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Effects of the Configuration of Road Networks on Landscape Connectivity

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Abstract: Wildlife biologists, traffic planners, and decision makers are increasingly concerned about the effects of landscape fragmentation caused by transportation infrastructure. Data on the degree of landscape fragmentation are urgently needed for monitoring environmental change, identification of trends, and as a basis for investigating the effects of fragmentation on larger scales. The method of effective mesh size is currently used in several countries for national environmental reporting, e.g., as one of 24 core indicators in Germany. The objectives of this paper are to develop a new method for the quantification of landscape connectivity that incorporates variable barrier strengths into the effective mesh size, and to apply it to the question of how the configuration of transportation networks affects landscape connectivity, using empirical data on ungulates and amphibians. The paper also addresses the question of how crossing structures can enhance landscape connectivity most efficiently depending on their placement and spatial arrangement.

The outcomes include the following principles: (1) The more crossing structures were implemented, the higher the resulting landscape connectivity. (2) The higher traffic volume, the larger the difference between the configuration with and without crossing structures, and the more pronounced the differences among the various configurations with crossing structures. (3) The more patches can be accessed from any patch by few road crossings (i.e., high number of nearest neighbours and next nearest neighbours), the higher the degree of landscape connectivity. (4) The closer to each other the roads are (i.e., the more bundled the roads are), the higher the degree landscape connectivity. (5) However, putting all traffic on one road can be better or worse for landscape connectivity, depending on how quickly crossing success decreases with increasing traffic volume. (6) The number and quality of crossing structures are highly relevant. Wildlife passages that are not satisfactorily functional provide little benefit to landscape connectivity. (7) Large patches should be connected first. Only once the large patches are well enough connected does the additional connection with smaller patches provide higher additional connectivity than an improvement of the connectivity between the large patches.

The results demonstrate that the topology-sensitive effective mesh size is a suitable tool to study the effects of road network configuration and wildlife passage location on landscape connectivity. Because traffic volume may vary over time, landscape connectivity can vary over a day, week, or year. This new method will probably be applied widely in the future as the current lack of quantitative empirical data on the barrier strength as a function of road type, traffic volume, and animal species is currently addressed more and more systematically by wildlife biologists.

Introduction

Landscape fragmentation caused by transportation infrastructure is a serious threat to the sustainability of human land uses because it has a number of detrimental effects on the environment including spread of noise and pollution from traffic, effects on local climate, reducing the size and persistence of wildlife populations (e.g., by the dissection of populations and the isolation of habitats), and impairing the scenery and recreational quality of the landscape (Underhill and Angold 2000, Jaeger 2002, Forman et al. 2003). Data on the increasing degree of landscape fragmentation are urgently needed for monitoring environmental change, identification of trends, and as a basis for investigating the effects of fragmentation on a regional and national scale (Jaeger 2002, Heinz Center 2002, Kupfer 2006, Jaeger et al. 2007).

The scientific literature offers a number of metrics to measure the degree of landscape fragmentation (e.g., Hargis et al. 1998, Gustafson 1998, Jaeger 2000, Ritters et al. 2000, Rutledge and Miller 2006). However, few of them have been developed in a form that can be easily applied to transportation infrastructure. For example, it is notoriously difficult to use raster-based metrics since the resolution of raster images of the landscape is often too coarse to depict smaller roads correctly. Even with larger roads, there can be problems when the size of the raster cells is in the order of the width of the roads. Consequently, the lines of raster cells representing roads may be discontinuous, i.e., may have holes, which can lead to flawed results when the patches on either side of the roads appear to be connected through these “holes”. For this reason, vector data should be used preferably, and therefore, metrics should be chosen that are applicable to vector data.

