack of absolute scientific certainty must not be a pretext for postponing adoption of effective measure aimed at preventing environmental degradation.*

4.2 The 'Birds' and 'Habitat' Directives

The implementation of the conventions described above is often described as being 'activated' through the issuing of two directives by the European Council. However, the first, known as by the shorthand of the '**Birds Directive**' (*Council Directive on Wild Bird Conservation* (79/409/EEC)) was actually signed on 2nd April 1979 (earlier than both the Bonn and Berne Conventions of the same year) and was enforceable from April 1981. This directive deals with the conservation, management, control and usage of bird species living naturally in a wild state, and provides for the nomination of special sites (*Zones de Protection Spéciales* (ZPS)) aimed at the long-term conservation of the habitats of the most threatened bird species, as well as migratory species.

As well as the ZPS sites, each EU country was required to nominate an inventory of additional sites regarded as important bird conservation sites (ZICO: *Zones Importantes pour la Conservation des Oiseaux*), although there was likely to be considerable overlap in these sites.

The Birds Directive provided a fundamental impetus to research and discussion of important conservation sites throughout Europe although most activity to this end was concentrated in the main Western European Member States. In addition, and to some extent independent of this process, the long-running United Nations program known as *Man and the Biosphere* (MAB) was launched by UNESCO in the 1970. This program aimed to establish a world-wide system of Biosphere reserves for the "conservation of natural areas and the genetic material they contain". While nominally global in scope, this program has been especially successful and active in Europe where 158 sites have been designated MAB reserves of varying status in 27 countries.

Even more significant than all of the preceding instruments was the so-called '**Habitat Directive**' (*Council Directive on Conservation of Natural Habitats, Wild Fauna and Flora* (92/43 EEC)) which was signed on 21st May 1992). This directive is seen as a direct transcription of the Berne Convention into European law, and required member states to pay close attention to the conservation, management and restoration of sufficient representative habitat in respect to each country as part of the whole of the European biosphere. The administrative and legal strength of this directive lies in the stipulation for each country to nominate a network of sites with the specific aim of "ensuring continued biological diversity by conserving natural habitats as well as wild fauna and flora".

The Habitats Directive is comprised of two parts, the first dealing with the designation of special conservation areas, and the second concerned more directly with extensive lists of species nominated in various addenda. Both parts have proven to be of great importance.

The first section requires Member States of the EU to establish a "coherent network of sites of key conservation significance (*Zones Spéciales de Conservation* (ZSC))". This Europe-wide network is known as *Natura 2000* and properly constituted would provide the best landscape-level framework for the long-term conservation of biodiversity in the continent. As such, the nomination of each site, the ecological linkages between sites and the functionality and integrity of the apparent geographical network are profoundly important to all of Europe.

The second section of the directive concerns specific species which may be listed as a means of strict legal protection or for sustainable management. For example, European mink *Mustela lutreola*, otter and lynx *Lynx lynx* are listed as 'requiring strict conservation' (Addendum IV) while others (including stone marten *Martes foina*, polecat *Mustela putorius* and blue hare *Lepus europaeus*) may be 'subject to management measures' (Addendum V). The discovery of any species listed in the more serious addenda will have immediate and significant implications for a project.

The advent of these directives has lead to a profound change in the responsibilities of national governments and consequently in the way that developments are approved and planned with respect to possible environmental impacts. The directives have led most Member States to draft their own legislation and to promulgate important changes in the manner in which both pre-approval Environmental Impact Assessments and post-approval compliance are undertaken. Moreover, the existence of a wide variety of significant sites throughout Europe (Figure 4.1) has largely clarified the degree to which attention is required when projects directly or indirectly impact or influence the ecological integrity of a recognised site. Not unexpectedly, legal challenges have been frequent but the general consensus of jurisprudential experience is that the "degradation [of a listed site] can only be justified for imperative reasons dictated by greater general importance than ecological interests" (SETRA 2005: 26). Breaches of a directive, such as failing to respond appropriately to the presence of a listed site or species can lead to a member state appearing before the European Court of Justice. The existence of these sites – now included in the *Natura 2000* network – is taken very seriously indeed.

4.3 The Natural 2000 network

The Habitats Directive listed almost 200 types of 'natural habitat' and about 500 'species habitats', closely associated to the species listed in the various addenda. However, this was primarily a form of 'indicative' nomination. Member states were required to clarify the sites listed and to amend, modify and expand the lists based on further scientific investigations undertaken specifically as part of a verification process by each country. The process has been underway at varying levels of intensiveness across the EU with the addition and in a few cases, deletion, of sites. At present (late 2010), about 16 years since the 1994 enforcement date, a total of 22,419 Sites of Community Importance and a further 5,242 Special Protections Areas (resulting from the 'Birds Directive') have been gazetted. In total these cover fully 17% of all EU lands.

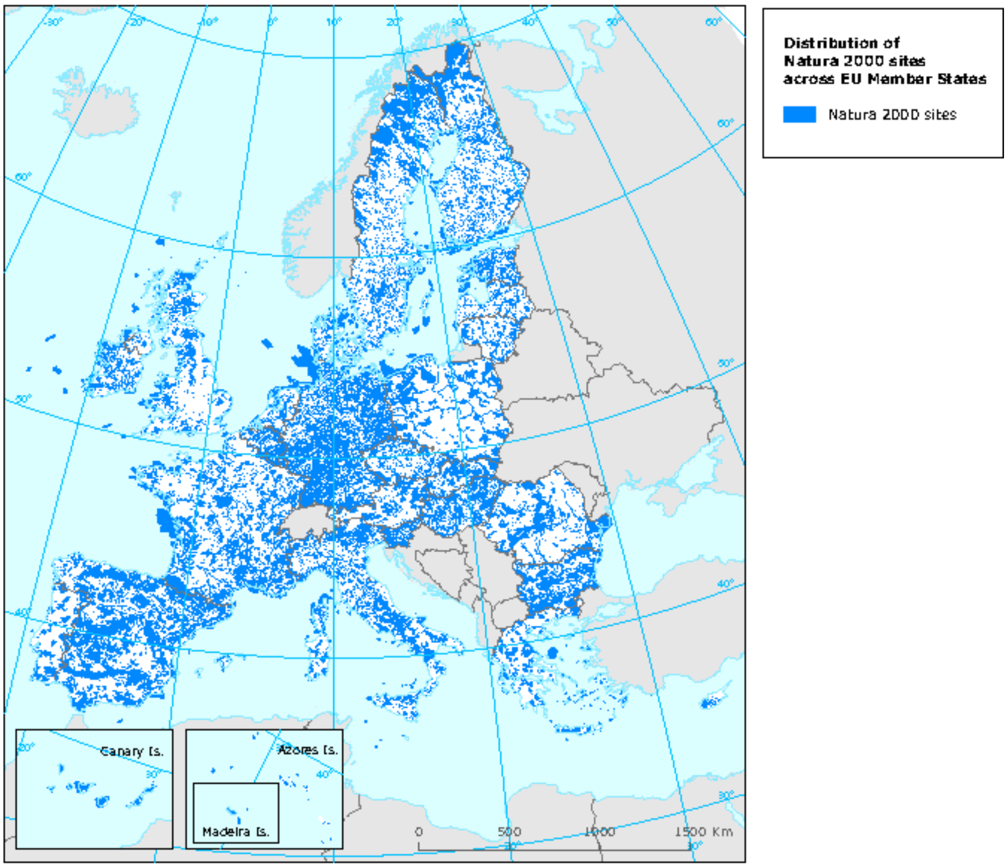


Figure 4.1 Distribution of *Natura 2000* sites as of 2010 (source - http://www.eea.europa/data-and-maps/)

Figure 4.2 *Natura 2000* wetland site in southern France crossed by new motorway

5 Responding to the Directives

The identification of the *Natura 2000* sites and the formal requirement that any developments potentially likely to impact either directly or indirectly on the function and integrity of these sites had a rapid and long-lasting influence on the process of planning and execution of most sizeable developments throughout Europe. Unavoidably, because of their massive geographical scale and well-recognised potential for environmental impacts, transport infrastructure project have been especially likely to be affected by these directives. Moreover, the increasing appreciation of the importance of connectivity to European biodiversity inevitably placed the forces leading to fragmentation on centre stage.

