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# Implementing Landscape Fragmentation as an Indicator in the Swiss Monitoring System of Sustainable Development (MONET)

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## Abstract

There is an increasing need and interest in including indicators of landscape fragmentation in monitoring systems of sustainable landscape management. Landscape fragmentation due to transportation infrastructure and urban development threatens human and environmental well-being by noise and pollution from traffic, reducing the size and viability of wildlife populations, facilitating the spread of invasive species, and impairing the scenic and recreational qualities of the landscape. This paper provides the rationale, method, and data for including landscape fragmentation in monitoring systems, using as an example the Swiss Monitoring System of Sustainable Development (MONET). We defined and compared four levels of fragmentation analysis, or fragmentation geometries (FGs), each based on different fragmenting elements, e.g., only anthropogenic, or combinations of anthropogenic and natural elements. As each FG has specific strengths and weaknesses, the most appropriate choice of FG depends on the context and objectives of a study. We present data on the current degree of landscape fragmentation for the five ecoregions and 26 cantons in Switzerland for all four FGs. Our results show that the degree of landscape fragmentation as quantified by the effective mesh size method is strongly supported by the postulates and indicator selection criteria of MONET, and we identify the most suitable FG focusing on the land area below 2100 m (e.g., excluding lakes) and allowing for an equitable comparison of fragmentation degrees among regions that differ in area covered by lakes and high mountains. For a more detailed analysis of landscape fragmentation in the context of environmental impact assessments and strategic environmental assessments, a combination of all four FGs may provide a more informative tool than any single FG.


*Keywords:* Cross-boundary connections procedure; Effective mesh size; Environmental assessment; Environmental indicators; Landscape conservation; Monitoring; Protected areas; Roads; Switzerland; Urban sprawl

## 1. Introduction

Transportation infrastructure, such as roads and railroads, together with the associated urban development that such infrastructure attracts, has transformed European landscapes. In Switzerland and Baden-Württemberg, Germany, land area used for settlement and transport has increased during the last 50 years by as much, or more, as during the preceding 2000 years (Häberli et al., 1991; Jaeger, 2002). Ground traffic in Europe is predicted to

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increase further over the next 20 years as a result of European Union enlargement, economic globalisation, and resulting increase in trade (e.g., UBA, 2005). Many environmental impacts are associated with this development, including changes in soil and vegetation composition, water balance, and local climate, air pollution, the effects of emissions from traffic on the health of plant populations, the impact of landscape fragmentation on the dispersal and population dynamics of plants and animals, the facilitation of the spread of invasive species or weeds, and the loss of scenic and recreational quality of landscapes due to noise, and the reduction in size and quality of recreation areas (e.g., Jaeger, 2002; Spellerberg, 2002; Sherwood et al., 2002; Forman et al., 2003; Trocmé et al., 2003).

One of the most pressing issues is the increasing impact on wildlife. Landscape fragmentation due to transportation infrastructure and urban sprawl is known to be a major cause of the alarming decrease of many wildlife populations in Europe and North America (Reck and Kaule, 1993; Trombulak and Frissell, 2000; Underhill and Angold, 2000; Forman et al., 2003). Roads and railroads affect wildlife populations detrimentally by reducing habitat area and quality, enhancing mortality due to collisions with vehicles, limiting or preventing access to resources through the barrier effect of transportation infrastructure, and by subdividing and isolating animal populations into smaller and more vulnerable fractions (Forman et al., 2003; Jaeger et al., 2005). The subdivision of habitats is particularly harmful if complementary types of habitats are separated, e.g., breeding and feeding habitat of amphibians (e.g., Pope et al., 2000).

In Switzerland, several recent political declarations concern landscape fragmentation by transport infrastructure. The Swiss Federal Agency for the Environment, Forests and Landscape (SAEFL) and the Swiss Federal Office for Spatial Development (ARE) emphasised in their vision for the future of Swiss landscapes (''Landschaftskonzept Schweiz'') the objective of limiting transportation infrastructure to a necessary minimum, and to minimize the barrier effects of new and existing transportation infrastructure (SAEFL & ARE, 1998). The equally important concept ''Landschaft 2020'' (SAEFL, 2003) proposed the goal of preserving all contiguous areas (i.e., areas with no class 1 or 2 roads; see below for definition of road classes) that exceed 50 $km^2$. A quantified target value for the maximum permissible degree of fragmentation is, however, lacking, as is any coherent mechanism by which fragmentation due to transport infrastructure can be evaluated and monitored. To assess whether such objectives will be met, and to define more specific objectives to manage future development, quantitative information on the degree of fragmentation is needed, and required to be included in statewide monitoring programs.

By ratifying ''Agenda 21'' and the Rio Declaration in 1992, Switzerland is demonstrably committed to sustainable development, a goal that was included in the revised Federal Constitution in 1999. The Agenda 21 and the Federal Council's Strategy for Sustainable Development demand the identification of sustainability indicators as measuring instruments by which Switzerland's progress in achieving a sustainable development can be monitored. In 2000, the Swiss Federal Statistical Office (SFSO), the Swiss Agency for the Environment, Forests and Landscape (SAEFL), and the Swiss Federal Office for Spatial Development (ARE) launched the Monitoring Sustainable Development project (MONET) with the aim of establishing a system of indicators for sustainable development in Switzerland (SFSO/SAEFL/ARE, 2004).

MONET is representative of many other monitoring systems of sustainable development. It uses 163 indicators, of which 135 are considered currently feasible for implementation, nested within 26 ''themes'', or topics, that encompass social, economic and environmental issues (SFSO/SAEFL/ARE, 2004). Of the total, 76 indicators are related to 'ecological responsibility' (SFSO/SAEFL/ARE, 2004). Despite this, MONET lacks any indicator for landscape fragmentation. Thus, one purpose of this paper is to evaluate effective mesh size (Jaeger, 2000) as a fragmentation indicator generally, and within MONET specifically. Effective mesh size, $m_{eff}$, can also serve as a surrogate of other human disturbances because roads and urban development are correlated with a range of human activities (e.g., Schupp, 2005). The German Federal Environmental Agency (UBA) has already adopted $m_{eff}$ to propose limits to landscape fragmentation in Germany (UBA, 2003; Penn-Bressel, 2005).