In most cases, former methods to quantify the degree of landscape fragmentation have based the decision of whether or not to include roads as barriers on the road’s category (e.g., include district roads but exclude municipal roads) or on a minimum amount of traffic (e.g., include only roads with >1000 vehicles/day, BFN 1999, Gawlak 2001). Therefore, these methods do not take into account the varying degree of a road’s barrier strength that depends on traffic volume, on several characteristics of the road itself (e.g., width, type of surface), and on the surrounding landscape (e.g., slope). For example, the effective mesh size (see below) is based on the ability of two animals – placed in different areas.
somewhere in a region – to find each other within the landscape (e.g., for reproduction), and in its most basic version, it only includes those connections between points that do not cross a barrier, i.e., it is based on the probability that two randomly chosen places in a region will be found in the same patch (Jaeger 2000, Moser et al. 2007). Following the successful implementation of this indicator in Baden-Württemberg in 2003 (fig. 1), this method is currently used as one of 24 core indicators for environmental reporting in Germany (Schupp 2005), and in the indicator system for Monitoring Sustainable Development (MONET) in Switzerland (fig. 2; Jaeger et al. 2006b, Bertiller et al. in press, Jaeger et al. in press), and it is also used by the European Environmental Agency and by Environment Canada. An ongoing project of the Road Ecology Center at UC Davis determined the current degree of landscape fragmentation in California at multiple scales (Girvetz et al. 2008 in this volume). The inclusion of quantitative data on the degree of landscape fragmentation in environmental reporting is a major progress during the last five years, and in many countries, has not yet been completed.
Landscape fragmentation can be understood as a reduction in landscape connectivity. Landscape connectivity is defined as “the degree to which the landscape facilitates or impedes movement among resource patches” (Taylor et al. 1993, Tischendorf and Fahrig 2000; for a discussion of different interpretations of the term see Fischer and Lindenmayer 2007). Landscape connectivity is species-specific and landscape-specific, i.e., it is a characteristic of a landscape and depends on the movement behaviour of the species. When landscapes become more and more fragmented then the movement of animals among their resource patches is increasingly impeded. Consequently, the degree of landscape fragmentation increases.
volumes, and on their design (e.g., width, shape of the embankment, presence of jersey barriers). This paper addresses the question of how landscape connectivity is affected by the configuration of road networks and traffic volume on the roads. This requires the following questions to be answered:

1. How can the differing barrier strengths of roads be included in monitoring and reporting on the degree of landscape fragmentation?
2. In relation to what processes should the differing barrier strengths be defined?
   a. In relation to animal species? Which ones?
      i. as a function of traffic volume?
      ii. as a function of other road/traffic variables?
   b. In relation to other effects of fragmentation? Which ones?

The reference to the movement of some species, or to some other landscape process, makes the resulting values of the degree of fragmentation species-specific, or process-specific, respectively. I developed a new method for the quantification of landscape connectivity that incorporates variable barrier strengths into the effective mesh size. The connections across linear barriers are included by introducing additional terms in the formula of the effective mesh size (see below). This new method can also be applied to investigate how the placement of crossing structures affects the degree to which crossing structures enhance landscape connectivity. This paper presents some illustrative examples of how to apply the new method using empirical data on ungulates and amphibians. In these examples, the barrier strength depends on traffic volume (increasing barrier strength with increasing traffic volume).

Figure 2. Time series on the degree of landscape fragmentation caused by transportation infrastructure and urban development in the Swiss Environmental Statistics, using the effective mesh size (SFSG/FOEN 2006; data from Jaeger et al. 2006b, Bertiller et al. in press, Jaeger et al. in press). A: Title page of the report. B: Text and diagram for the indicator “landscape fragmentation” when it was reported for the first time in Switzerland in 2006 (p. 10 of the report). (Reprinted with permission from the Swiss Federal Statistical Office and the Swiss Federal Office for the Environment.)
**Methods**

**Effective Mesh Size and Effective Mesh Density**

To capture the effect that road construction and road improvement reduce the connectivity of the landscape, the effective mesh size $m_{\text{eff}}$ is an expression of the probability that any two points chosen randomly in a region will be connected, i.e., not separated by barriers such as roads, railroads, or urban areas (Jaeger 2000, 2002). It can also be interpreted as the ability of two animals of the same species – placed randomly in a region – to find each other. Therefore, the effective mesh size corresponds nicely with the suggestion by Taylor et al. (1993) that “landscape connectivity can be measured for a given organism using the probability of movement between all points or resource patches in a landscape.” The more barriers in the landscape, the lower the probability that the two points will be connected, and the lower the effective mesh size. If a landscape is fragmented evenly into patches all of size $m_{\text{eff}}$, then the probability of being connected is the same as for the fragmentation pattern under investigation.