Running parallel with these attempts at environmental control within the European Commission were EU programmes designed to foster development, improve communication and encourage economic efficiency, especially among emerging countries in Central and Eastern Europe. A key initiative to this end was the Trans-European Transport Network (TEN-T) which resulted in an unprecedented doubling of transportation infrastructure between 1970 and 1996 with the construction of about 100,000km of roads and similar lengths of railway (de Vries & Damarad 2002). Given that approximately 10ha of land is lost for every 1km of motorway constructed, and that local road networks actually expand despite the building of motorways, the impact of these developments was obviously immense.

5.1 Infra Eco Network Europe (IENE)

Many of these concerns and challenges were raised at one of the first European conferences on the subject held in Maastricht, The Netherland in September 1995. As a direct outcome of this conference, a diverse group of road engineers, planners, researchers, and representatives of government agencies and Non-Government Organisations (NGOs) agreed to form a truly international cooperative group, eventually known as the **Infra Eco Network Europe (IENE).** IENE has been at the forefront of attempts to facilitate the exchange of ideas and information in relation to fragmentation associated with transportation infrastructure. One of the first actions of this new group was to approach the European Commission for funding to undertake a comprehensive review of current knowledge and practices internationally. This funding was approved in 1998 by the European Commission's *European Co-operation in the Field of Scientific and Technical Research* (COST) under the direction of the Directorate General for Research. In essence, as summarised in retrospect at the completion of the project, the goal of this review was to seek answers to two colossal questions:

> *How can the European transportation infrastructure network be upgraded and extended without significantly increasing the fragmentation affect, and how can the problems associated be addressed?* (de Vries & Damand 2002: 14)

The planning, coordination and delivery of this major project was the principle activity of the IENE for the following five years, culminating in a conference in 2003 (Brussels) at which most of the outcomes of the COST 341 were presented and launched (see below). This period of concerted and productive activity was followed by period of hiatus for IENE but which saw a dramatic expansion in de-fragmentation activities at national levels, the most significant being the production of country-specific versions and translations of the handbook (see 5.3).

Although IENE has organised several small-scale symposia and workshops in recent years, the convening of the second international-scale IENE symposium (see www.cbm.slu.se/iene/conf2010/conf2010.php) in Velence, Hungary in September-October 2010 was evidence of rejuvenation of what is certainly the most importance organisation of relevance in Europe. Over 200 participants attended this meeting, representing 24 European countries as well as North America, Australia, India, Japan, Korea, Brazil and Argentina. The leadership of IENE announced closer links with ICOET, the foremost North American meeting on this topic, and indicated the intension to hold biennial conferences in the years between those of ICOET. (The 2011 ICOET conference will be held in Seattle, USA and the next IENE (2012) meeting is scheduled to be hosted by Germany.)

5.2 The COST 341 project

The COST Action project number 341 was entitled *Habitat Fragmentation due to Transportation Infrastructure* (universally known as **COST 341**). Chaired by Hans Bekker of the Centre for Transport and Navigation within *Rijkswaterstaat* in The Netherlands, this remarkably ambitious undertaking has been extremely influential successful in achieving its aims. This has largely due to the motivation and conviction of the people involved from 16 EU countries and the European Centre for Nature Conservation.

The general goals of COST 341 were to assemble existing knowledge, review this critically and offer clear guidelines for those engaged in future transport planning. As general guiding principles, Damarad & Bekker (2003) emphasised three key points:

(i) *Such is the importance and complexity of fragmentation of natural habitats due to transportation infrastructure that solutions will only be possible through the acceptance of the issues at the policy level. Moreover, only a truly interdisciplinary approach – involving all of the participants from economists, engineers and ecologists – can provide the necessary skills to address the problem. Furthermore, the genuine engagement with the public is essential for a successful outcome.*

(ii) *Preservation of habitat connectivity should be seen as a strategic goal of the environmental policy of the transport sector.*

(iii) *Avoiding and mitigating impacts should be applied as a leading principle from the very start of planning.*

The IENE working group took an unexpectedly pragmatic view of the importance of clear and uncomplicated communication in the production of the reports and findings resulting from the project. The result was a series of accessible documents intended to facilitate understanding and adoption of the approaches described by the main audience, and including decision makers at national, regional and local levels. (All are available free of charge from the IENE website: http://www.cbm.slu.se/iene/cost341).

Seven integrated products were delivered by the COST 341 project as follows:

1 **National State-of-the-Art Reports**
As a first step in the process, individual countries were requested to produce national reports on the state of play, including successes and remaining challenges. A total of 13 national reports were received (Belgium, Cyprus, Czech Republic, Denmark, Estonia, Hungary, The Netherlands, Norway, Romania, Spain, Sweden, Switzerland and the United Kingdom)

2 **The European Review**
This Review (Trocmé *et al*. 2002) provides a valuable synthesis of the National Reports as well as an up-to-date (at the time) summary of international findings of research and understanding of the processes associated with fragmentation. Despite its date, this review remains one of the clearest and most effective descriptions of the complex processes associated with the impact of roads and presents convincing and practical arguments for action. Along with the Handbook (see below), this review is highly recommended reading.

3 **The European Handbook**
The most important and influential of all outcomes of COST 341, the Handbook provides the detailed technical guidelines required by road planners and engineers. Because of its central role in the development of European policy and practice, the Handbook is described in further detail below.

4 **On-line databases**
IENE provides a free and easily accessed source for the massive and growing array of reports, research findings and project-related information.

5 **Resources CD-ROM**
In addition to the on-line resources, all products are available free of charge on CD-ROM (see IENE website for details).

6 **The Final Report**

Effectively an extended Executive Summary of the key findings, this 16-page report provides a useful overview of all aspects of the project without necessary details.

7 **Proceedings of the 2003 conference**

The COST 341 project concluded with a conference and presentation of the findings held in Brussels 13-15 November 2003. All related documents are included in this package.

5.3 The COST 341 Handbook

A lack of knowledge can no longer be seen as a valid motive for not taking the necessary action to avoid or mitigate against the fragmentation problem. (Jansson 2002, *The European Review*)

The single most important product of the COST 341 project was 'The Handbook' (*Wildlife and Traffic: A European Handbook for Identifying Conflicts and Designing Solutions* (Iuell *et al*. 2003). This masterpiece of clear and effective communication is a synthesis of ecological concepts and engineering pragmatism that has become the cornerstone of the European approach to transport-related infrastructure development. Of the numerous reasons for its successful adoption across the continent, two of the keys have been:

(i) Its 'solution-orientated' approach, which was based on the accumulated knowledge of a vast network of experiences; and

(ii) An open acknowledgement that, while many of the issues were similar across international boundaries, the many important cultural, historical, economic and legal differences between countries have meant that in many situations, universal solutions were not possible. Explicitly:

It remains necessary to adapt and adjust measures to the local context. There is no substitute for the advice of local experts.