The application of $m_{eff}$ requires specification of the landscape elements that cause fragmentation, and the definition of scales (e.g., federal state, rural districts, ecoregions) over which fragmentation is to be determined (Gulinck and Wagendorp, 2002). The combination of these selections defines the fragmentation geometry (FG).

In seeking to evaluate the suitability and reliability of $m_{eff}$ as a landscape indicator we address the following questions:

(1) Does effective mesh size, as a method for measuring the degree of landscape fragmentation, meet the suitability criteria for indicators of monitoring systems, as represented by the Swiss Monitoring System of Sustainable Development (MONET), and which level of fragmentation analysis, or FG, is the most suitable one to be used?
(2) What is the extent of landscape fragmentation in Switzerland today?
    (a) What are current values of effective mesh size in Switzerland? How many contiguous areas that exceed 100 and 50 $km^2$ remain?
    (b) How variable is $m_{eff}$ among the different ecoregions and cantons in Switzerland?
    (c) How does the degree of landscape fragmentation in Switzerland differ from comparable regions in Europe (e.g., in Germany: Baden-Württemberg, Hesse; and Italy: South Tyrol)?

Few, if any, studies analyse landscape fragmentation statewide at this level of detail. We expected large differences in the degree of landscape fragmentation between the different regions of Switzerland because the Alpine and Jura regions are much less populated than the Lowlands. As many valleys in the Swiss Alps are heavily developed, we were also interested in whether localised fragmentation in valleys is similar to that in the Swiss Lowlands. Additionally, the inventory of the landscapes of national importance (BLN-areas) in Switzerland (Eidgenössisches Departement des Innern, 1977ff.) lists 162 landscapes highly deserving protection from anthropogenic impacts, and comprising 19% of the country's area. We were also interested in evaluating the degree to which these areas differ from other areas in Switzerland in terms of landscape fragmentation.

In Switzerland, the additional methodological challenge arises of how to include natural barriers due to mountains and lakes. In studies in central Europe (Baden-Württemberg (Esswein et al., 2002), Saxony (LFUG Sachsen, 2002), Bavaria (Esswein and Schwarz-von Raumer, 2003), Hesse (Roedenbeck et al., 2005), Schleswig-Holstein (Neumann-Finke, 2004), Thuringia (Voerkel, 2005)), the issue of how to treat the natural barrier effect of high mountains and large lakes has not been addressed because these features do not occur. To accommodate natural barriers, this study analyses and compares four different FGs (see below), in contrast to just two as undertaken by Esswein et al. (2002) in Baden-Württemberg, and Roedenbeck et al. (2005) in Hesse. Working with four FGs allows for differing interpretations and a more complete analysis of concepts of landscape fragmentation.

## 2. Methods

### 2.1. Definition of FGs

To analyse landscape fragmentation it is first necessary to specify which landscape elements are important. Landscape fragmentation results from the patchwork conversion and development of sites into, for example, settlements, and from linkage of these sites via linear infrastructure (Harris, 1984; Forman, 1995). We selected all landscape elements that have been shown to impede the movement of animal species, as well as those that limit recreational opportunities, or act as sources of emissions (e.g., Trombulak and Frissell, 2000; Forman et al., 2003). These included motorways, roads, railroads, areas of urban development and industrial zones (urban zones).

In Switzerland, several classes of roads are distinguished. In addition to motorways, roads of class 1–3 were taken into account as fragmenting. Class 1 roads are at least 6 m wide and are of national importance for road traffic. Class 2 roads are at least 4 m wide, paved, and include all connections of relevance for traffic between towns. Class 3 roads are at least 2.8 m wide, mostly paved, can be used under all weather conditions, and can be used by trucks. They correspond to municipal roads in Baden-Württemberg, Germany. As we wanted to compare our results with those from Baden-Württemberg bordering to Switzerland in the north, we chose similar road categories as Esswein et al. (2002) who investigated and compared situations with and without municipal roads. Therefore, we omitted class 3 roads in FG 2 and included class 3 roads in geometry 3 accordingly (Table 1). Large rivers and other water bodies also act as natural or semi-natural barriers to animal movement (Gerlach and Musolf, 2000). Therefore, we included running waters that are classified as rivers in the topographic map of Switzerland and lakes in FGs 2 and 3 (see below).

In Switzerland, a new question that has not been addressed by earlier studies of landscape fragmentation using the effective mesh size method arises: what is an appropriate way of accounting for mountain barriers, which include steep cliffs, rubble slopes, and glaciers? Holzgang et al. (2001), in their study of wildlife corridors in Switzerland, considered large areas of rock as impassable. This is particularly relevant for species that move along valleys where human activities are focussed. To keep the method simple, all areas above 2100 m were selected as high mountains (the tree-line is between 1600 and 2300 m in the Swiss Alps; Veit, 2002), and this contour was considered to be a fragmenting element in FGs 2 and 3. We chose this in accordance with the study on the Swiss national habitat network (REN, Réseau écologique national) by the SAEFL (2004) which excluded all areas above 2100 m from being considered as parts of the habitat network. The resulting map of mountainous areas is also very similar to the impassable rocky areas in the study by Holzgang et al. (2001).

High mountains above 2100 m cover 20.7% of Switzerland's surface area (8554 $km^2$ out of 41294 $km^2$) and for some alpine animal species this region represents a largely contiguous area of habitat which includes the Swiss National Park. It can therefore be argued that for some animal groups (such as the alpine ibex or steinbock *Capra ibex*) high mountains should not be considered as a fragmenting element. For humans too, the natural scenery of the high mountain area is attractive for recreational purposes as it is largely undisturbed by roads. Therefore, we decided to define four different FGs (Table 1) to allow for various interpretations of landscape fragmentation from different perspectives, and to illustrate the differences and implications of the various assumptions (see Tables A1 and A2 in the Appendix A for a complete list of fragmenting elements).