This method aggregates the information on landscape fragmentation into a single value that can be easily obtained and interpreted. The method has several advantages over other methods used in surveys. It encompasses all the patches remaining in the “network” of transportation infrastructure and urban zones, according to patch size. The effective mesh size is suitable for comparing the fragmentation of regions with differing total area and with differing portions occupied by housing, industry, and transportation structures. This measure can be applied to both vector data and raster data.

The formula of the effective mesh size is:

$$m_{\text{eff}} = \frac{1}{A_t} \sum_{i=1}^{n} \frac{A_i^2}{A_t},$$

where $n =$ the number of remaining patches (excluding urban development), $A_i =$ size of patch $i$, and $A_t =$ the total area of the region under research which has been fragmented. The definition of the effective mesh size is transparent and makes intuitive sense, since the probability of two points being connected can be directly expressed in a mathematical formula: The probability that a randomly chosen point is in patch 1 is $\frac{A_1}{A_t}$. So is the probability that the second point is in A1. The probability that both points are in patch 1 thus is $\left(\frac{A_1}{A_t}\right)^2$. The probabilities for all the patches 1 to $n$ are added up:

$$\left(\frac{A_1}{A_t}\right)^2 + \left(\frac{A_2}{A_t}\right)^2 + \left(\frac{A_3}{A_t}\right)^2 + \ldots + \left(\frac{A_n}{A_t}\right)^2 = \sum_{i=1}^{n} \left(\frac{A_i}{A_t}\right)^2$$

To make this result comparable to the results from other regions with different total areas, the probability of two points being connected is re-calculated in terms of the size of a patch: the effective mesh size. This is arrived at through multiplication with $A_t$ which leads to the above formula for $m_{\text{eff}}$, since

$$A_t \cdot \sum_{i=1}^{n} \frac{A_i}{A_t} = \frac{1}{A_t} \sum_{i=1}^{n} A_i.$$

The effective mesh size has several highly advantageous mathematical properties, e.g., $m_{\text{eff}}$ is relatively unaffected by the inclusion or exclusion of small or very small patches (Jaeger 2000, 2002). The maximum value of the effective mesh size is reached with a completely unfragmented area; $m_{\text{eff}}$ then equals the size of the whole area. If an area is divided up into patches of equal size, then $m_{\text{eff}}$ equals the size of these patches. However, $m_{\text{eff}}$ is not usually equal to the average size of the patches. The minimum value of $m_{\text{eff}}$ is 0 km$^2$; such is the case where a region is completely covered by transportation and urban structures. To avoid bias of the resulting values due to the reporting unit’s boundaries, the cross-boundary connections procedure should always be applied in the calculation of $m_{\text{eff}}$ (Moser et al. 2007).

Alternatively, the effective mesh density $s_{\text{eff}} = 1/m_{\text{eff}}$ can be used which expresses the number of meshes per unit area, e.g., per 1000 km$^2$. It has the advantage that an increasing degree of fragmentation will be represented by an increasing curve.
The New Method: Topology-sensitive Effective Mesh Size and Mesh Density