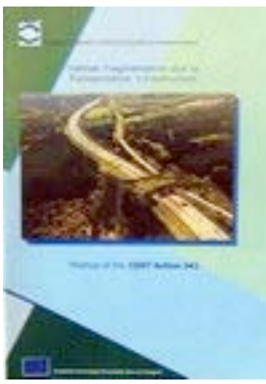
With these perspectives in mind, the Handbook tackles the main topic – the minimisation of the ecological barrier and fragmentation effects by transportation infrastructure – by making this a straight-forward objective at every stage of a major project, from the preliminary decisions associated with its instigation, through the design and planning phases and onto the implementation and construction phases.

One of the primary reasons for the influence of the Handbook is its promotion of an overall approach to the minimisation of fragmentation by a project. By ensuring that this issue is seen as one of the numerous engineering constraints – including costs, time frames, topography, cultural heritage, land-use, etc. - that must be assessed by the project's designers and planners, fragmentation can be integrated into the overall 'solution framework'.

The generally widespread adoption of this process has certainly been strongly promoted by the two levels of environmental assessment that is required of all construction projects within EU countries. Environmental Impact Assessment (EIA) legislation has been in place for several decades and aims to identify any possible environmental impacts of proposals during the planning phase. As has been the case in most countries, the effectiveness of the EIA process has sometimes been undermined by minimalist assessments and constrained by differing national opinions and priorities. Despite the intention of the legislation to ensure unequivocal protection to certain sites, selective interpretations have been able to inflate the projected benefits over the likely ecological losses.

An important milestone in the process of improving the integrity of EIAs and of promoting the integration of environmental issues into the overall planning process was the 2001 'Strategic Environmental Assessment' (SEA) Directive (2001/42/EC). This Directive required that all new regional plans and programmes in the EU were subject to an SEA, ensuring that environmental considerations become an unavoidable component of the process of development of long-term schemes (Damarad & van Straaten 2002). Thus, SEAs were to be undertaken at the strategic planning phase; EIAs came into play with the development of specific projects.

With the instruments of SEAs and EIAs in place, scrutiny of all aspects of an intrastructure's design became a technical reality and legal necessity, requiring more than basic compliance by the project team. The timely advent (in 2003) of the COST 341 Handbook provided a welcome and sound guide to approaching the significant challenges now associated with progressing many projects in Europe. The success of this document can be gauged partially through its widespread adoption throughout the EU and the fact that direct translations or official variations are now available in French, German, Spanish (and Catalonian), Swedish and Hungarian. In addition, technical guidelines and overviews, directly adapted from the Handbook are available in France, Spain, Poland and Switzerland.



The general approach that has been so influential in Europe can be traced back to the simple procedures initially formulated in The Netherlands in 1993 (Cuperus 2004). A bill (*National Structure Plan for the Rural Areas*) provided a decision-making procedure that involved the formal analyses of the perceived necessity of a project and its anticipated benefits against the projected loss of ecological values. The operational principal of the procedure was 'No net-loss of ecological value' through the following 'policy ladder'.

In strict order, these policies seek, with respect to a proposed development, to:

(i) **avoid** ecological impacts,
(ii) **mitigate** any unavoidable impacts, and
(iii) **compensate** for any impacts that many remain.

Theoretically, the application of this procedure should lead to 'zero-sum' loss, with the least mature of these level – that of compensation – being only applied as a last resort.

Because of their centrality to the European approach to de-fragmentation, each of these three components will be discussed separately in the sections that follow.

Figure 5.1. Approach to fauna overpass in open landscape in central Spain

6 Avoiding ecological impacts

The designation of the many thousands of internationally recognised sites comprising the *Natura 2000* network provided a significant challenge to the developers of many large-scale linear infrastructure projects. Given the rapid increase in costs associated with required mitigation measure and the legal complexities (and ambiguities; see below) associated with compensation, the option to completely avoid all notifiable impacts should typically be preferred. Indeed, the formulation of the policy ladder mentioned above has this as an explicit principle.

In explaining the optimal integration of a road into the local landscape, the Handbook states that: "The best mitigation [of ecological impacts] involves the selection of the least damaging alignment combined with sensitive scheme design" (Iuell *et al.* 2003: Chapter 6). Because these impacts can involve subtle influences (such as noise and invisible pollution which can affect natural areas over considerable distances), as well as the all-too obvious direct impacts associated with habitat destruction and degradation, full avoidance of sites is taken to be the normal first principle of effective road planning.

However, any attempt to achieve avoidance throughout the zone of potential influence of an infrastructure project will require the following from all associated stakeholders (Iuell *et al.* 2003: Chapter 4):

- (i) the application of the approach [outlined above] at every stage of the project's development;
- (ii) a commitment to the integration of all considerations – engineering, legal, logistical, social, environmental, etc. – within the wider planning framework where all affected interests are acknowledged;
- (iii) operational cooperation between all relevant authorities and organisations; and
- (iv) a willingness to include the involvement of a range of interest groups.

Needless to say, these conditions posed a significant challenge to the traditional approaches taken by most major project developers and their statutory supporters. Nonetheless, such integration has become commonplace if not the norm in most EU countries. Certainly numerous recent major infrastructure projects in The Netherlands, France and Sweden offer excellent examples of how cooperation and transparency have yielded clear logistical, environmental and social benefits (see Richter *et al.* 2010).

While careful consideration of route alignment option has always been fundamental to road planning, integrated consideration of effective site avoidance and minimising ecological impact has not always been evident. Beyond seeking routes that avoid sensitive areas, the Handbook (Iuell *et al.* 2003: Chapter 6) recommends that all earthworks should respond to the broad-scale of the landscape as well as to local-scale landform. The general guiding principle is to work with the topography in order to minimise habitat fragmentation while maximizing the opportunities for retaining (or enhancing) connectivity.

Four engineering solutions to these challenges are now routinely considered for roads in Europe.

(i) Tunnels

Although obviously among the most expensive structures associated with transportation infrastructure, tunnels are now remarkably common among recent European road projects. While obviously being extremely useful in avoiding ecological impacts, the primary motivation for their widespread adoption is associated with contemporary engineering standards which require extremely flat passageways (see Box 1). This has lead to some of the most significant environmental benefits being a by-product of changing construction practices (Figure 6.1). Nonetheless, the inclusion of tunnels can also be seen as one of the best ways for effecting site avoidance, at least in mountainous terrain.

Figure 6.1. Entrance to tunnel in southern Hungary on M7 motorway. The tunnel is under moderately sized hill in agricultural landscape which also supports numerous roe deer

(ii) Embankments

This engineering approach is particularly suited to wider, shallow valleys where the road route is able to follow the flow of the terrain by placing the passageway on an earthen bank. These structures are suited to situations where avoidance of the valley floor – especially in the case of sensitive wetlands are present – is an alignment priority. Provided the embankment is perforated with suitably designed underpasses and culverts, an embankment is preferred to the usual practice of cutting into the valley slope. By setting the road away from the existing landscape and providing sufficient permeability, the barrier effect as well as land-take can often be minimised. The slopes of the embankment can also be planted to enhance the habitat running parallel to the road.

Box 1: Maximising ecological connectivity by engineering flat roads

The current requirement for all new European motorways to minimise gradients (generally to less than 1.5%) is ensuring that tunnels and viaducts are often normal, if expensive, components of many recent projects traversing mountainous terrain. Calculations of the costs of fuel and traffic speed associated with different road slopes demonstrate clearly that flat roads are critically important, especially in relation to the movement of goods via long-haul lorries. Prior to these cost-benefit analyses, the costs of providing tunnels and viaducts for ecological reasons alone would have been prohibitive. Now, provided that sound avoidance principles are adhered to during all phases of the design and construction, high levels of connectivity has never been more achievable.

