### Title
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# INVERTEBRATES – A FORGOTTEN GROUP OF ANIMALS IN INFRASTRUCTURE PLANNING? BUTTERFLIES AS TOOLS AND MODEL ORGANISMS IN SWEDEN

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**Abstract:** There is a growing concern about the ecological effects of roads and railways on animals. There is increased mortality due to road kills, changes in movement patterns and changes in the physical environment in areas affected by infrastructure. A majority of all studies have been on larger mammals. There are also a growing number of studies on smaller animals like birds, amphibians and small mammals. However, the studies of invertebrates are few in comparison with vertebrates, and the knowledge of the effects of infrastructure on this group is limited. The importance of also including invertebrates in the studies of infrastructure is evident. First of all, this group of animals is the richest of species that exists. They are also ecologically important. In Sweden, a majority of the red-listed species are invertebrates. Of 4,120 red-listed species, fully 2,337 are invertebrates. Their generation times are fast, which also makes the response on changes in their environment fast, compared to mammals and birds. For that reason, invertebrates can be expected to give an indication earlier than mammals if an area is negatively affected by infrastructure.

Butterflies have several traits that make them suitable as model organisms to represent the invertebrates when studying problems due to infrastructure. In Sweden, they inhabit one of the most species-rich habitats: floral-rich semi-natural grasslands and open deciduous forests. This habitat has decreased 82 percent since 1880. Today it contains more than 1,000 red-listed species in Sweden. The habitat is sensitive to further fragmentation due to effects of infrastructure. There is a need to identify species that are dependent on these landscapes and that are possible to monitor. Butterflies are good candidates. It is relatively easy and cheap to catch and mark a large number of butterflies. They are active in daytime, and it is easy to put marks on their wings with simple equipment. Since some butterfly species are sensitive to habitat fragmentation and occur in species-rich habitats they may act as indicators of biologically rich landscapes and, therefore, as model organisms in infrastructure planning. Many butterflies are dependent on systems of patches, and that contact between them and the area of the patches are key elements in the preservation.

In one study we examined the changes in the butterfly fauna across a gradient from an intensively managed agricultural landscape with a large amount of open fields to a landscape rich in semi-natural grasslands and deciduous forests. The study took place in the province of Östergötland in southeast of Sweden. About 70 percent of the species showed a positive response to the amount of semi-natural grasslands and open deciduous forests in the landscape. More species showed a significant response at the landscape level compared to at the site-level (e.g., site area).

There seems to be clear thresholds in area demands where a small increase in the amount of habitats has large effect on occupancy probability. If you look at single species, the value for 50 percent probability of occurrence varied between 3-10 percent grasslands and deciduous forests for the seven species where the landscape factor was positively significant. For these species, there was a sharp drop in probability of occurrence at the thresholds. The individual species and groups of species that show clear thresholds in area demands can be used as indicators of biologically rich landscapes. In this study the whole group of the family Zygaenidae and the fritillaries may be used as indicators.

In another study we investigated the barrier effect by marking and recapturing butterflies along the motorway E4 in southeast Sweden. The motorway was surrounded by semi-natural pastures with portions of deciduous trees on both sides. Every capture of an individual was positioned by GPS, and by plotting the data in a GIS application we could analyze the dispersal ability and the flight direction of most of the species. The results showed that there were large differences between species regarding the dispersal ability. We used the data set to simulate a new data set of random movements. For the Ringlet (*Aphantopus hyperantus*) we expected 12 percent crossings of the motorway but (we) found only 3 percent in our field data. The barrier effect was therefore calculated to 75 percent for the Ringlet. The migratory species Green-veined white (*Pieris napi*) showed another pattern, and we both expected and found 14 percent crossings.

The main conclusions from this study of using butterflies in the planning process are:

- Butterflies can be used to identify rich landscapes.
- There exist critical thresholds, and infrastructure has probably the largest impact around the thresholds (3-10% of natural habitat left).
- Indicator species may be used to identify rich landscapes.
- Roads may act as barriers to some species.
- Invertebrates are a significant group to consider in infrastructure planning.