FG1 is designed to be sensitive to the scenic and recreational qualities of the landscape and, therefore, is based exclusively on anthropogenic fragmentation elements (including class 3 roads) and does not consider natural features to be fragmentation barriers. It is also appropriate for species for which high mountains and large water bodies are not significant barriers. It can be used to

Table 1
Definition of the four fragmentation geometries investigated in this study

| Number and name of the fragmentation geometry | Definition and relevance | Fragmenting elements taken into account | |
|---|---|---|---|
| | | Anthropogenic | Natural |
| (1) Anthropogenic barriers only | Only anthropogenic elements were taken into account as fragmenting elements, no natural elements. Useful for assessing the anthropogenic pressure on the entire landscape; appropriate for the assessment of the scenery and the recreational quality. | Motorways, highways of class 1–3, railways, areas of urban development | None |
| (2) Barriers including 2nd class roads | Combination of anthropogenic and natural fragmentation elements; for comparison with data from Baden-Württemberg (Esswein et al., 2002) for the fragmentation level "without municipal roads" | Motorways, highways of class 1–2, railways, areas of urban development | Rivers, lakes, and mountains (>2100 m elevation) |
| (3) Barriers including 3rd class roads | Combination of anthropogenic and natural fragmentation elements; for comparison with data from Baden-Württemberg (Esswein et al., 2002) for the fragmentation level "including municipal roads" | Motorways, highways of class 1–3, railways, areas of urban development | Rivers, lakes, and mountains (>2100 m elevation) |
| (4) Focus on the inhabitable parts of the landscape | Only the inhabitable parts of the landscape are included, i.e., the area that could actually be used for building houses or roads; therefore, the parts of the landscape where no development is feasible (e.g., on glaciers, lakes) were excluded from the reporting units. | Motorways, highways of class 1–3, railways, areas of urban development | Rivers, lakes, and mountains (>2100 m elevation) are excluded from the reporting unit (i.e., the reporting unit is being rearranged). |

For a detailed list of the fragmenting elements included see Tables A1 and A2 in the Appendix A.

identify extensive low-traffic areas that may be suitable for designation as protected areas.

FGs 2 and 3 include both anthropogenic and natural barriers to animal movements, and are in accordance with Esswein et al. (2002). The difference between them is that FG2 does not include class 3 roads while FG3 does, and the latter is therefore a more sensitive measure of fragmentation.

FG 4 is based on the assumption that the lakes and high mountain features (e.g., glaciers) will not be developed and are therefore effectively immune from fragmentation. Therefore, when two regions (e.g., Swiss cantons) are compared, it may be more appropriate to compare the accessible and habitable regions of the defined areas having accounted for respective areas occupied by lakes and high mountains which may otherwise heavily bias the outcome. Therefore, FG4 differs from FG3 only in that it excludes lakes and high mountain areas from the analysis. Because these areas are included as fragmenting elements by FG3, the effective mesh size calculated in FG3 is always lower (or at least never higher) than in FG4.

To answer the question of how suitable $m_{\mathrm{eff}}$ is as an indicator within monitoring systems of sustainable development (first part of question 1), we systematically applied the suitability criteria for indicators and postulates of the MONET system to effective mesh size (SFSO/SAEFL/ARE, 2004; see below Table 2). To reveal which FG is the most suitable for being used in monitoring systems (second part of question 1), we made use of quantitative data related to question 2 about the current degree of landscape fragmentation in Switzerland. Therefore, we first report the quantitative results on the degree of landscape fragmentation, before addressing question 1.

## 2.2. Effective mesh size $m_{eff}$

The scientific literature offers a variety of methods for quantifying landscape fragmentation (Haines-Young and Chopping, 1996; Gustafson, 1998; Jaeger, 2000). We chose *effective mesh size* (Jaeger, 2000) as a measure of fragmentation as this method aggregates the information on landscape fragmentation into a single value that can be easily obtained and interpreted and, additionally, has several other advantages:

- It takes account of *all* patches remaining in the "network" of transportation infrastructure and urban zones.
- It is suitable for comparing the fragmentation of regions with differing total areas and with differing proportions occupied by housing, industry, and transportation structures.
- Its reliability has been confirmed on the basis of nine suitability criteria through a systematic comparison with other quantitative measures (Jaeger, 2000, 2002).
- It can be extended to include the permeability of transportation infrastructure for animals or humans moving in the landscape (i.e., filter effect; Jaeger, 2002).

Table 2
Criteria for selecting indicators for monitoring systems of sustainable development, using as an example the Swiss monitoring system for sustainable development (MONET) (SFSO/SAEFL/ARE 2004, p. 30), and assessment of the effective mesh size ($m_{eff}$) as an indicator of landscape fragmentation to be included in the indicator set