Example of 'Flat Road Syndrome': the C37 highway in northern Catalonia, is not only exceptionally low-gradient but as a result of minimising impacts below viaducts and above tunnels and cuts, is also Europe's most permeable road (see Box 2)

(iii) Viaducts

Probably the most impressive structures being routinely included as part of modern European motorways are viaducts (Figure 6.2). Along with tunnels, viaducts are an essential element in the minimisation of gradients on new roads. However, these structures also offer significant opportunities for avoidance of impacts to the valley floor, provide the process of construction follows certain procedures. Typically, watercourses are the key habitats to be avoided and suitably designed viaducts can minimise land-take and achieve complete site avoidance.

These aims have been meet through the adoption of pillar-centred construction techniques, where the construction site zone of disturbance is strictly limited to the immediate vicinity of the base of the pillar. Moreover, once the pillar has been completed, the body of the viaduct is either constructed symmetrically from the top of the pillar, or the horizontal elements are pushed into place from above. In any situation, the key principle is to minimise ground-level disturbance and to remain as far from the sensitive sites and habitats as possible.

Figure 6.2. *Les Salines* viaduct on C37 road in northern Catalonia. This 269m long structure was designed to avoid the sensitive stream within the valley by the use of only three pillars and with construction of the carriageway being undertaken completely above the ground

Viaducts are particularly well-suited to narrow, steep-sided valleys. However, as connectivity is critically important, as well as minimising construction phase impacts, special attention must be paid to avoiding or minimising ground-level disturbance. Many examples exist where otherwise excellent potential connectivity has been nullified by the construction of service roads, fencing or drainage lines directly beneath the viaduct (Figure 6.3).

Figure 6.3. An example of an otherwise excellent viaduct in Hungary, constructed by the pillar-centric process but with all potential connectivity benefits cancelled by post-construction service roads and drainage ditches

(iv) Avoidance bridges

Avoiding impacts to rivers and streams can be achieved though the construction of special bridges that are effectively smaller-scale viaducts, designed explicitly to avoid disturbance to sensitive sites such as watercourses. French environmental agencies have been particularly active in the employment of these structures (SETRA 2005), providing details in their excellent Technical Manual.

Figure 6.4. Avoidance bridging on C37 motorway in southern France designed to enable complete avoidance of *Natural 2000* watercourse site harbouring European mink.

By specifying that impacts associated with road construction must remain at least 20m from nominated watercourses, French road engineers have devised a range of structure suitable for variously sized streams (Figure 6.4). However, ensuring minimal disturbance during the construction phase remains an important issue, especially in enabling the movement of heavy machinery from one side to the other.

Box 2: Case Study - Europe's most permeable motorway (C37 Spain)

Primarily because of the technical necessity for constructing a direct yet flat road (see Box 1) through the mountainous regions of northern Catalonia, the C37 roadway from Vic to Olat, is Europe's most permeable road. Although only 19 km in length, the road has five tunnels (totalling 6.85 km), six viaducts (totalling 1.23 km and five cut-and-cover overpasses (totalling 0.94 km), providing effectively 47.5% complete permeability. This remarkably degree of habitat connectivity was only achieved, however, through the direct involvement of the Catalonian consultancy group *Minuartia*, who provided advice on all aspects of design and construction and ensured strict compliance to low-impact standards. The technical accomplishment of the pillar-centre viaduct construction process was of a particularly high standard.

Views of the two viaducts on the motorway showing (top) the pillars bearing the weight of the structure while minimising the disturbance to the valley and watercourse beneath, and (below) the fully permeable section of the road between fully reconstructed overpass in the foreground and tunnel in the distance.

7 Mitigation ecological impacts

7.1 General concepts: Permeability and ecological context

The reality for the majority of large infrastructure projects is that complete avoidance of sensitive sites is only possible in a small number of cases. This is especially likely in regions without significant changes in relief where the construction of tunnels and viaducts is not an engineering option. Thus, with roads unable to avoid some degree of impact through proximity or land-take, designers are obliged to consider measures which attempt to mitigate these unavoidable affects. In the majority of situations such measures will take the form of a structure that enables fauna to move safely across the road. This diverse body of structures are known as fauna passages.

Consideration of fauna passages in the context of a road plan must always be undertaken with regard to the concept of permeability. Without passages any major road (or any form of linear infrastructure), especially one that is also fenced, is essentially a complete barrier to the movement of most terrestrial animals. The inclusion of passages is aimed at reducing this barrier effect and maintaining connectivity between and within populations of the animals occurring in the immediate vicinity of the road. The actual functionality and effectiveness of these passages will depend on a wide range of features, including the design of the structure, the species expected to use them, and various aspects of the road itself. However, the placement of the passage within the local landscape is especially important. “A fauna passage cannot be properly considered except in relation to habitats and species” (Iuell *et al.* (2003) Chapter 7).

Passages will be necessary where the:

- (i) construction of the road leads to significant disturbance or loss of habitat in locations with specified habitats, communities or species;
- (ii) road is likely to impact species that are especially sensitive to the road barrier effect or traffic mortality;
- (iii) general permeability of the landscape is significantly impaired;
- (iv) other options and measures are unlikely to be effective;
- (v) target species are likely to use the structures; and
- (vi) road is fenced (Iuell *et al.* (2003) Chapter 7).

Due to the origins of these responses in the conservation-orientated Directives of the EU, a major focus is inevitably on ‘target species’. These are either the species with the highest conservation status, or the most significant in terms of movements. Thus measures will be required because of the local occurrence of small sedentary species (such as, for instance, endangered European mink *Mustela lutreola*) as well as common and abundant species with large home ranges (especially roe deer *Capreolus capreolus*), although the type of passage will obviously be very different. In general, the more critical habitat connectivity is to the local persistence of the species, the more elaborate the passage will be. For example, a modestly sized avoidance bridge may be entirely effective for the

European mink, whereas a road that severs an internationally important habitat corridor used by large mammals (such as migrating reindeer in northern Sweden) may require a series of carefully sited landscape overpasses.

Obviously, effective placement of passages will require detailed ecological information on population size, movement characteristics and traditional crossing locations along the route of the proposed road. In the cultural landscape that now exists in much of Europe, many species have traditionally followed features such as hedgerows, forest edges and even rows of trees; such features are known to be critically important for the movements of many species of bats (Abbott *et al*. 2010).

As an aid to discussions concerning the installation of fauna passages generally, the French agency SETRA offer two design 'rules' (SETRA 2005):

(i) Evaluate the ecological sensitivity of the landscape being crossed

> Not all areas require similar attention with regard to achieving permeability. However, while even uniform agricultural lands may not support populations of listed species, the persistence of common species remains important to biodiversity conservation. Thus, some passages will be required at regular intervals in all habitat types. Priority should always be given to key sites or species, however, and given budgetary constraints a greater number of passages would be more effective in such sensitive sites.

(ii) Encourage diversity of passage types

> Passages intended primarily for smaller species are likely to be available mainly to those animals living close by. Nonetheless, many small mammals appear to prefer using small diameter culverts while larger species tend to use larger structures more readily. Moreover, there are likely to be many complex interactions between species which may influence usage, most of which are very poorly understood. In the absence of detailed species-specific information, providing a variety of passage types is suggested as being the best general option for overall permeability.

Finally, the number of passages along a road requires careful consideration; one structure will rarely be sufficient for effective permeability, as only those species living immediately adjacent to the passage or with relatively large home ranges are likely to benefit. In almost all cases, achieving permeability will require a package of different types of passages situated at intervals through the length of the infrastructure. Although some jurisdictions make specific recommendations (for example, SETRA suggests at least one structure every 300m and one every 30m in 'exceptional habitats' in France (SETRA 2005)), it is impossible to proscribe passage density beyond suggesting that more will be necessary in areas supporting large populations and where the road barrier affect is significant.

