Mitigation and Compensation of Habitat Fragmentation Caused by Roads: Strategy, Objectives, and Practical Measures

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Experiences with the Dutch Second Transport Structure Plan are presented, the strategy is introduced, the general objectives are reviewed, and habitat fragmentation caused by roads is treated as a special case. The general effects of habitat fragmentation on sensitive species and ecosystems will be addressed, and the ecological effects of roads and traffic will be discussed in more detail. Bottlenecks between the existing and planned roads and the National Ecological Network in the Netherlands are analyzed. Finally, examples of mitigation and compensation are given that show how to solve the conflict between planning and building roads and the fragmentation of nature and landscapes caused by roads by various means of ecological engineering.

The Dutch Second Transport Structure Plan is an example of an approach to integrating environmental aspects in a policy document for which an environmental impact assessment is not compulsory. The plan deals with transport in a sustainable society.

STRATEGY OF SECOND TRANSPORT STRUCTURE PLAN

The strategy of the Second Transport Structure Plan consists of the following elements:

1. Tackling problems at their source (e.g., vehicles must be as clean and as safe as possible);
2. Managing and restricting mobility (e.g., reducing the travelling distances between home and work by means of location policy as well as by encouraging a more appropriate use of cars);
3. Improving alternatives to the private car (e.g., facilities for cyclists, standards of public transport, and a more shared use of vehicles);
4. Implementing selective accessibility on the roads (e.g., special corridors for each type of transportation); and
5. Strengthening the foundations with support measures (e.g., better communication, financial planning, and research).

The five elements of the strategy have been translated into 35 policy areas (Figure 1)—air pollution, energy saving, noise nuisance, and so on—and grouped into four categories: environment and amenity (livability), managing and restricting mobility, accessibility, and foundations (means of support). For all the policy areas, qualitative and quantitative targets have been formulated.

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HABITAT FRAGMENTATION

The overall impact of infrastructure on nature is called fragmentation: the partition of ecosystems or habitats of plant and animal populations into smaller, more isolated units. Infrastructure is one of the main causes of habitat fragmentation. Four aspects of fragmentation can be distinguished:

- *Destruction:* absolute loss of a habitat area through the physical presence of the road and associated infrastructural elements.
- *Disturbance:* deterioration of the habitat due to traffic noise, emission of xenobiotic substances, the effects of visual stimuli (artificial lighting), and so on.
- *Barrier action:* separation of functional areas.
- *Collisions:* injury or death of fauna due to motorized traffic.

These aspects can influence the chance of survival of populations of individual species and of essential ecosystem processes.

Isolation can cause subpopulations, or their feeding and breeding habitats, to become separated; then the viability of a population decreases. These aspects may have a strong negative effect on the ecological value of habitats.

To mitigate negative effects of roads on fauna elements, certain measures such as warning signs, wildlife warning reflectors, fences, badger tunnels, and adapted culverts were introduced in the 1970s and 1980s; more recently, ecoducts (overpasses for fauna) have been used to allow animals to move more safely between otherwise isolated habitats.

Activities to mitigate habitat fragmentation caused by infrastructure are now embedded in the policy of the Dutch government. But should the problem be solved?

In the Dutch Second Structure Plan formulated, the target scenario for the short term is to prevent further fragmentation of the countryside; in the long term fragmentation will be reduced. First, an attempt is made to prevent habitat fragmentation by restricting infrastructural development and by integrating the infrastructure into the landscape. Second, the aim is to counteract fragmentation, which can be done by mitigating existing situations (by constructing suitable verges, providing barrier fencing and tunnels for badgers and amphibians, building ecobridges that enable wild animals to cross roads without risking being hit by a vehicle, and reducing speeds and noise levels).

Where the effects of fragmentation cannot be mitigated, it is desirable to take compensatory measures (replacing lost habitats or enhancing marginal habitats through appropriate forms of environmental improvement). Recently, compensation became compulsory in the Netherlands for certain areas with a conservation status.