| Criteria | | Significance | Assessment of $m_{eff}$ | |
|---|---|---|---|---|
| | | | Suitability | Explanation |
| Frame of reference | 1. Of importance to Switzerland: The indicator is relevant in the Swiss context, giving an indication of the "state of the nation". | Mandatory | High | Landscape fragmentation is an important issue in Switzerland. $m_{eff}$ provides an answer to the question of what the degree of landscape fragmentation in Switzerland is. |
| | 2. Relevance with regard to MONET postulates about sustainable development: the indicator may be directly derived from at least one of the MONET postulates. | Mandatory | High | The postulates 15b, 16b, 18c, 19, and 20 support the inclusion of the effective mesh size as indicator (see text). |
| | 3. Unambiguous with regard to the assessment of the indicator's value: the indicator is clear and there is no uncertainty about which direction is good and which bad. | Desirable | High | The definition of $m_{eff}$ is clear and transparent and mathematically simple; higher values of $m_{eff}$ indicate a lower degree of landscape fragmentation and are favourable over low values of $m_{eff}$. |
| | 4. Responds rapidly to change: the indicator responds rapidly to changed conditions. | Desirable | High | The effective mesh size detects changes in the degree of landscape fragmentation immediately (i.e., as soon as the effective mesh size is calculated after a new road has been built or an old road has been removed). |
| | 5. Spatial and temporal range: the indicator is applicable to a large spatial range (e.g., all of Switzerland) and over a long time in the past and in the future. | Desirable | High | The effective mesh size is applicable to all of Switzerland and can be calculated for all times in the past and in the future, i.e., it has a large spatial and temporal range. |
| | 6. Urgency of the problem indicated: the indicator stands for problems that are urgent in terms of sustainable development, including problems over the long term. | Desirable | High | Landscape fragmentation has a number of detrimental effects (see text). In particular, it is a major cause of the dramatic decrease of many wildlife populations and of the increasing endangerment of species; lost species are almost impossible to reintroduce once their habitats have become unsuitable; therefore, this problem has a high priority and cannot be postponed. |
| | 7. Scarcity of the goods that the indicator is based on: the indicator prefers entities that constitute a limiting factor. | Desirable | High | Un-fragmented landscapes are a limited and non-renewable resource for recreation of humans and as undisturbed habitats for wildlife populations; in most European countries, they have been decreasing at a rapid pace, in particular since 1950. |
| User friendliness | 8. Readily comprehensible: the indicator is easy to interpret and its definition is transparent. | Mandatory | High | The definition of $m_{eff}$ is clear, transparent, and mathematically simple; the interpretation as the possibility of two individuals to meet is intuitive and easy to understand. |
| | 9. Reasonable level of information content: the indicator contains an appropriate amount of information (gradual, no just yes/no indication). | Mandatory | High | The value of the effective mesh size is given as a degree on a gradual scale; its value is between 0 and the size of the reporting unit (the size of Switzerland). |
| | 10. Relevant to the general public: the indicator is attractive and relates to the users' everyday life. | Desirable | High | The definition of the effective mesh size is transparent and based on the idea that two animals can find each other in the landscape which is an attractive and easy to communicate concept. In addition, the value of the effective mesh size can be related to the minimum habitat sizes of viable populations. |
| | 11. Politically relevant: the indicator relates to an international or national commitment or objective. | Desirable | High | Landscape fragmentation is subject to several official declarations of objectives (see text). |
| Validity | 12. Scientifically well-founded: there is broad scientific consensus regarding the validity and reliability of the indicator. | Mandatory | High | The effective mesh size has been widely used in various countries, e.g., in many German states (see text), in South Tyrol, in Canada and by the European Environmental Agency. The German Umweltministerkonferenz (Conference of Environmental Ministers) has recommended to use the effective mesh size in all German states. The |

Table 2 (*continued*)

| Criteria | | Significance | Assessment of $m_{eff}$ | |
|---|---|---|---|---|
| | | | Suitability | Explanation |
| | | | | reliability of the effective mesh size has been demonstrated several times (e.g., Jaeger, 2000, 2002; Esswein et al., 2003). |
| | 13. Consensus regarding interpretation: there is broad agreement with regard to the meaning of the indicator. | Desirable | High | The meaning of the effective mesh size is clear and there is wide agreement about it. |
| Data availability | 14. Available at low cost: the indicator is based on readily available data or data that may be provided with little financial expenditure. | Mandatory | High | Low data requirements; the data base used (VECTOR25) is provided by the Swiss Federal Office of Topography and is updated periodically; the calculation of the effective mesh size can be easily done in a Geographic Information System (GIS). The data for the current state are presented in this paper; data for earlier time steps will be accessible soon due to an ongoing project. |
| | 15. Regularly and homogeneously recorded data: the indicator is based on data which at present are and in the future will be recorded regularly and in a homogeneous manner. | Mandatory | High | The data base VECTOR25 is periodically updated in a consistent manner by the Swiss Federal Office of Topography, and the effective mesh size can easily be calculated for the updated data. |
| | 16. Quantifiable: the indicator is based on quantifiable data. | Mandatory | High | The effective mesh size is a quantitative measure. |
| | 17. Representative of the whole of Switzerland: the indicator is based on data which are representative of the whole of Switzerland. | Desirable | High | The effective mesh size is calculated from the data set VECTOR25 which is provided by the Swiss Federal Office of Topography, is a consistent data set, and is readily available for all of Switzerland; data from all parts of Switzerland are taken into account in calculating the effective mesh size. |

The effective mesh size is an expression of the probability of two points chosen randomly in a region being connected, i.e., not separated by barriers such as roads, railroads, or urban zones, or natural features, depending on the criteria selected. The more barriers in the landscape, the lower the probability that the two points will be connected, and the lower the effective mesh size. The connection probability is given by

$$C = \sum_{i=1}^{n} \left(\frac{A_i}{A_t}\right)^2,$$

and the effective mesh size is

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

where $n$, the number of remaining patches (not urban zones); $A_i$, size of patch $i$; and $A_t$, the total area of the region under research which has been fragmented. Effective mesh size has several highly advantageous mathematical properties, notably, $m_{eff}$ is relatively unaffected by inclusion or exclusion of small or very small patches (Jaeger, 2000, 2002), making it amenable as an indicator as exhaustive surveys are not required. The maximum value of the effective mesh size is reached in a completely unfragmented landscape, when $m_{eff}$ equals the size of the area, and the minimum value is 0 km$^2$, which would occur when a region is completely covered by transport and urban structures. If a landscape is divided evenly into patches of equal size, then $m_{eff}$ equals the size of these patches. However, $m_{eff}$ is not usually equal to the average size of the patches, because large patches are weighted higher than small patches.