In the future the results can be used to identify potentially species rich areas without expensive field surveys, before the start of road and railway projects. Using data from aerial photos or satellites and analyzing them with thresholds for groups of species in a GIS application could give us a tool to prevent further fragmentation by infrastructure. The development of this tool is the next challenge, but there is also a need to confirm our findings in other landscapes as well. The thresholds in this study should be interpreted with some caution as the landscapes around some sites sometimes overlap each other.

Fig. 1. Semi-natural grasslands are one of the most species-rich habitats in Sweden with more than 1,000 red-listed species.

## Introduction

There is a growing concern about the ecological effects of roads and railways on animals. For example, based on road-effect zones, an estimated 15-22 percent of the United States is ecologically impacted by roads (Forman 2000, Forman and Alexander 1998). A number of negative effects of roads and railways have been indicated. Among others, there is increased mortality due to road kills, changes in movement patterns and changes in the physical environment in areas affected by infrastructure (Trombulak and Frissell 2000). A majority of all studies have been on larger mammals, e.g., road kills of moose (*Alces alces*), negative effects of roads on the distribution on elephants (*Loxodonta africana*) in Gabon (Barnes and others 1991) and threshold effects of road density on wolfs (*Canis lupus*) (Mech 1989). There is also a growing number of studies on smaller animals like birds, amphibians and small mammals (Trombulak and Frissell 2000). However, the studies of invertebrates are few in comparison with vertebrates, and the knowledge of the effects of infrastructure on this group is limited.

## Why Study Invertebrates?

There are a number of reasons why the studies of infrastructure effects also should include invertebrates. First, they are the most species-rich group of animals that we have. Insects alone comprise more than 80 percent of the estimated number of species on earth (Samways 1993). They are also ecologically important. Insects constitute an indispensable part of many food chains, do nutrient recycling, provide us with model organisms in science (e.g., *Drosophila melanogaster*) and have a major role in plant pollination. Pollination is estimated to be worth US$1.6-5.7 billion annually in the U.S. alone (Gullan and Cranston 1994).

In Sweden, a majority of the red-listed species are invertebrates. Of 4,120 red-listed species, fully 2,337 are invertebrates (Gärdenfors 2000). Many of the invertebrate species also use the landscape in the same scale as infrastructure affects the landscape. Populations of threatened invertebrates often exist in small areas, and a road construction may eradicate the whole habitat and population. Some of the species have a low dispersal ability ranging in hundreds of meters, and if the road acts as a barrier, populations may lose contact with each other. Inbreeding and reduced colonization rate may then be the result of road constructions. Their generation times are fast which makes the response to changes in their environment fast compared to mammals and birds. For that reason, invertebrates may give an indication earlier than mammals if an area is negatively affected by infrastructure.

## Butterflies and Infrastructure

Butterflies have several traits that make them suitable as model organisms to represent the invertebrates when studying problems due to infrastructure. In Sweden, they inhabit one of the most species-rich habitats: floral-rich semi-natural grasslands (fig. 1) and open deciduous forests. The reason for the richness of species of this habitat is probably that it is a remnant of a very old half-open, park-like ecosystem, formed by now extinct herbivores (Vera 2000). Among others, large grazers like aurochses and tarpans created a park-like landscape with a very high diversity of biotopes and a rich animal life. The remnant of this flora and fauna now survives in unfertilised semi-natural pastures managed by farmers and grazing animals, domesticated forms of aurochses and tarpans. This habitat has decreased 82 percent since 1880 (Angelstam and others 1993). Today it contains more than 1,000 red-listed species in Sweden.