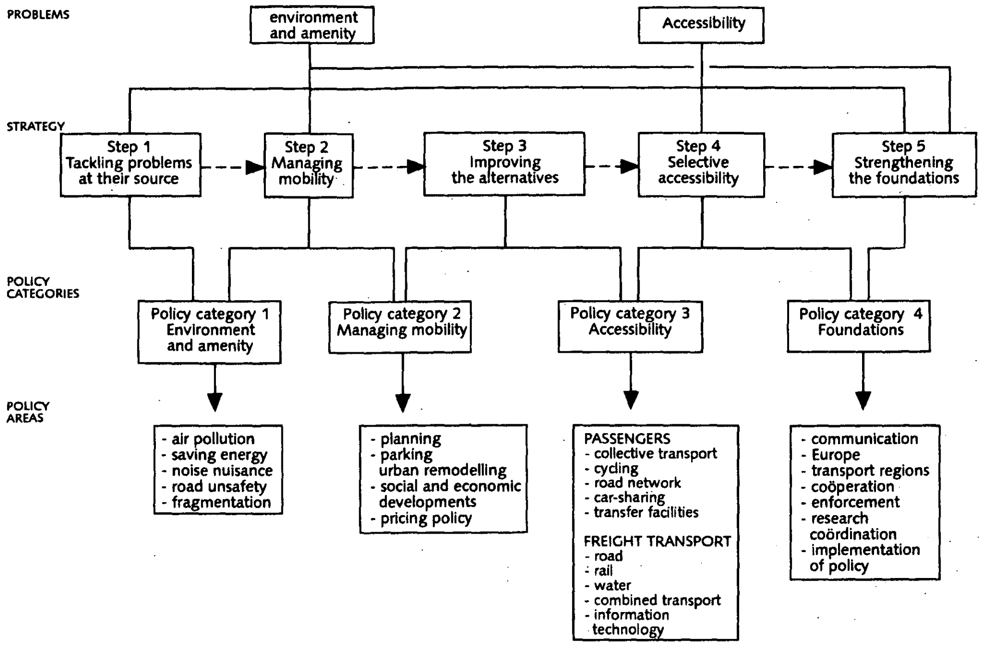

FIGURE 1 Objectives of Second Transport Structure Plan.

There is a growing interest in compensation, motivated by a desire to promote ecological functions and natural values in a given area and to replace those functions and values that have been damaged or have disappeared because of the presence of infrastructure. Examples of such regulations in other countries include Germany's "Eingriffsregelung" (1976) and the no-net-loss principle for wetlands (1986) of the United States and Canada.

The scientific basis of these measures is of major importance. In this respect the author finds it worth mentioning the island biogeographic theory (*1*) and the metapopulation concept (*2*). (A metapopulation is a system of local populations that are linked by dispersal.)

The island biogeographic theory draws attention to the importance of patch size and isolation; the metapopulation concept is important because it makes one realize that landscapes consist of heterogeneous mosaics that are changing continuously over time.

Besides concern for individual species, more attention will soon be given to maintaining ecological processes in highly man-influenced landscapes.

BOTTLENECKS BETWEEN NATIONAL ECOLOGICAL NETWORK AND ROADS

To discover ways to implement measures in concrete situations, the main bottlenecks between roads and wildlife were investigated (*3*). In this study a bottleneck was defined as a situation in which a road (*a*) is located in an actual or potential habitat of a species that is vulnerable to fragmentation, (*b*) is situated in a priority area from a viewpoint of conservation, or (*c*) shows large numbers of dead animals from traffic collisions. Figure 2 shows the bottlenecks that can be resolved by mitigation or compensation:

- Mitigating measures: otter subways, small tunnels or bridges for such species as badger and pine marten, and large tunnels or ecoducts for larger species such as rose deer, wild boar, and red deer.
- Compensating measures: habitat improvement or habitat enlargement along the road (spatial, layout, and management measures).

This study was followed by an investigation of all the locations of intersections between the National Ecological Network and the existing and planned main infrastructure (*4*). The Dutch National Ecological Network comprises habitats of international and national importance in a logical hierarchical structure (*5*). It is a complex of core areas, nature development areas, and corridors (ecological connecting zones). Figure 3 shows the coherent Dutch National Ecological Network of sustainable ecosystems that are of (inter) national importance, and it shows the bottlenecks with the main infrastructure: about 500 km of intersection between the network areas and the highways. Additional information on the ecological functions and species composition of the intersected areas was collected.

The study in Figure 2 is based on species and species composition of ecosystems. It is assumed that the selected species more or less represent the ecosystem concerned. The species were selected on the basis of international nature conservation values as well as their sensitivity to fragmentation caused by roads. Both aspects have been combined in the form of a measure of vulnerability. Figure 3 is the result of the information about the different conservational categories of the Dutch National Conservation Policy Plan, which was confronted with the existing and planned highways.