We applied the *cross-boundary connections procedure* that attributes the connections between two points that are located in different reporting units (the regions for which the degrees of fragmentation are calculated) to both reporting units to equal parts (Moser et al., 2007). As a consequence, the effective mesh size can sometimes be larger than the size of the reporting unit when the patches are larger than the reporting unit. This procedure has the advantage that the boundaries of the reporting units do not bias the values of the effective mesh size because the connections across the boundaries are not cut off.

### 2.3. Data processing

The calculation of the degree of landscape fragmentation was based on digital topographic maps produced by the Swiss Federal Office of Topography. For the analysis of the current state, the most recent digital maps called *VECTOR25* were of the year 2002 at a scale of 1:25,000.

The topic layers of the various fragmenting elements were selected according to the respective FGs (Table 1, Tables A1 and A2 in the Appendix A), and the layers were superimposed. This mosaic is a set of polygons where the edges are the linear fragmenting elements. The parts of the resulting mosaic that were urban zones, lakes, or

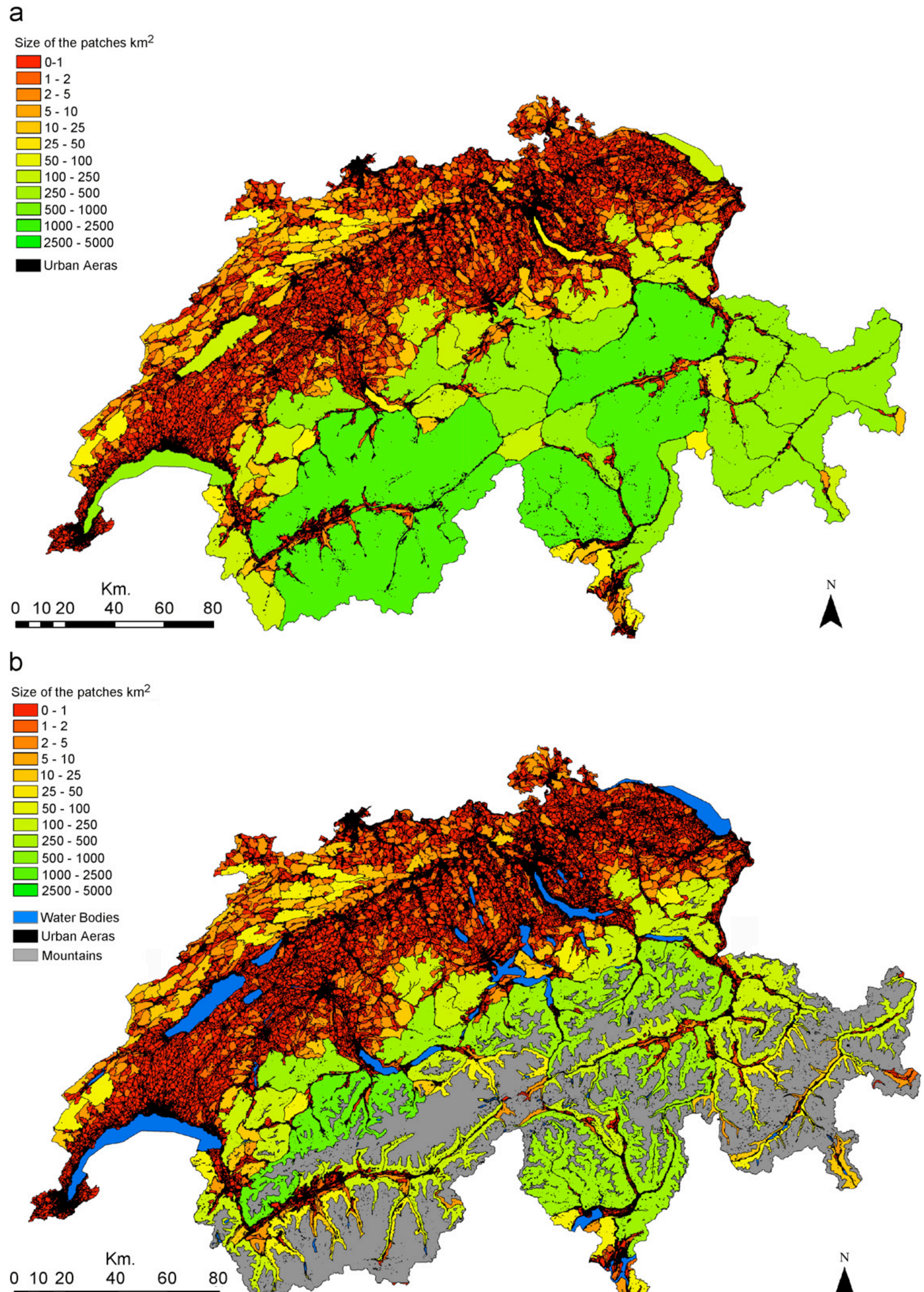


Fig. 1. Current state of landscape fragmentation in Switzerland for (a) fragmentation geometry 1 (''Anthropogenic barriers only'') and (b) fragmentation geometry 3 (''Barriers including class 3 roads''), see Table 1. The colours indicate the sizes of the patches that have remained in the network created by transportation infrastructure and urban zones.

mountains, when they were considered as fragmenting elements, were not included in the areas $A_i$ used for calculating the effective mesh size ($i = 1, \ldots, n$). The roads were represented by vector data having zero width. We omitted roads that were joined to the network at only one intersection (i.e., incisions) and, therefore, did not entirely dissect a patch, since a usable definition of when such roads cause fragmentation is difficult to establish, and their traffic density is, in any case, usually extremely low. Roads that extend into high mountains (>2100 m elevation) were, however, included in FGs 2, 3, and 4 because they dissect the patches located next to the high mountain areas. We programmed a tool in AML running under the *ArcGIS* 9.1 geographical information system (ESRI, 2005) for an automated calculation of the effective mesh size for these mosaics of polygons (available from the authors).