The habitat is sensitive to further fragmentation due to effects of, e.g., infrastructure. There is a need to identify species that are dependent on these landscapes and that are possible to monitor. Butterflies are good candidates. Several studies have shown that butterflies are dependent on systems of patches, and that contact between them and the area of the patches are key elements in the preservation of butterflies

(Thomas and Hanski 1997). The same is probably true for most other invertebrate species. One obvious effect of infrastructure is that whole patches and populations may disappear due to the construction work, but as the habitat semi-natural grasslands is dependent on grazing to maintain its diversity, in the long run, other effects also occur. A large road in a system of semi-natural grasslands may make it very difficult for a farmer to transport animals between the patches. As a result, some of the patches are often abandoned, and the park-like grassland slowly transforms to forests, and much of the flora and fauna goes extinct during the succession. Many butterfly species react quickly on succession. A review of 22 detailed studies of butterflies concluded that in 20 of them butterflies were sensitive to successional changes (Bergman 2001). Most of the reported local extinctions of butterfly populations in Britain have been due to successional changes that arose upon cessation of management (Bergman 2001). Recently, a three mile stretch of a large road in Britain was totally removed and replaced by a footpath to be able to graze one 400 ha patch that harbours one of the last large populations of the threatened march fritillary (*Euphydryas aurinia*) (BBC Wildlife 2001).

Alternation of movements and population densities is another possible negative effect of infrastructure. There exist many studies of how infrastructure affects mammal density and movements, but there are few studies of invertebrates. Roads were effective barriers of movement for carabid beetles and spiders in a study in Germany (Mader 1984, Mader et al. 1990). Also flying invertebrates may be affected. A motorway (c. 50m wide) in Britain reduced the flow of individuals of the butterfly *Antocharis cardamine* by 91.8 percent (Dennis 1986). Mungiura and Thomas (1992) found smaller effects on butterfly movements near smaller roads. However, there were significantly fewer crossings than predicted assuming random movements.

No studies have so far been made to our knowledge about how the barrier effect may affect population survival in the long term for invertebrates. This kind of research is often time- and money-consuming. However, it is relatively easy and cheap to catch and mark a large number of butterflies. They are active in daytime, and it is easy to put marks on their wings with simple equipment. Since some butterfly species are sensitive to habitat fragmentation and occur in species-rich habitats they may act as indicators of biologically rich landscapes and therefore as model organisms in infrastructure planning.

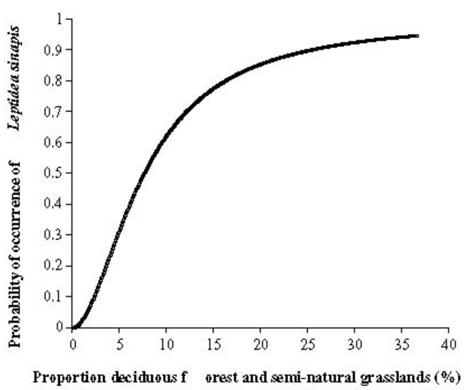


Fig. 2. The probability to find the butterfly *Leptidea sinapis* in a single site as a function of the proportion of semi-natural grasslands and deciduous forests in the surrounding landscape (a circle around the site with a diameter of 5km).

## Butterflies as Landscape Indicators

One of the main aims of our studies was to investigate the possibility to identify landscapes with semi-natural grasslands and open deciduous forests of high conservation interest by using butterflies. We set up a study where we examined the changes in the butterfly fauna across a gradient from an intensively managed agricultural landscape with a large amount of open fields to a landscape rich of semi-natural grasslands and deciduous forests. We also analyzed the effects of the surrounding landscape on the butterfly community at different scales. The study was carried out in the province of Östergötland in the southeast of Sweden. The distribution of potential butterfly habitats was identified through interpretation of infrared aerial photos. In total the study covered about 1,750km$^2$. A total of 12,824 areas were identified and butterflies were recorded in 62 of these sites. The 62 sites consisted of open to half-open semi-natural grasslands with at least 30 percent of the site area unfertilized since oligotrophic unfertilized areas support the richest flora.

In total, 12,179 butterfly individuals of 57 species were observed on the 62 sites. An analysis of the data showed that a total area of open deciduous forests and semi-natural grasslands with a tree and bush cover greater than 25 percent in the landscape was important for the species diversity of butterflies. The area of grasslands and deciduous forests in 5000m from the studied butterfly site had a significant positive effect on both species richness and occurrence of single species. The areas in 500m and 2000m were not as important. Therefore, our study indicates that a relevant scale to predict the occurrence of species richness of butterflies in a certain site, is to study the occurrence of suitable habitats 5km from the site.