The method can be refined in such a way that it includes the varying barrier strengths of roads and railways. This is achieved at by including additional terms in the formula of the effective mesh size. They have the form

\[ 2 \cdot A_i \cdot A_j \cdot (1 - B), \]

where \( A_i \) and \( A_j \) are adjacent patches and \( B \) is the strength of the barrier between them, \( 0 < B < 1 \) (Jaeger 2002, chapter 6.5; Fig. 3A). When the strength of the barrier is 100% (\( B = 1 \)), then this term is 0 and \( m_{eff} \) is as before. When the barrier is 0 (\( B = 0 \)), then \( A_i \) and \( A_j \) are not separated from each other but just form one patch size of \( (A_i + A_j) \), correctly taken into account in \( m_{eff} \) because

\[ A_i^2 + A_j^2 + 2A_iA_j = (A_i + A_j)^2. \]

In addition, the animals may be able to cross a suite of barriers in sequence, and the barriers can have differing barrier strengths \( B_i \) (\( i = 1, ..., n; n = \) total number of barriers crossed). In this case, the additional terms have the form

\[ 2 \cdot A_i \cdot A_j \cdot (1 - B_1) \cdot (1 - B_2) \cdot ... \cdot (1 - B_n). \]

This situation is illustrated in fig. 4.

The addition of crossing structures can be taken into account by terms the form of

\[ 2 \cdot A_i \cdot A_j \cdot D \cdot N, \]

where \( D \) is the perforation of the road as determined by the number of crossing structures and \( N \) is the acceptance (likelihood of use) of the crossing structure by the species of interest (fig. 3B).

![Figure 3](image_url)

Figure 3. Illustration of the barrier strength \( B \) of a road and potential crossings of the road by animals that accept crossing structures. A. The animals can cross from \( A_i \) to \( A_j \) with a likelihood of \((1-B)\). B. The animals can cross the road using a crossing structure with a likelihood of \(D \cdot N \) where \( D \) is the perforation of the road barrier by crossing structures and \( N \) is the willingness of the species to use crossing structures.
Figure 4. Example of a landscape where the animals have to cross two roads to move from patch 1 to patch 3. \( A_1 = 10 \text{ km}^2, A_2 = 20 \text{ km}^2, A_3 = 30 \text{ km}^2, A_t = 60 \text{ km}^2 \).

In the refined version of the effective mesh size, the relative position of the patches matters (see example below, fig. 7). In mathematical language, the study of the relative positioning of objects is called “topology”. Therefore, the refined version of \( m_{\text{eff}} \) is called “topology-sensitive effective mesh size”.

The formula of the topology-sensitive effective mesh size can be written in matrix form:

\[
m_{\text{eff}} = \frac{1}{A_{\text{total}}} \bar{L}^r \cdot \bar{A}.
\]

For example, for the configuration of three patches as shown in Fig. 7B, the matrix \( \bar{L} \) and the vector \( \bar{A} \) would look like this (while assuming for the sake of simplicity that the likelihood of successful crossing is the same from either side of the road and is a function of traffic volume \( V_{ij} \), i.e., \( Q_{ij} = Q = f(V_{ij}) \)):

\[
\bar{L} = \begin{pmatrix}
1 & f(V_{12}) & f(V_{13}) \\
f(V_{12}) & 1 & f(V_{23}) \\
f(V_{13}) & f(V_{23}) & 1
\end{pmatrix},
\bar{A} = \begin{pmatrix}
A_1 \\
A_2 \\
A_3
\end{pmatrix},
\]

whereas in the configuration shown in Fig. 7A, looks like this:

\[
\bar{L} = \begin{pmatrix}
1 & f(V_{12}) & f(V_{12}) \cdot f(V_{23}) \\
f(V_{12}) & 1 & f(V_{23}) \\
f(V_{12}) \cdot f(V_{23}) & f(V_{23}) & 1
\end{pmatrix}.
\]

**Examples of Application of the New Method**

I applied the topology-sensitive effective mesh size to several road network configurations using data on the likelihood of successful crossings as functions of traffic volume for amphibians (Hels and Buchwald 2001) and moose (Seiler and Helldin 2005) (fig. 5). Landscape connectivity can be reduced for differing reasons. For amphibians, the reason for the decreasing success ratio is traffic mortality. For moose, the reason for the decrease in success ratio is a combination of traffic mortality and traffic avoidance. At traffic volumes > 20,000 veh. per day, moose almost entirely avoid the road and consequently, very few individuals are killed, whereas amphibians try to cross the road at any traffic volume and consequently, a high percentage of them are killed.
Figure 5. Likelihood of successful road crossings ($Q$) as a function of traffic volume; based on data from Seiler and Helldin (2005) for moose and from Hels and Buchwald (2001) for the Grass Frog Rana temporaria.