## 3. Results

### 3.1. Degree of landscape fragmentation in Switzerland

FG 1 is shown in Fig. 1a. Lakes are not considered as fragmenting elements and, therefore, are shown as relatively large patches, e.g., the Lake Geneva (581 km$^2$) in the south-west and the Lake of Neuchâtel (218 km$^2$) in the north-west in green. The effective mesh size in Switzerland is 661.61 km$^2$ in FG1 where only the anthropogenic fragmentation elements including class 3 roads are considered (Fig. 2). In this fragmentation geometry, there are 41 contiguous areas larger than 100 km$^2$ (53% of the country's area), and 58 areas larger than 50 km$^2$ (56% of the country's area).

When the natural fragmentation due to lakes, rivers, and mountains is added, effective mesh size is reduced to 133.29 km$^2$ (FG3; Fig. 2). This FG is shown in Fig. 1b

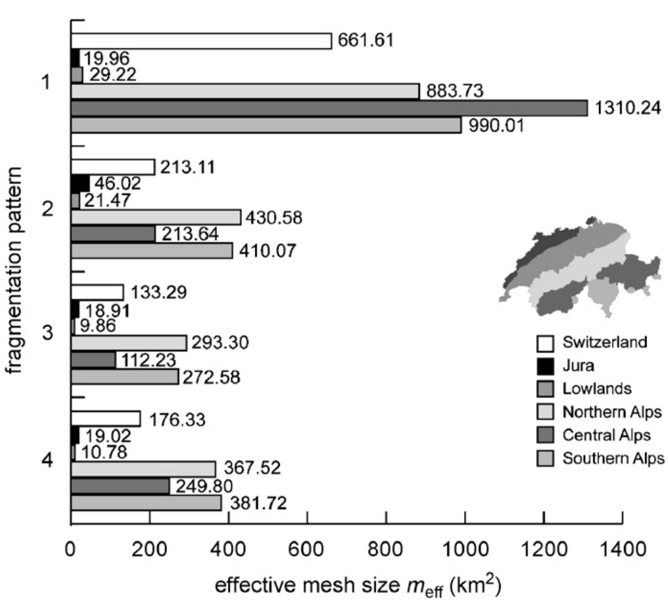


Fig. 2. Effective mesh size in Switzerland and its five ecoregions. The values for all four fragmentation patterns defined in Table 1 are given.

where the lakes appear in blue and are considered barriers. It includes 38 contiguous areas larger than 100 km$^2$ (26% of the country's area), and 64 areas larger than 50 km$^2$ (31% of the country's area).

When the class 3 roads are not included, effective mesh size is 213.11 km$^2$ (FG2; Fig. 2), i.e., 59% higher than in FG3. The proportion of large un-fragmented areas is also higher: 40 contiguous areas larger than 100 km$^2$ (32% of the country's area), and 71 areas larger than 50 km$^2$ (37% of the country's area).

In FG4, the effective mesh size is 176.33 km$^2$ (the lakes, rivers, and mountains are excluded; Fig. 2). The number and amount of large contiguous areas is the same as in FG3 because the only difference between them is the definition of the reporting unit (see above).

The degree of fragmentation varies considerably among the five ecoregions (Fig. 2). There is a distinct pattern in how these values differ:

(1) Across all FGs, the effective mesh size in the Swiss Lowlands and in the Jura region is between 9 and 50 km$^2$, exhibiting the lowest values. The values for the three Alpine regions are in all cases much higher (between 100 and 1350 km$^2$). The effective mesh size for all of Switzerland is between these values, i.e., higher than in the Lowlands and the Jura ecoregion and lower than in the Alpine regions.
(2) In FGs 2–4, the effective mesh sizes in the Lowlands are lower than in the Jura region. However, in FG1, the effective mesh size is higher in the Lowlands than in the Jura region. The values of the Jura region in FGs 1 and 3 show only a small difference.
(3) In FGs 2–4, the effective mesh size in the Central Alps is lower than in both the Northern and the Southern Alps. However, in FG1, the effective mesh size is higher in the Central Alps.

The degree of fragmentation varies greatly among the 26 cantons of Switzerland (Fig. 3). The pattern of how these values differ follows mostly the observations about the five ecoregions. Cantons most affected by urban sprawl, such as Basel-Stadt (BS), Zurich (ZH), Thurgau (TG), Aargau (AG), and Zug (ZG), have very low effective mesh size values (in all FGs), while those with high effective mesh size occur only in the Northern, Southern, or Central Alps, e.g., Glarus (GL). A few larger cantons such as Berne (BE) are located across several ecoregions and, therefore, are influenced by all of them resulting in intermediate values of effective mesh size. In general, the degree of fragmentation in the areas defined by political boundaries is more heterogeneous than within the ecoregions.

For the analysis of the BLN-areas (landscapes of national importance), we used FG1 because the objective of the inventory of the landscapes of national importance is to preserve particular landscapes that are natural or close to natural, and may include lakes or mountainous areas at high altitude. Therefore, the lakes and mountains should