Here I describe some of the principles and practices associated with fauna passages being constructed in Europe, based on a review of the literature accessed and discussions with many authorities. For more details see, in particular, IGH (2002), Iuell *et al.* (2003) and SETRA (2005).

7.2 Fencing

Preventing animals from gaining access to the road may be regarded as the most fundamental means of reducing or eliminating the most direct form of impact – collisions with traffic. This aim is also critically important for ensuring road safety. Therefore, fences have traditionally been the very first measure to be incorporated into road design.

As is now abundantly clear (see Fahrig 2010), however, fences lead to roads becoming complete barriers to most animals; overcoming this barrier effect is a crucial component of the overall de-fragmentation project. As well as minimising the risk of being hit by traffic, however, fences are essential for directing animals away from the road and onto nearby crossing structures. To achieve this, the fence must carefully merge with the sides of an overpass or the entrance to an underpass, leaving no gaps or dead-end passages above the structure. These details will require different solutions at each location.

Figure 7.1. Two different approaches to fencing for roe deer. Left: Typical roe deer fencing beside motorway with lower level of mesh to exclude smaller species. This fence extended 30cm below the surface (The Netherlands). Right: Combined roe deer fence and sound and noise barrier on a game-specific overpass in southern France

Again, there is little to be gained from a detailed description of the types of fences used in Europe. Suffice to say, the height and mesh width at the base will relate to the main species present in site. For example, in a typical agricultural landscape where roe deer are the main target species, a simple open mesh (20x20cm or 50x50cm) of height 2.0-2.45m would be suitable. If, however, smaller species were of concern, the lower section (140cm for badger and 60cm for hare, for example) would be reinforced with a finer-scale mesh (38x38cm is common, though this must be as small as 6.5x6.5cm for amphibians). In addition, the fence would normally be buried to a depth of 30cm to prevent digging through (E.g., see SETRA 2005 for details of seven fence styles employed in France).

Possibly the most uncertain aspect associated with fencing and roads relates to so-called 'escape doors' or 'exit hatches'. These are measures incorporated into the exclusion fencing to allow animals that find themselves on the road side of the fence to move through the barrier back to the habitat away from the road. Obviously, such a device must be entirely one-way, making it impossible for any animals to access the road through it. Throughout Europe, many thousands of simple escape hatches (Figure 7.2) have been incorporated into roadside fences routinely for several decades. Unfortunately, no serious studies have yet been undertaken to assess their effectiveness. This is hardly surprising as the number of animals being able to access the road and then attempt to return through the fence must be exceptionally small. Nonetheless, there is not even anecdotal evidence from the many researchers and fence maintenance staff suggesting that any of these devices has been used as intended. There is, however, many reports of hatches becoming jammed shut through corrosion or weed growth, or worse, being wedged permanently open, probably by people seeking a short-cut through the fence.

Figure 7.2. Two typical escape hatches at the base of exclusion fencing. Both require an animal on the road-side of the fence to locate the device then push with the head to open the hatch. (Left: J. Malo, near Madrid in Spain; Right: E. van der Grift, The Netherlands)

Some escape structures designed for larger species such as deer have been used by animals in experimental conditions. These 'ramps' are extensions of the exclusion fence leading away from the road that guide the animals into an apparent dead-end from which they escape by jumping down a drop (often of about 1m in height). From the other side, animals are confronted with effectively a metre high wall. Although such ramps have been constructed along motorways, no data exists to should whether they are effective.

7.3 Underpasses

It is beyond the aims of this review to discuss in detail the specific details of the range of the many types of underpass employed throughout Europe. Moreover, describing the recommendations of structure type, dimensions and placement features which are now routinely made with specific reference to a large number of species is unlikely to be of much value outside the region. This is largely because of the relatively limited number of species (of mammals and amphibians, the main taxa of relevance here) and their conservation importance throughout the continent. Studies conducted in numerous countries have resulted in a large body of comparable information, enabling very detailed specifications on the size, shape, internal features and placement requirements of such underpasses. Indeed, technical Standards documents are now available in some countries, with the Swiss examples being among the most detailed and widely used (see Swiss Association of Road and Transportation Experts; http://www.transport-research.info/web/publications/thematic.cfm).

In large part, the design of most fauna underpasses can be regarded as relatively straight-forward extensions or adaptations of structures that are routine elements in road design, especially the conduit of water through and around the roadway. As such, many of these structures are simply pipes, box culverts, bridges and the like; all will be thoroughly familiar to road engineers worldwide.

Figure 7.3. Entrance to large multiple box-culvert underpass in Parc Natural deis Aiguamolls de l'Empordia, Cosa Brava, eastern Catalonia, Spain. This underpass is used daily by large numbers of wild boar, as well as numerous other local mammal species. Although the floor of the culvert was originally concrete, this has now been covered in silt. Although no plants grow inside, the natural vegetation on either end is continuous with the surrounding habitat.

To function as a conduit for fauna, however, several important features must be considered:

(i) Local placement features

While the positioning of each structure will obviously need to be considered at a landscape scale, placement at the local scale is also important. Again, with the aim being to facilitate fauna movements through the structure, features that discourage entry need to be minimised. This includes attention to the post-construction state of the land at the entrances; poor clearance of construction-phase debris, significant physical disjunctures (such as the edges of concrete slabs) and large areas of 'hostile' surface (such as broken brick, large stones or even bare concrete) all discourage the movement of the smaller species likely to use the structure. Overall, the structure should always (or at least normally) be dry (see below), meaning it would usually be situated well above any nearby watercourses.

As well as ensuring a minimum of aversive features, the immediate vicinity of the entrances should encourage easy access and possibly even attraction to the site. In all cases, the local exclusion fencing should unequivocally guide animals directly to the entrance of the structure. The nature of the entrance environment should provide some level of shelter and protection, usually through restoring habitat in a style suited to the target species, and in continuity with the surrounding existing vegetation.

(ii) Size and shape

A sizable literature now exists on the most suitable dimensions of an underpass preferred by smaller European mammals and amphibians (see e.g., Holzgang *et al*. 2001, SETRA 2005). This information may be somewhat useful as a guide in other regions but also points to the necessity for research on key species. However, some general principles may be suggested. First, although the smallest species will use the smaller pipes and culverts, larger species will not. The smaller species will, however, use large overpasses provided there is suitable shelter or escape routes. This suggests that, except in specific situations where a structure has been designed for a single species or taxa (such as highly localised migration routes for amphibians), a larger but well 'furnished' underpass will be of greater overall benefit.

Secondly, square culverts are better than circular pipes. This appears primarily because of the shape of the floor; except were a flat false-bottom can be inserted into a typical pipe, the concave shape is not attractive for most small species. Box culverts or bridge-style structures allow a flat floor as well as potential space for furniture.

Figure 7.4. Two large ovoid underpasses, with about 3.5m clearance. This design can bear considerable pressures. The structure to the left (southern France) is targeted on roe deer and also allows passage of a small stream. The structure shown to the right (eastern Spain) is also used by roe deer but is strongly co-use, being used by local farmers as well as recreationalists.

An engineering comprise to these issues has been found in a range of larger ovoid-shaped underpasses (Figure 7.4), which provide a flat natural surface floor and allow far greater height by virtue of superior weight-bearing capacity.