About 70 percent of the species showed a positive response to the amount of semi-natural grasslands and open deciduous forests. Furthermore, it was more relevant to analyze species occurrences at the landscape level than the site-level (e.g., site area). Species showing negative correspondence of grasslands and deciduous forests are known migratory species utilizing man-made habitats as the Small white *Pieris rapae* and Small tortoiseshell *Aglais urticae*.

There seems to be clear thresholds in area demands where a small increase in the amount of habitat has a large effect on occupancy probability. One example of using butterflies as landscape indicators can be to look for all areas that have a probability above 50 percent to harbor greater than 20 species. Our results show that a single site has a 50 percent chance to harbor greater than 20 species in landscapes with proportions of more than 7 percent habitat area. If you look at single species, the value for 50 percent probability of occurrence varied between 3-10 percent grasslands and deciduous forests for the seven species where the landscape factor was positively significant. For these species, there was a sharp drop in probability of occurrence at the thresholds (fig. 2). This means that for successful conservation, it is important to identify landscapes above the threshold in the planning process of infrastructure.

Individual species and groups of species that show clear thresholds in area demands can be used as indicators of biologically rich landscapes, instead of studying a large number of species that may need expensive expertise. One group of demanding species seems to be the whole family Zygaenidae. For a site to harbor at least one species of Zygaenidae, there has to be greater than 5.2 percent of grasslands and deciduous forests. Some other indicator species seem to be the whole group of fritillaries and especially *Mellicta athalia, Boloria selene, B. euphrosyne* (Nymphalidae and *Heodes virgaureae,* (Lycaenidae). These species have in common low dispersal abilities and host plants from oligotrophic habitats.

## Barrier Effects

Another important factor regarding infrastructure is the barrier effect. Even if it is possible to avoid suitable habitats when planning for infrastructure and even if the total area affected is small, there can be problems for species to survive in the long term. If populations lose contact between each other due to the barrier effect of the road, recolonisations after extinctions may be greatly delayed. The populations may in the long run go extinct on both sides of the road if the fragment on each side is too small to exist without the help of migrating individuals. To investigate the impact on dispersal, the barrier effect, of a road we marked and recaptured butterflies along the motorway E4 in the southeast Sweden near the boarder of the provinces of Östergötland and Jönköping (fig. 3). The motorway was surrounded by semi-natural pastures with deciduous trees on both sides. The habitat was considered suitable and with small differences on both sides.

Fig. 3. Study site for the mark-release-recapture work.
A motorway intersects a species-rich semi-natural grassland.

The results showed that all species were found on both sides. Every capture of an individual were positioned by GPS and a total of 8,415 individuals of 55 species were marked and recaptured. By plotting the data in a GIS application we could analyze the dispersal ability and the flight direction of the species (fig. 4). The results show that there were large differences between species regarding their dispersal ability. Some species like *Pieris napi* and *Gonepteryx rhamni* (Pieridae) crossed the road relatively often. However, some species like *Coenonympha arcania, Aphantopus hyperantus* (Nymphalidae) and *Polyommatus semiargus* (Lycaneidae) seldom crossed the road in spite of large populations on both sides of the road.