Using these data, the topology-sensitive effective mesh size for the road configuration shown in fig. 4 becomes a function of the two traffic volumes $V_{12}$ and $V_{23}$. The resulting values of $m_{\text{eff}}$ are between 60 km$^2$ when there is no traffic on the roads, and 23.33 km$^2$ when both roads are complete barriers (fig. 6).

How does the configuration of transportation networks affect landscape connectivity, and what configurations are less detrimental to landscape connectivity than others based on the calculated species-specific degrees of connectivity?

I used seven road configurations to evaluate the effect of road network configuration on landscape connectivity (fig. 7), and seven configurations of crossing structures to study the effect of crossing structure location on landscape connectivity (fig. 8). In particular, I was interested in the effects of road bundling and of putting all traffic on one road rather than on several roads (as discussed in Jaeger et al. 2006c). I also asked if a configuration where a patch has only two neighbouring patches has a lower connectivity than one where most patches have three or more neighbouring patches, i.e., a crossed vs. parallel pattern (fig. 7, as in Jaeger et al. 2006c).
The effect of crossing structures on $m_{\text{ref}}$ depends on how strongly adding crossing structures increases the value of $D$ in the formula. Future research is needed to determine these values from empirical data. For the calculations, I used the following assumptions: $N = 0.95$ (i.e., acceptance of crossing structures by the animals is 95%), $D_1 = 0.4$ (perforation of a road by the first crossing structure), $D_2 = 0.6$ (perforation of a road by two crossing structures), $D_3 = 0.75$ (perforation of a road by three crossing structures). The more crossing structures are put along the road, the higher the value of $D$, approaching 1 for high numbers of crossing structures. When the entire road is covered by overpasses, the situation would be equivalent to the road being located in a tunnel, and $D$ would be 1.
Results

Road Network Configuration

The resulting values of the degree of landscape connectivity (topology-sensitive effective mesh size; fig. 9) show a clear ranking among the first three road configurations from fig. 7A-C. The difference between the configurations A (“parallel evenly”) and B (“Y-configuration”) demonstrates that the Y-configuration is advantageous (because the animals need to cross only one road to move from patch A1 to patch A3). However, the difference between these two and the configurations “bundled” and “all traffic on one road” is much larger for traffic volumes > 5000 veh. per day indicating that preservation of large patches is more important at higher traffic volumes when the roads become less permeable. These results are qualitatively similar for moose and grass frogs (fig. 9).

However, the result for configuration D (“all traffic on one road”) is less clear: For low traffic volumes, landscape connectivity for D is lower than for configuration C (“bundled”) for moose. This indicates that moose more often successfully cross two roads than one road with combined traffic. At traffic volumes > 7000 veh. per day, the order of these two configurations changes. For grass frogs, however, configuration D always has a higher degree of landscape connectivity than C.

![Figure 9. Results of the topology-sensitive effective mesh size for the road configurations shown in Fig. 7 (traffic volume is assumed to be the same on all roads; in the configuration “all traffic on one road”, traffic volume is the sum of the traffic of the two roads from the configurations A and C, i.e., on the x-axis half the traffic volume of the large road is given; in veh. per day). Left column: results for moose, right column: results for grass frog (Rana temporaria).](image-url)

The three other configurations from fig. 7 show a clear ranking: The configuration “parallel 4 roads” has the highest degree of landscape connectivity, and the configuration “gridded pattern” which has also four roads has the second highest landscape connectivity. For low traffic volumes, configurations F (“parallel 4 roads”) and E (“gridded pattern 4 roads”) have very similar degrees of landscape connectivity indicating that here it is the number of roads that deter-
mines the degree of landscape connectivity rather than the number of patches that are created. However, for higher traffic volumes, the effective mesh size depends only on the number of patches, regardless of what their configuration is. Therefore, the difference between “gridded pattern 4 roads” and “parallel 8 roads” vanishes for high traffic volumes (both creating 9 patches). Again, these results are qualitatively similar for moose and grass frogs (fig. 9).