(iii) Floor

A number of studies have now confirmed that many smaller species prefer a flat floor to a concave surface within an underpass. They are also far more likely to use a structure that has a natural surface, such as soil, leaf litter or mulch, than a bare concrete (or sometimes metal) floor. In addition, it is widely appreciated now that underpasses are more likely to encourage movement if they include some form of 'furniture': branches, logs, and rocks may be suitable, and sections of earthenware or polyurethane pipes that are fixed to the walls.

Figure 7.5. Floor of recently constructed box culvert underpass showing sand/earth surface and habitat logs (The Netherlands)

The main problem with including any of these materials or objects within an underpass is the risk associated with water entering the structure. Either the materials could be swept away or they could lead to an obstruction causing a build-up of debris requiring extensive maintenance.

In general, these risks should be able to be reduced through careful local positioning of the structure.

(iv) Ledges

A wide variety of ledges, benches, raised platforms, shelves and tiers are all now widespread and typical components of fauna underpasses throughout Europe. This follows the discovery that numerous species of smaller mammals are more likely to cross a road using these raised features than by moving along the floor. Although some of these ledges may be 1m in width, more typically they are 40cm wide or less.

The key features of a successful ledge are to be always (or mainly) above the level of the water and for the access onto the ledge to be simple and easy for the target species to find. Obviously, the spatial relationship between the exclusion fencing and the features leading onto the ledge must be carefully considered.

Most ledges are relatively small in relation to the size of the overall culvert, with the structures added retrospectively or incorporated into the wall. However, many recent under-road structures have reversed this ratio, with the bulk of the overpasses being taken up by a raised dry bed with a smaller side drain for water passage to one side. This design is particularly useful in moderate rainfall areas where flooding is less likely.

Figures 7.6. Examples of solid ledges incorporated into the walls of two different underpasses in southern France.

7.4 Overpasses

Fauna overpasses (also known as game bridges, green bridges, land-bridges and ecoducts) refers to a broad range of structures which are constructed over the road to allow the safe movement of fauna. These are the most elaborate, complex and therefore most expensive of all specifically fauna-related passages. They are also the only effective measure for allowing the movement of the largest mammals. Furthermore, overpasses are certainly the most effective means for overcoming the fragmentation associated with transport infrastructure for all vertebrate species. Although overpasses have been traditionally constructed with large mammals – in Europe these are various species of ungulate, wild boar, bear and wolves – in mind, there is increasingly interest in encouraging a far wider range of species to use and live on these structures.

It is also important to appreciate that many European overpasses have been built to allow the passage of game species, primarily red deer and roe deer but also wild boar. These species form the basis for the ancient and still extremely strong hunting traditions in most European countries. Indeed, the very first (1960s) fauna overpasses constructed in The Netherlands, France and other countries, resulted from pressure from hunting organisation concerned about the impact of roads on the persistence of local deer populations. Hunting groups hold significant political power and are among the first stakeholder groups approached by road planners in many countries. This position remains powerful: the only two overpasses on the latest major motorway in France (the A65 in southern France) were built to allow roe deer to access hunting reserves on one side from farmlands on the other. Such arrangements represent the most single focussed form of overpass and are less likely to be designed for other species.

The primary ecological aim of an overpass is to provide connectivity between populations of animals living on either side of the road. This is best achieved by providing continuity of habitat across the structure, allowing the passage to act as a fauna movement corridor. If successful, an overpass should eventually connect populations and habitats at an ecosystem level (Iuell *et al.* (2003) Chapter 7).

To function in this way, four features must be carefully considered.

(i) Placement

First, as already discussed, the placement of the structure must relate to natural movement patterns of the key target species. This will usually be associated with the distribution of local vegetation and terrain. However, it is also appreciated that characteristics of the landscape will often influence where such large structures can be sited; nonetheless, ease of construction should not override ecological function.

Figure 7.7. Examples of post-construction loss of connectivity caused by independent actions at the end of fauna overpasses (both from Spain). In both cases, the construction of irrigation pitches (left) and the imposition of a concrete barrier (right) resulted from poor engagement with local landholders (Photograph: Cristina Mata)

An important consideration associated with the placement of overpasses to ensuring that animal movements are not prevented or discouraged by landholders occupying the areas on either side of the structure. As can occur with viaducts, post-construction actions can serious undermine the aims of continuity; care attention needs to be paid to on-going landholder relationships (e.g., see Figure 7.7).

(ii) Width

The feature of fauna overpasses given the greatest attention in Europe is that of width. (This refers to the size of the structure measures along the road (or as viewed across the road); length refers to the total distance of the span of the structure's surface.) Because of the traditional emphasis of the movement of larger species such as deer and carnivores, the overpass must be wide enough to allow such animals to cross undeterred. Although debate as to optimal width continues, the usual recommendation is for a width of 40-50m; certainly anything less than 20m wide is strongly discouraged. This width is regarded as being sufficient to allow large animals to pass without being disturbed by traffic noise and light (also reduced by barriers see below) as well as providing enough space to allow escape if necessary. This width also allows the inclusion of fencing, barriers and habitat features if considered useful (see below).

Minimum size recommendation are usually not an issue with the much larger dimensions associated with landscape overpasses, which are typically greater than 80m in width (see below).

(iii) Barriers

Almost without exception, European fauna overpasses have a range of physical barriers installed along the edges closest to the road. These are designed to reduce or eliminate the amount of traffic noise and light reaching the surface of the structure, thereby limiting anthropogenic disturbances and enhancing the perception of a safe passage for the animals. These barriers are normally additional to the usual exclusion fencing which is constructed to run parallel to the road before continuing over the overpass, ensuring no access to the road from any point. In some cases, the barrier is sufficiently robust and high to function as for exclusion and noise reduction.

Figure 7.8. Recent sound and noise barrier structure on fauna ecoduct in The Netherlands.

Barriers have been constructed of a wide variety of materials and with various degrees of permeability. The simplest barriers tend to be rows of poles or posts, while some incorporate artistic designs which enhance their attractiveness; some of recent overpasses in The Netherlands have taken this aspect to new creative heights.

A common addition to the physical barrier is the use of an earth mound running adjacent to the barrier on the inside of the overpass, and typically planted with rows of dense vegetation. As well as providing an additional measure of screening, this vegetation also greatly adds habitat substrate to the structure.

(iv) Surface environment

With most fauna overpasses constructed primarily with large mammals in mind, the surface has typically been left open, although some planting may occur along the slopes. Normally, the limited soil depth on the surface of the structure, as well as safety issues, has prevented the planting of trees. In many cases, such open surfaces are preferred by deer and other large animals and are often typical of the surrounding environment.

Figure 7.9. Surface conditions on two well-established fauna ecoducts in The Netherlands

In areas where forests occur on either side of the road, or where the structure was designed to encourage use by a wider diversity of species, the surface of overpasses may be much more complex. Among the features included are far greater amounts of vegetation, including trees and large shrubs. While many plants can be intentionally introduced, considerable amounts of spontaneous recruitment is also encouraged and will quickly aid in achieving in the formation of a continuous habitat across the road. In addition, the structural complexity of the surface can be easily and cheaply enhanced by including rows of discarded tree roots (left), a typical by-product of the road construction process.

Figure 7.10. Rows of tree-roots as habitat on overpass (Netherlands)

Finally, in certain situations, taxa-specific habitat conditions can be established with a view to enhancing the structure as residential habitat. This may has been achieved through the planting of certain plant species referred by particular butterflies, and, especially successfully, by providing waterbodies on the overpass which resulted in remarkable levels of colonisation by amphibians (see Box 3).

Box 3. The *Groene Woud* amphibian ecoduct.