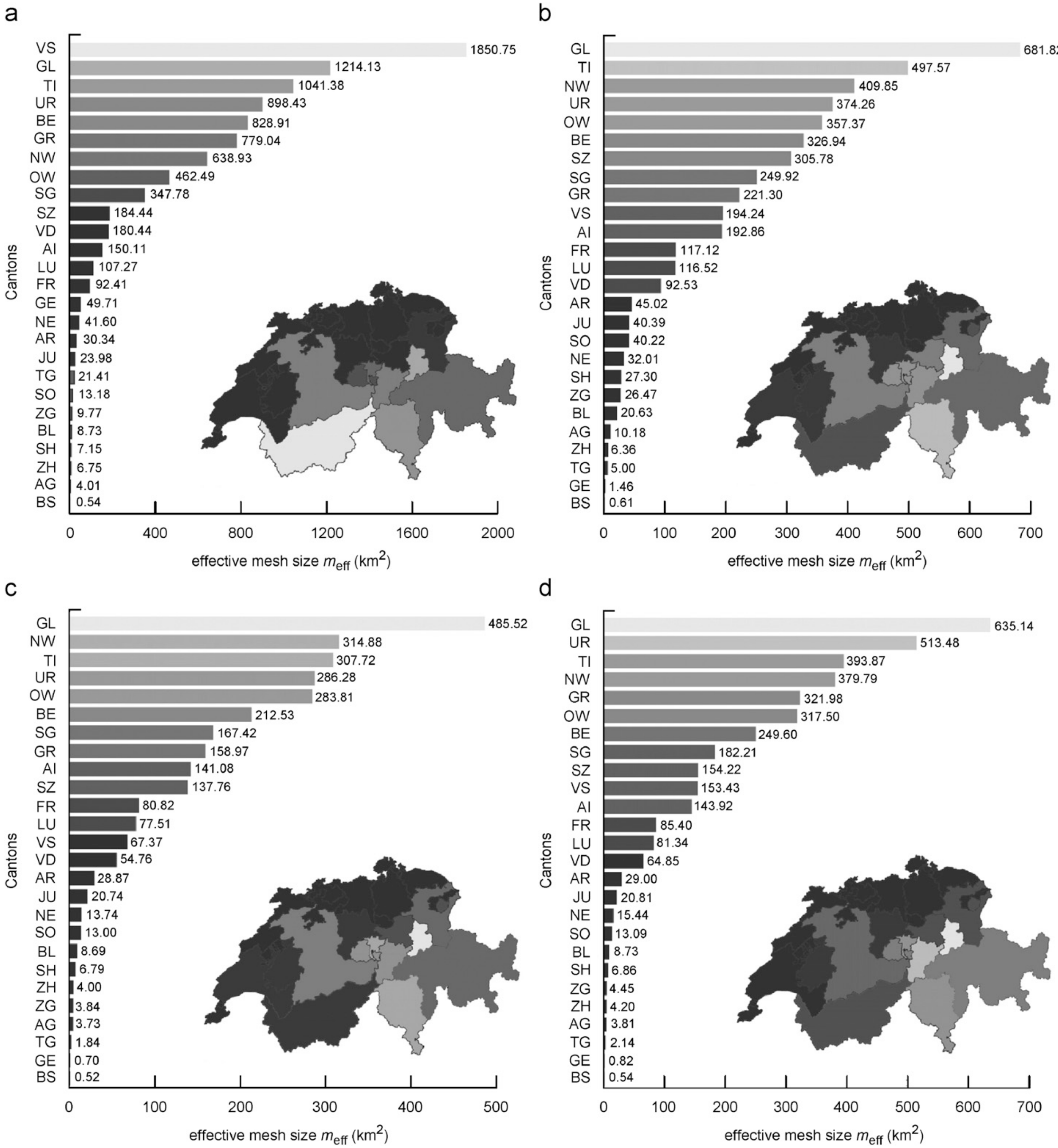


Fig. 3. Effective mesh size in the 26 cantons of Switzerland according to the four fragmentation geometries: (a) FG 1, (b) FG 2, (c) FG 3, and (d) FG 4 (Table 1). Dark shading indicates lower values of the effective mesh size. (AG, Aargau; AI, Appenzell-Innerrhoden; AR, Appenzell-Ausserrohden; BE, Berne; BS, Basel-Stadt; BL, Basel-Landschaft; FR, Freiburg; GE, Genf; GL, Glarus; GR, Graubünden; JU, Jura; LU, Luzern; NE, Neuenburg; NW, Nidwalden; OW, Obwalden; SG, St. Gallen; SH, Schaffhausen; SO, Solothurn; SZ, Schwyz; TG, Thurgau; TI, Tessin; UR, Uri; VD, Waadt; VS, Wallis; ZG, Zug; ZH, Zurich.)

not be considered barriers (as in FG 2 and 3) nor be excluded from the reporting unit (as in FG4). Effective mesh size of BLN-areas is larger by about 60% than outside such areas (Fig. 4). This observation holds across all ecoregions (Fig. 4), though the magnitude of the difference varies, as in, for example, the Lowlands where the effective mesh size of the BLN-areas is 95% higher than outside.

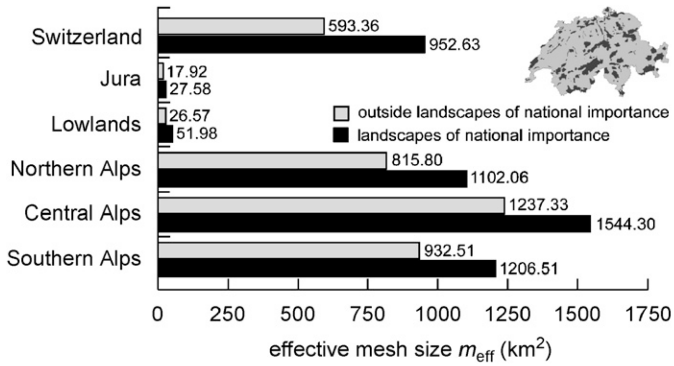


Fig. 4. Effective mesh size of the BLN-areas (landscapes of national importance) in Switzerland and in its five ecoregions compared with the effective mesh size outside of the BLN-areas (according to FG 1). The map indicates the locations of the BLN-areas.

### 3.2. *Effective mesh size as indicator in the Swiss monitoring system Monet*

Any contribution to improving the indicator set of Monet has to demonstrate its suitability according to the 17 criteria for selecting indicators for Monet (Table 2). The assessment of $m_{eff}$ through these criteria reveals a high suitability as all 17 criteria are met (Table 2). This is true regardless of which FG is used. Criterion 2 specifically refers to the relation between indicators and the 20 postulates of the Monet project. Effective mesh size is clearly related to five of these postulates (biodiversity, consumption of non-renewable resources, precautionary approach, accounting for appropriate temporal scales, socially acceptable natural and agricultural landscapes) (SFSO/SAEFL/ARE, 2004).