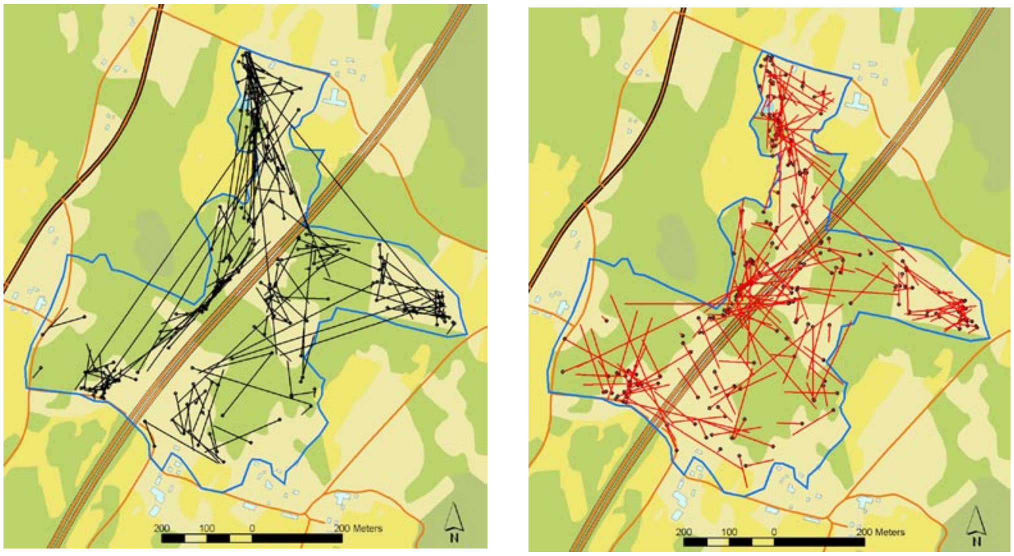


Fig. 4. The dispersal and crossings over a motorway of the Ringlet (*Aphantopus hyperantus*) in semi-natural pastures surrounding the motorway E4 southeast of Sweden. The black lines (left image) are real data from the mark-release-recapture study and the red lines (right image) are a random simulation of the same data set.

We used the data set to simulate a new data set of random movements based on the found pattern of dispersal distances for each species but with random angles in each movement. For the Ringlet (*Aphantopus hyperantus*) we expected 12 percent crossings of the motorway but we observed only 3 percent in our field data (fig. 4). The barrier effect was therefore calculated at 75 percent for the Ringlet. The migratory species Green-veined white (*Pieris napi*) showed another pattern, and there were no differences between expected and observed crossings (14% in both cases). For this species we could not estimate any barrier effect. This indicates that roads may act as barriers also to flying insects, but that it may be species specific, and that careful planning may be needed for keeping the contact between populations even though the butterfly sites themselves are untouched.

## A Hypothetical Example of Infrastructure Effects

A hypothetical example may shed light upon the difficulties in infrastructure planning and invertebrate conservation. From the beginning (A) there is a system of patches of semi-natural grasslands forming a metapopulation for several butterfly species (fig. 5). The existence of the meta-population is balanced by local extinctions and colonization's among the local populations. In the planning process each site is identified and a road is planned to avoid the sites (B). When the road is built (after building of the road) populations go extinct in the smaller patches south of the road (blue-crossed markings) as a consequence of the barrier effect of the road, because migrating animals from other populations cannot recolonize the areas. In the long run, the whole meta-populations north of the road may also go extinct, because the number of sites is now only six and nine on each side of the road, and the total area on each side is no longer enough to maintain the system – an important threshold has been passed. Field data indicate that butterfly meta-populations living in systems with less than 15-20 patches are very sensitive to further loss of patches (Thomas and Hanski 1997).

The example above shows how fragmentation of natural habitats could cause extinctions, but most important is that the severe effects of fragmentation can be avoided if knowledge of population processes is introduced in the planning process.