Later targets for reducing the effects of habitat fragmentation due to roads were based on the evaluation of the Dutch Second Structure Plan:

- In 2000, 40 percent of the bottlenecks will be resolved.
- In 2010, 90 percent of the bottlenecks will be resolved.
- In situations in which mitigation is not possible, compensation measures will be implemented.

FIGURE 2 Map showing bottlenecks from a natural viewpoint (mitigation measures: ⊙ ottertunnels, ○ badger tunnels, and ● ecoducts; compensation measures: M = waterfowl, W = meadow birds, K = birds of small-scale areas, H = heathland birds, and B = woodland birds).

MITIGATION MEASURES

Mitigation can be defined as measures used to stop or reduce negative effects on ecological values caused by building and the use of infrastructure. The measures involve tunnels, underpasses, and overpasses in accordance with the behavior and needs of the species concerned. They include fencing to funnel animals and to prevent road kill.

Badger Pipes and Tunnels

In the Netherlands, 15 percent of the badger population (400 to 450 individuals) is killed by road accidents each year. The total population in summer numbers about 2,200. Some years ago the yearly increase of badgers corresponded with the yearly losses caused by death. The main bottlenecks between badgers and highways have been solved by implementing measures such as badger tunnels and barrier fencing along the road to create safe connections between habitats. During the past few years the reduced mortality has brought about an increase in population size (approximately 100 to 200 net).

Such measures for badgers, and also for amphibians, are mainly species-specific, although other animals can use such provisions.

Tunnels for Amphibians

Besides temporarily closing roads and moving caught amphibians in buckets, special tunnels for amphibians and prefab conducting elements are a successful solution today.

Ecopipes

All kinds of species can use stream culverts (Figure 4) to cross a road, if the culvert is completed with a dry path beside the water. It is important that the ground has a slope beginning below water level (ALWL in figure) and ending above water level (AHWL). This last development is called the so-called ecopipe. There is a growing interest in prefab conducting elements.

Ecoducts

Along with the construction of a new highway (A50) in 1988, two overpasses (cerviducts and ecoducts) were built to enable the red deer (hence cerviduct) to migrate from one side of the highway to the other (Figure 5). Both ecoducts were situated on an old migration track of the red deer. The location is on ground level so the an-

FIGURE 3 Dutch ecological network and highway system.

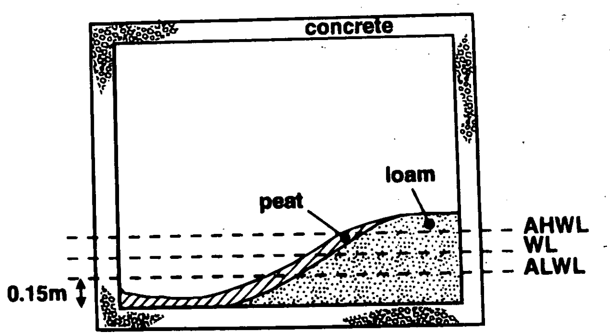

FIGURE 4 Stream culvert: cross section of passage for swamp species.

imals do not have to climb or descend in an unnatural manner (for this reason the highway is built below ground level). The ecoducts are protected against the visual and acoustic influences of the highway by means of a wall and trees.

The northern ecoduct ("Woeste Hoeve") is shaped like a parabola, and the narrowest part is 50 m wide. The traffic drives through three Armco pipes. The southern one ("Terlet") is built like a common viaduct. Both ecoducts are used intensively, not only by red deer, but also by other species such as roe deer, boar, badger, hedgehog, and fox.

The number of passages across Highway A50 through the ecoducts at Terlet and Woeste Hoeve in 1989 is as follows:

	Terlet	*Woeste Hoeve*
Red deer (edelhert)	294	153
Wild boar (wild zwijn)	690	292
Roe deer (ree)	38	43
Fallow deer (damhert)	–	51

Recently a new ecoduct was built over Highway Al near the Dutch town Almelo (Boerskotten). At least seven species of larger mammals use this ecoduct.

So that more can be learned about the effectiveness of ecoducts on population levels, a new monitoring and evaluation program has been set up.

Joint use of Construction

Bridges, viaducts, aqueducts, and culverts can also serve as crossing places for animals. Isolating parts of these constructions from traffic increases these possibilities.