**Location of Crossing Structures**

The resulting values of $m_{ef}$ (fig. 10) show a clear ranking among the configurations of the crossing structures from Fig. 8A-C. The crossing structures significantly increased landscape connectivity. The more crossing structures were implemented, the higher the resulting landscape connectivity. The higher traffic volume, the larger the difference between the configuration with and without crossing structures, and the more pronounced the differences among the various configurations with crossing structures. The connection of the two largest patches by two crossing structures (B) was more effective than the placement of one crossing structure on each of the two roads (C).

The placements of crossing structures for the Y-configuration of the roads (fig. 8D-G) also showed a clear ranking order and increasing differences with increasing traffic volume. The number of crossing structures was more important than their location. Surprisingly, the placement of all three wildlife passages on the road between A$_2$ and A$_3$ (fig. 8F) was more effective than placing each one on a different road (G).

However, the ranking of the placements of crossing structures depended on the value of N. For lower values of N, the results (not shown in the figures here) demonstrated that it is better to improve a crossing structure that is not satisfactorily functional rather than to build a new one which is not fully functional either. Only when the two largest patches (A$_2$ and A$_3$) are well enough connected does the addition of more patches provide higher additional connectivity than an improvement of the connectivity between the two largest patches.

**Discussion and Conclusions**

The results on the effects of road configuration on landscape connectivity can be generalized in the following form:

- The more patches can be accessed from any patch by few road crossings (i.e., high number of nearest neighbours and next nearest neighbours), the higher the degree of landscape connectivity.
- The closer to each other the roads are (i.e., the more bundled the roads are), the higher the degree of landscape connectivity.
- However, putting all traffic on one road can be better or worse for landscape connectivity, depending on how quickly crossing success decreases with increasing traffic volume. For grass frogs, this curve (fig. 5) decreases slowly (after a first steep decline), whereas for moose, the corresponding curve (fig. 5) decreases steeply between 0 and 7000 veh. per day.

There is a trade-off between the number of patches a landscape is broken up into, and the accessibility of neighbouring patches. Therefore, the ranking of the configurations can even change when traffic volume changes (see example in Jaeger 2002, chapter 6, and Jaeger 2001).

Regarding the location of crossing structures, the following observations were made:

- The number and quality of crossing structures is highly relevant. Wildlife passages that are not satisfactorily functional provide little benefit to landscape connectivity.
- Large patches should be connected first. When there is room for improvement for the connection between large patches then this is more effective than adding small patches at the periphery. Only once the large patches are well enough connected does the additional connection with smaller patches provide higher additional connectivity than the improvement of the connectivity between the large patches.

The accuracy of these results regarding moose and grass frogs depends on the accuracy of the data provided given by Seiler and Helldin (2005) and Hels and Buchwald (2000). The accuracy of the results on the location of crossing structures depends on the validity of the assumptions on how D increases with increasing numbers and quality of crossing structures along a road (see above).

The results demonstrate that the topology-sensitive effective mesh size is a suitable tool to study the effects of road network configuration and wildlife passage location on landscape connectivity. The barrier strength of roads depends on traffic volume which may vary over time. Therefore, landscape connectivity can vary over a day, week, and year. In addition, animal behaviour may also vary over time (e.g., during the rut) which will also affect species-specific landscape connectivity. The topology-sensitive effective mesh size is a convenient tool to investigate such changes.