Opened in 2005 on the A2 motorway in central Netherlands, this very large overpass was the first designed to provide habitat connectivity for amphibians

The ecoduct is 50m wide and 65m long with ramps of 110m and 85m on either side. Uniquely, it is equipped with pumps to supply water to a series of shallow ponds on the tops and sides of the structure. Intensive monitoring (mainly by local volunteers) showed a 50% increase in amphibian use after the establishment of the wetland features. The percentage of detections per survey have been: common frog (78%), common toad (15%) and the Red-listed great crested newt (1.5%; pictured)(van der Grift *et al*. 2010).

8 Ecological compensation

Theoretically, the third pillar of what can be termed the European approach to de-fragmentation – compensation - is only to be considered once all avenues of avoidance and mitigation have been proposed, assessed and found to be unavoidable. Compensation is always to be regarded as a final attempt to redress a necessary impact. Perhaps inevitably, issues associated with compensation are common, complex and among the most perplexing of all aspects of contemporary approaches to road impacts.

In theory, compensation should be required to offset three different forms of impact of infrastructure developments on lands: (1) **loss** (due to land-take); (2) **degradation** (including disturbance associated with initial road construction, as well as the on-going impacts of noise and pollution); and (3) **isolation** (or fragmentation)(Cuperus 2004). Compensation for these impacts may involve the 'improvement of ecological quality' through some combination of the restoration of impacted areas, the rehabilitation of existing sites and the acquisition of entirely new natural areas. Just how such measures are appraised as being acceptable compensation of the impacts is far from obvious, however.

Note also that these measures need to be regarded as 'ecological' compensation to emphasise the explicit aim of offsetting environmental impacts; the goal is to aim for an effective zero-loss of lands. In contrast, financial or economic compensation abandons this aim and attempts to pay for the impacts.

In the most detailed discussion of these issues in the European context to date, Cuperus (Cuperus *et al*. 1999, Cuperus 2004), distinguished four possible approaches to ecological compensation:

(a) in-kind, in-site (providing same habitat in the same location)
(b) in-kind, off-site (same habitat but located elsewhere)
(c) out-of-kind, in-site (different by equivalent value habitat on-site)
(d) out-of-site, off-site (different habitat elsewhere).

The difficulties of operationalising these approaches quickly become apparent; for instance: Can offsetting impacts of a particular habitat by substitution a different habitat type or even in a different location be regarded as equivalent?; How distant can an off-site offset be acceptable?; and What about the all-too common situation of there being no unaffected sites or habitats anywhere nearby?

These issues remain extremely problematic and are far from resolved. To date, Europe has not established the types of compensation ratios now increasingly being employed in the United States. For example, the US Environmental Protection Agency (US EPA 2010) has stipulated ratios of 'replaced to lost lands' or 1:1 to 1:4, with associated with specified definitions as to acceptable methods of ecological compensation.

Such a proscriptive approach has not been consistently advanced in Europe for a variety of reasons including the difficulty of finding suitable 'natural' compensation sites. However, more salient is an appreciation that the 'site or site offset' approach ignores or downplays the many other aspects of the impacts of roads, including the complex array and interplay of landscape, land use, social and health issues involved (Cuperus 2004).

The lack of standarised guidelines and general ambiguity associated with expected compliance has resulted in both low levels of reported compliance practice and a large number of inadequate or unsustainable outcomes (Villarronya & Puig 2010a). Nonetheless, the importance of the compensation issue increased progressively. In an attempt to provide a new approach and to generate much-needed discussion, some Spanish researchers have recently proposed a method based on three characteristics of the main impacts. First, **area** of the impact (Is it local or global?); second, its **measurability** (Are standarised measures possible (e.g., noise levels) or not (e.g., fragmentation)?; and third, its **visual** effect (Can the impact be perceived or not).

Using these three impact characteristics, four main kinds of impacts may be distinguished, allowing the following recommended approaches to compensation (Villarronya & Puig 2010b):

(i) Local, measurable, not visible.

Examples may include increases in local noise, pollution or soil disturbance levels. These impacts can be addressed by in-site enhancement compensation, aimed at improving the local overall ecological quality.

(ii) Global, measurable, not visual.

Examples may include increases in greenhouse emissions, which spread far from the site but cannot be seen. Compensation may involve measured directly aimed at emissions reduction and given the widespread nature of the impact, could be either on or off-site.

(iii) Local, measurable, visual

Examples may include immediate habitat loss. Compensation should be aimed at the restoration of damaged habitat or creation of equivalent, usually elsewhere as requiring compensation will have meant mitigation was inapplicable.

(iv) Not local, not measurable, visual.

These characteristics are typical of fragmentation and any compensation approach must be aimed at reconnecting severed populations and possibly increasing the parcel size of a suitable habitat. As local mitigation must have been inapplicable, the most likely appropriate action would be off-site acquisition or extensive restoration activities.

9 Monitoring: a necessity

The inclusion of monitoring – often termed (sometimes disparagingly) 'research' or even 'science' – as a component of a major infrastructure plan, if at all, is often considered as an addition, possibly an option, to the far more tangible production of plans, specifications and passage designs. Even when the design team is fully supportive of the necessity for considering passages, the importance of monitoring is often regarded as somewhat trivial, or simply 'academic'. A frequent observation, especially in Europe, is that as considerable research will have already been undertaken to establish the optimal placement of passages, their design, sizes and a plethora of tiny details, what is the point of further study?

To respond to this valid question, we must accept that at one level, the main observation is correct: sufficient research has been undertaken to allow us to state with great certainty that the bulk of structures do indeed 'work'; a wide variety of species have been detected using many passages, sometimes in large numbers, often on a daily basis. Moreover, many studies have provided the basis for reliable recommendations of passage design and specifications to suit a large number of key target species. That animals use these structures is not longer in any serious dispute; what is far more critical is whether they are affective at the population and landscape level (van der Ree *et al.* 2010). The answer to this question lies at the heart of the overall European de-fragmentation project, and must be regarded as the principle aim of any attempt at mitigating the impact of roads.

Broadening the aims of monitoring in this way allows us to re-consider its inclusion in the approach as a whole. The Handbook (Iuell *et al.* 2003; Chapter 9) is adamant that monitoring is of crucial importance as a mechanism for assessing whether the measures included are actually achieving their intended aims. Properly integrated into the overall project, the aims of monitoring should serve a variety of purposes. These will include: the detection of failures or shortfalls during installation, construction and maintenance; establishing whether measures are actually functioning as planned; and an evaluation of the value of long-term monitoring.

Although typically regarded as a post-construction process, monitoring in the form of quality control is a long-established engineering procedure, providing iterative assessments as a project proceeds. Similar attention is required in relation to defragmentation decisions. Monitoring will have a fundamental role in each phase of the life of an infrastructure project (Box 4).

Two general types of monitoring are recognised, distinguished by scale and time-frame:

(a) **Routine monitoring**, which forms the basis of most regular, on-going inspections and maintenance checks of passages, as well as assessments of passage use, road-kill surveys etc.

(b) **Ecological monitoring**, which involves broader research goals such as assessments of population change and genetic diversity at habitat or landscape scales.

Box 4. The role of monitoring in the phases of an infrastructure project (adapted from Iuell *et a*l. (2003))

1 Planning Phase
  a. Establishment of baseline information
  b. Identification of measures to be applied
  c. Design of future monitoring program

2 Construction Phase
  a. Supervision of installation or passages and measures
  b. Re-design of measures following problems

3 Operational Phase
  a. Testing the suitability and effectiveness of measures
  b. Checking for suitable functioning
  c. Evaluation of effectiveness

4 Combined outcomes
  a. Improvement of ineffective measures
  b. Gathering information on responses of species poorly understood
  c. Provision of information on the cost and benefits of different measures

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In either type, a vital component of the approach must be the development of clear and achievable goals and objectives. It is relatively easy to collect a lot of data; it is far more challenging to seek information that will enable questions to be answered adequately. Nonetheless, most effective and successful monitoring schemes share the following features: they are cheap, simple, well coordinated and employ appropriate and standardised methods.