Costs of Mitigation Measures

General figures are given to provide some information about the costs of mitigation measures, these figures are rough, and the real costs involved depend on the local situation.

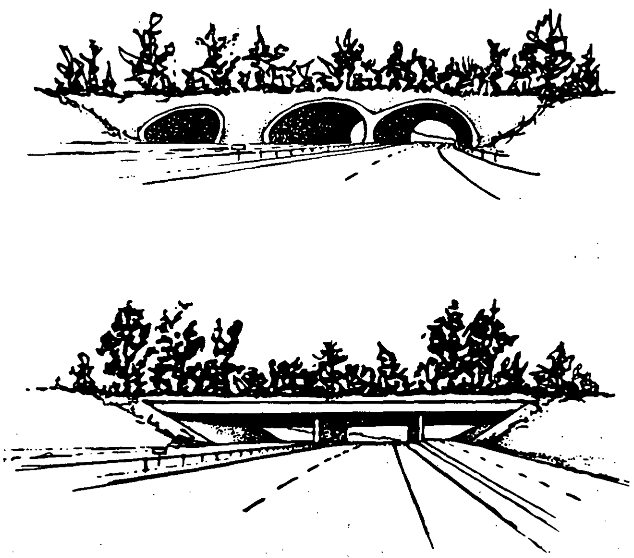

FIGURE 5 Ecoduct: *top*, cerviduct Woeste Hoeve; *bottom*, cerviduct Terlet.

Measure	*Cost (Fl.)*
Ecoduct	3,000,000
Roe deer passage	1,000,000–2,000,000
Adaption of bridge for joint use	100,000–1,000,000
Pipe passage	10,000–100,000

COMPENSATION

Compensation entails that ecological damage, expected to result from human intervention, is repaid financially, the funds being used for the benefit of nature and the environment. In the Netherlands and elsewhere in Europe, interest in compensation has grown recently; it is motivated by a desire to promote ecological functions and nature reserves in a given area and to replace functions and values that have suffered or disappeared because of the presence of infrastructure.

Mitigation and compensation can be defined clearly; these terms can be related to the recovery and replacement, respectively, of ecological functions and natural values. For mitigating measures such as barrier fencing and badger tunnels, the effect of the intervention can be connected to the measure that is implemented. In the case of compensation, however, it is more difficult to establish such a connection.

It is important to give a clear-cut set of criteria to set priorities for the location and nature of compensation and to establish the relationship between compensation and mitigation. A logical order of priority might be to apply compensation first *inside*, then *adjacent to*, and finally *outside* the intervention area, thereby aiming to achieve a higher or (if not possible) equal quality of nature. The product of the area and the quality of nature in the intervention area should remain equal before and after intervention. If the identical replacement of ecological functions and natural values is impossible, the best approach is to aim for similar ecological functions and natural values and, if this is not feasible, for dissimilar ecological functions and nature values.

It is difficult to give detailed figures for compensation measures because little practical experience is available. Clearly costs will involve the acquisition of the site and construction and management.

RESEARCH

The Road and Hydraulic Engineering Division has set up research activities to help determine project priorities and select the best mitigating and compensating measures.

1. Studies on the minimum requirements for population sustainability;
2. Studies on the minimal critical areas for ecosystem processes;
3. Research on dose-effect relations;
4. Effectiveness of mitigating and compensating measures;
5. Comparison of compensation based on species or landscape elements;
6. Studies on the implementation of measures in the policy of national, regional, and local governments; and
7. Evaluation of the defragmentation policy.

CONCLUSIONS

It is important to realize that mitigation and compensation are elements of an integrated landscape conservation strategy to maintain values of natural ecosystems. Moreover, a network of greenways across the landscape can help to achieve the goals of biodiversity conservation. Both are invaluable components of the overall conservation strategy (*6*).

If a road needs to be built, ecological engineering techniques such as mitigation and compensation measures can help to reduce the negative effects on the landscape. Mitigation measures are mainly species-specific, and compensation is aimed at replacing both species and ecosystems (increasing area or improving quality). The species approach involves working with gaps in knowledge, particularly in terms of the dose-effect relationship, and the compensation of landscape elements can make up only partly for overall impact, but it is relatively easy to implement.

Hopefully it has been shown that it is possible to integrate attempts to conserve valuable ecosystems and reduce the negative effects of infrastructure and transportation in planning and building roads.

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