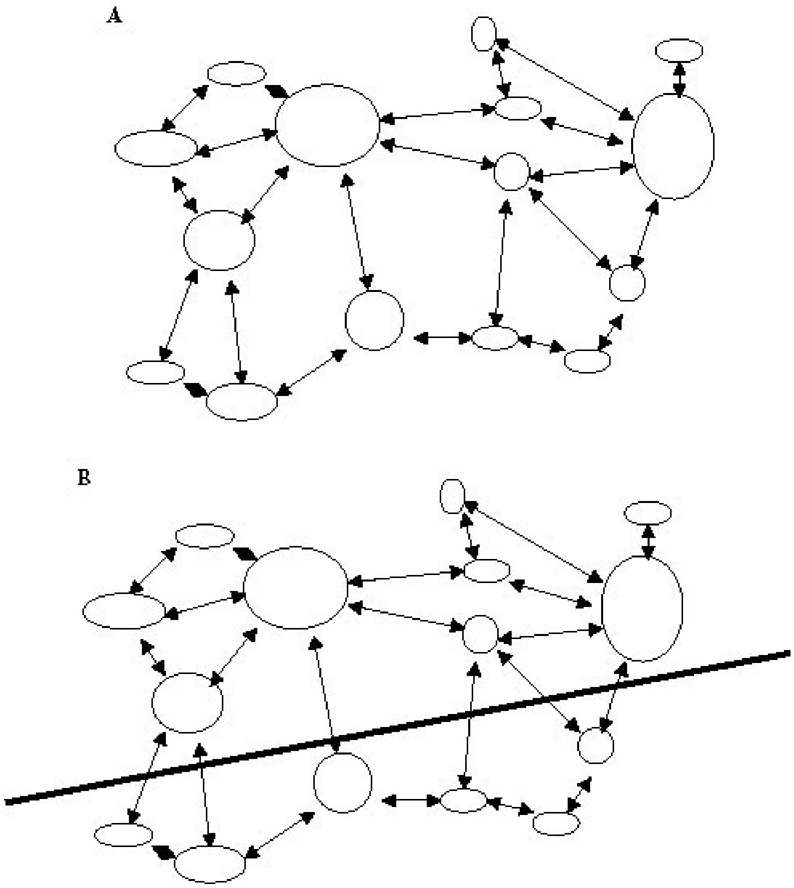


Fig. 5. A hypothetical example of a meta-population in balance between extinctions and colonizations where the populations in the different patches have just enough contact with each other to exist in the long term. A road may in the long run cause the extinction of the whole metapopulation.

## Conclusions of Using Butterfliers in the Planning Process

In this study we have focused on invertebrates in general and butterflies in particular to investigate if they are a possible object to study in open to half-open habitats with high conservation values. Our main conclusions, so far, are:

- Butterflies can be used to identify rich landscapes.
- There exist critical thresholds, and infrastructure has probably the largest impact around the thresholds (3-10% of natural habitat left).
- Indicator species may be used to identify rich landscapes.
- Roads may act as barriers to some species.
- Invertebrates is a significant group to consider in infrastructure planning.

In the future the results can be used to identify potentially species-rich areas without expensive field surveys, before the start of road and railway projects. Using data from aerial photos or satellites and analyzing them with thresholds for groups of species in a GIS application could provide a tool to prevent further fragmentation by infrastructure. The development of this tool is a challenge, but there is also a need to confirm our findings in other landscapes as well. The thresholds in this study should be interpreted with some caution as the landscape around some sites overlaps.

**Biographical Sketch:** John Askling received his Bsc in biology in 1995 after studying at the Universities in Linköping and Lund. From 1992 he was a research assistant until 1996 in a project concerning butterfly communities in semi-natural grasslands. In 1992 he also was one of the founders of CALLUNA AB, which is a conservation consultancy corporation. Since 2001 he has been is the CEO of the company. At CALLUNA he has worked with many projects concerning infrastructure and the environmental impact assessment belonging to the planning process. He and CALLUNA have a special interest in making ecology applicable in infrastructure projects. Therefore he is taking part in the research project "Landscape ecological effects on invertebrates of roads and railways" in collaboration with Linköping University. The aim of the project is to study landscape ecological effects of roads and railways on invertebrates. The Swedish National Road Administration and the Swedish National Railroad Administration fund the project.

Karl-Olof Bergman received his BSc in biology in 1990 after courses at Linköping University. He moved on to do a PhD (2000) in conservation biology with the threatened butterfly *Lopinga achine* as a model organism along with teaching biology. *Lopinga achine* is included on the list of endangered flora and fauna compiled by the Bern Convention and in the EU Habitats Directive. He is now a lecturer and a researcher in conservation biology at Linköping University. His research includes the project "Landscape ecological effects on invertebrates of roads and railways" in collaboration with CALLUNA AB. The aim of the project is to study landscape ecological effects of roads and railways on invertebrates. The Swedish National Road Administration and the Swedish National Railroad Administration fund the project. He has also developed monitoring methods for insects for the Swedish Environmental Protection Agency and done research on population viability analysis of *Lopinga achine*.

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