Finally, monitoring should always include a means of dissemination. Communication of results, including failures, is necessary if the field is to continue to evolve and improve. A commitment to transparent dissemination will allow: mistakes to be avoided in the future; facilitate improvement of designs and approaches; provide vital information needed for on-going process of undertaking cost-benefit analyses; and ultimately, should save money for future projects.

10 Conclusions

10.1 Applications in Australia?

The third question posed at the outset was: ***What*** *can we learn from the European approach?* In other words, can any of this be applied to the situation as it exists in Australia?

At its broadest, the answer to this question suggests strongly that we could learn much from the legislative and policy perspective of the EU, where a long and complex history has resulted in powerful incentives to take impacts on nature seriously. This has led to a highly effective – if not always uniform – and *integrated* response where addressing the impacts associated with infrastructure developments are considered along with a range of issues and constraints. A similar process must eventually to introduced into Australia, with significant benefits to all involved (see below for further discussion).

In the narrowest sense, it could be argued that knowing the detailed specifications for a toad underpass or the mesh size needed to exclude a water vole is of little application to Australian conditions. This would miss the far more important point of the value to Australian road engineers of having access to sufficient data to allow passages to be designed to enhance the movements of specific species. Research is desperately needed on, for example, design of structures that will encourage under-road movements by Australian frogs or discourage antechinus from climbing exclusion fencing. The results of intensive studies from across Europe have been synthesised into a series of Standards documents that can be followed by any engineer seeking the specs of, for instance, an amphibian culvert (or badger tunnel etc). The development of similar Standards must be regarded as a serious aim of Australian road ecologists.

It is in the middle ground, however, that the richest areas of applicability are to be found. This area relates to the guiding principles and general approaches that are now standard throughout Europe that have resulted in the greatest biodiversity benefits. This begins with the foundations of the European approach: first avoid, then mitigate, and compensate as a last resort. All of these are, to some extent, already being employed in Australia, though this is mainly piecemeal and opportunistic. Again, genuine integration into the overall planning process is needed.

Possibly the most applicable discovery of this exploration is the extent to which otherwise familiar engineering principals and designs have been adapted to aid de-fragmentation. Obvious examples include the increasing use of weight-bearing underpass designs, and the retrofitting of ledges for small fauna. Dramatic examples of this expansive thinking can be seen in the ongoing evolution of fauna overpasses. From relatively modest deer bridges developed the idea of the massive sweeping ecoducts of The Netherlands and Switzerland. From conceiving of an overpass simply as a passage for movement for certain large mammals, the idea of the ecoduct as an extension of habitat has lead on to the spectacular cut-and-cover overpass were the entire landscape – terrain and vegetation - are reconstructed. The unexpected message is therefore: provide a clear concept and plenty of reliable advice and allow road engineers to do what they do best: find clever solutions.

10.2 The need for integration

On virtually every level – legislation and policy focus, strategic planning, instrument development, innovation in passage design, intensity of monitoring, international cooperation, to name only some aspects – the European approach to the challenge of fragmentation is impressive. Much of this can be described as having achieved an advanced level of maturity, the result of decades of concerted and intense international attention. Such maturity can be attributed in large part to the responses to the immense challenges associated with the necessity to comply with key EU Directives. The initiative of IENE to see international cooperation as the key to effective collective approaches – leading to the COST 341 actions – was unquestionably crucial, with far reaching consequences in both place and time.

Of course, the responses across the continent are far from uniform. Countries differ markedly in capacity and willingness to advance these approaches. These differences are not always as may be expected: Poland, with vast largely unaltered landscapes has over 300 fauna passages (including more than 50 overpasses) with a further 500 in at planning stage, while the United Kingdom has no overpasses and remains unexpectedly recalcitrant. Tiny Croatia currently has 16 fauna ecoducts, some of which are 100-150m in width; Italy has essentially no passages, even in the Alps.

Obviously there are profound differences between Europe and Australia in terms of environmental and social histories, and especially the intensity and necessity of international interactions. This background has influenced every aspect of the evolution of European responses to the ecological impacts of transportation infrastructure, with the legal and cultural frameworks of the European Union being both the most recent and most compelling of the numerous drivers at work.

Regardless of bald legislation, however, little can be forced upon independent countries if their populations (or at least legislatures) are not already convinced of the worth of protecting species and the natural habitats on which they depend. The long-term political pressures that lead eventually to the progression of national then international bills, rulings, decisions and directives has proven to be an inescapable reality for politicians and parliaments across Europe.

Australia shares many of these positions. Our parliaments have enacted numerous bills aimed at environmental protection and biodiversity conservation; powerful instruments exist for addressing impacts of certain listed species; and we are proudly proactive in promoting and upholding a variety of international biodiversity conventions. At the same time, however, Governments at all levels are confronted with some of the fastest growing urban populations in the world, as well as a booming resources industry earning the country astounding amounts of revenue. A well-appreciated constraint to both urban expansion and resource exportation is that of transportation infrastructure. The result is an unprecedented level of road and rail development. And it is in this interaction this is where the contrasts between the European and Australia responses become starkly obvious.

The European Union explicitly encourages the development of its emerging Member States and provides funds and advice for the planning of much needed transport infrastructure. However, fully integrated into this process are the now well-established procedures for addressing the attendant issues of habitat fragmentation. Indeed, the approaches described in this report will be especially important in the developments underway in Eastern Europe. Countries such as Poland, Romania and Bulgaria have retained the largest tracts of relatively unaltered landscape in Europe, and these support large populations of really large species such as moose, red deer, bison, brown bear and wolves, most of which are long-gone from most Western countries. Of course, tremendous challenges remain, including rampant corruption, the desire for rapid expansion and relatively lax construction standards. The existence of the now well-oiled EU instruments of incentive, compliance and reward, however, suggest that these massive and important projects need not be as experimental as was the case in earlier period of European development.

Australia needs to begin the journey towards a fully integrated process of transportation planning and development, where the ecological impacts of roads and other linear infrastructure are considered as just one of the constraints and challenges to an engineering solution. We have certainly started to venture along this road already, despite the absence of compliance-orientated legislation. Many major projects include fauna passages with some are being purpose-designed; there is also a growing recognition of the importance of monitoring in order to improve. It would be also far to say, however, that we are some way to go.

The ideas and innovations described in this document – and an appreciation of the considerable amount of invaluable information that already exists – will hopefully assist.

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Further Resources

A wide range of reports, studies and other material in English is readily available from the following sites:

Infra Eco Network Europe: www.cbm.slu.se/iene/

Currently hosted from Sweden, IENE is the foremost organization advancing road ecology and de-fragmentation in Europe. This site also provide free access to all of the COST 341 documents, as well proceedings and reports fromIENE workshops and conferences.

SETRA: www.setra.developpement-durable.gouv.fr

SETRA is the French Government Agency responsible for transportation and sustainable development. Several excellent reports are available from this site including *Facilities and Measures for Small Fauna: Technical Guide*.

European Environmental Agency: www.eea.europa

The main source for environmental and transportation information, research and predictions for the European Union.

Alterra: www.alterra.wur.nl/UK/

Alterra is a research institute based within the Wageningen University in The Netherlands and responsible for some of the most significant road ecology research in Europe.

Swiss Association of Road and Transportation Experts
www.transportation-research.info/web/publications

The Swiss agency that has developed many of the best technical reports and Standards now widely adopted throughout Europe.