Using a simulation model of population dynamics, Jaeger et al. (2006c) found that the configuration of road networks influences the degree to which roads affect the persistence of wildlife populations. However, a full species-specific simulation model of population dynamics is often not feasible because of lack of data on the demographic parameters of the population of interest. The degree to which roads reduce landscape connectivity may be much easier to determine using the new method suggested in this paper. This measure can then be used as an indicator of threat.
to the viability of populations due to landscape fragmentation, and as a proxy for assessing and comparing different locations of crossing structures. The more species-specific data are available, the more liable and useful the measure. The results from this paper correspond generally well with the results on the probability of population persistence from the population model. For example, the outcomes of the model demonstrated that the bundling of roads was almost always beneficial (and never detrimental). However, the effect of putting all traffic on one road also was often beneficial (and never detrimental) which was not in agreement with the degree of landscape connectivity for moose for low traffic volumes (see above). This raises interesting questions for future research.

One of the most important applications of the new topology-sensitive method is in environmental reporting. The German Federal Agency for Nature Conservation currently uses a cut-off criterion of 1000 veh. per day for the inclusion or exclusion of roads in the calculation of the degree of landscape fragmentation in Germany (fig. 11). This has the
major disadvantage that many roads are not “visible” any more when they branch and the two branches both have less than 1000 veh. per day. I suggest solving this problem by using barrier strength as a function of traffic volume as shown in Fig. 11.

As landscape connectivity is species-specific (because every species has differing crossing success ratios as a function of traffic volume), the resulting time series on the degree of landscape fragmentation will differ. Inclusion of time series for all species in environmental reporting (Fig. 1 and 2) is not practical. Therefore, a small number of representative species should be chosen. However, for investigating the effects of reduced landscape connectivity on animal populations, the new species-specific method is an appropriate tool and should allow for more detailed investigations and hopefully, more accurate results than former methods. To apply this new method to real landscapes, develop it to its full potential, and explore further options, I am currently combining it with graph-theoretical methods (e.g., Urban and Keitt 2001), least-cost analysis (e.g., Adriaensen et al. 2003), and circuit theory (McRae 2006).

Figure 11. Suggestion of how the cut-off criterion of the German Federal Agency for Nature Conservation for the inclusion or exclusion of roads in the determination of landscape fragmentation in Germany (BfN 1999, Gawlak 2001) (shown in A) should be replaced by a more consistent criterion (B) that can be implemented in the topology-sensitive effective mesh size. Instead of just a linear decreasing line, the curve could also have a different shape.

This new method is likely to be applied widely in the future as the current lack of quantitative empirical data on the values of \( B_i \) as species-specific functions of road type and traffic volume is currently addressed more and more systematically by wildlife biologists.

**Biographical Sketch:**
Jochen A. G. Jaeger is a research associate in the Department of Environmental Sciences at the Swiss Federal Institute of Technology Zurich (ETH Zurich), Switzerland with Prof. Dr. Jaboury Ghazoul (Group for Ecosystem Management). He studied physics at the Christian-Albrecht University in Kiel, Germany and at the ETH Zurich, and received his Ph.D. from the Department of Environmental Sciences at the ETH Zurich. He held a position at the Center of Technology Assessment in Baden-Württemberg in Stuttgart, Germany, and lectured at the University of Stuttgart, Germany. In 2001, he won a two-year research grant from the German Academy of Natural Scientists Leopoldina and went to Carleton University in Ottawa, Ontario, Canada as a postdoctoral fellow and work with Prof. Dr. Lenore Fahrig in her Landscape Ecology Laboratory (Department of Biology). In 2003, he returned to the ETH in Zurich, funded by a two-year research fellowship from the German Research Foundation (DFG) to work with Prof. Dr. K.C. Ewald. During the time April-June 2007 he was a visiting scholar at the Road Ecology Center at the University of California at Davis, U.S.A. His publications include one book titled *Landschaftszerschneidung* (2002). His research interests are in landscape ecology, quantification and assessment of landscape change, assessment of the suitability of landscape metrics, environmental indicators, road ecology, modelling, environmental impact assessment, urban sprawl, and novel concepts of problem-oriented transdisciplinary research.

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