## 4. Discussion

Our results have shown that effective mesh size can be usefully applied to state-level analyses to identify comparative fragmentation impacts of transport infrastructure and urban sprawl. Comparisons among the four FGs reveal the relative contributions of the natural fragmenting elements, the 3rd class roads, and the other anthropogenic fragmenting elements. Furthermore, as an indicator, $m_{eff}$ clearly meets the criteria for suitability under the Swiss MONET system and other monitoring systems of sustainable development.

### 4.1. *Differences among regions*

The large differences in the values of the effective mesh size among the ecoregions (Fig. 2) and cantons (Fig. 3) are mainly due to Switzerland's topography. Effective mesh sizes of the three Alpine ecoregions are 10–45 times higher than in the Lowlands, and 5–65 times higher than in the Jura ecoregion. Industrialisation, urban development, and the construction of transportation infrastructure are concentrated in the Lowlands and, to a lesser degree, in the Jura ecoregion and the valleys of the Northern and Southern Alps (e.g., canton Ticino). Higher elevation areas are less productive and accessible and therefore attract less infrastructural development, the construction of which is, in any case, more difficult. The topography of the Lowland regions, by contrast, facilitates urban growth and transportation infrastructure development such that the largest contiguous patches remaining are lakes. It is due to lakes that the large differences in the values of the $m_{eff}$ between FG1 (29.22 km$^2$), which includes lakes as contiguous patches, and FG4 (10.78 km$^2$) which excludes lakes, are apparent. The Jura ecoregion, which also has high infrastructural density, has far fewer lakes, and consequently effective mesh size values for geometries 1 and 4 are similar (19.96 and 19.02 km$^2$).

The observation that in FG1 the effective mesh size in the Lowlands exceeds the value for the Jura region by 50%, but is lower in FGs 2–4, is also due to the fact that the lakes in the Lowlands are considered as unfragmented areas in FG1, but barriers in FGs 2 and 3, and are excluded entirely from the reporting unit in FG4. In accordance to this, the values of the Jura region in FGs 1 and 3 show a very small difference due to the absence of areas above 2100 m and very few lakes. The finding that $m_{eff}$ is lower in the Central Alps than in both the Northern and the Southern Alps in FGs 2–4, but higher in FG1, is due to inclusion of areas higher than 2100 m, that predominate in the Central Alps, as contiguous areas in FG 1, in contrast to FG 2 and 3 where high elevation areas are counted as barriers. The low $m_{eff}$ of the Central Alps under FG 4 (which excludes high mountains from the analysis) compared to Northern and Southern Alps indicates that the valleys (areas below 2100 m) of the Central Alps are more heavily fragmented than the corresponding areas in the Northern and Southern Alps.

The landscapes of national importance (BLN-areas) are far less impacted by infrastructure than other regions, as determined by $m_{eff}$, and yet using $m_{eff}$ we were able to show that the BLN-areas in the Lowland and Jura ecoregions are already subject to high degrees of landscape fragmentation. The most severely impacted BLN-areas are located within the most developed ecoregions (Fig. 4). Prioritising protection of these BLN-areas is necessary to limit any further development in these most vulnerable locations. Special emphasis may need to be given to monitoring populations of plants and animals of conservation importance within these sites, as the relationship between effective mesh size and population dynamics has yet to be quantified.

### 4.2. *Comparison with other studies*

Three other studies, from Baden-Württemberg, Germany (Esswein et al., 2002), Hesse, Germany (Roedenbeck et al., 2005), and South Tyrol, Northern Italy (Moser et al., 2007), have used effective mesh size with similar FGs. Baden-Württemberg lies to the north of Switzerland along the Rhine which forms the common border of both countries, and Hesse lies north of Baden-Württemberg. FGs 2 and 3 (with and without municipal roads) are suitable for comparing our results from Switzerland with those from Baden-Württemberg and Hesse. The classification of roads is not exactly the same across countries, although they are sufficiently similar to allow a comparison. For both FGs, $m_{eff}$ of Switzerland is 10 times larger than in Baden-Württemberg where it is 13.66 km$^2$ with municipal roads and 20.24 km$^2$ without municipal roads. It is also about 9 to 13 times larger than in Hesse where $m_{eff}$ is 15.5 km$^2$ with municipal roads and 16.59 km$^2$ without municipal roads. The main reason for this large difference is that neither Baden-Württemberg nor Hesse have areas comparable to the Northern, Central, and Southern Alps (which cover about 60% of Switzerland). Additionally, lakes cover 3.5% of the Swiss land area. It is therefore clearly important to account for topography and other large scale natural features when comparing among regions and countries.

Only the Swiss Lowlands and the Jura ecoregion are comparable to the landscape in Baden-Württemberg and Hesse. The effective mesh size of the Lowlands in FG2 is 21.47 km$^2$, and only slightly higher than in Baden-Württemberg (20.24 km$^2$) and about 30% higher than in Hesse (16.59 km$^2$), suggesting a similar degree of fragmentation by class 2 roads and larger roads. However, $m_{eff}$ of the Lowlands in FG3 is much lower (9.86 km$^2$) than $m_{eff}$ of Baden-Württemberg (13.66 km$^2$) and Hesse (15.50 km$^2$), indicating much greater fragmentation by smaller roads (class 3 roads) with low traffic. Thus landscape fragmentation by large highways in the Swiss Lowlands is similar to Switzerland's northern neighbors, but the Lowlands are more heavily fragmented by class 3 roads than the landscapes in Baden-Württemberg and Hesse and, therefore, risk increased impact of infrastructural fragmentation effects. In the Jura ecoregion, the effective mesh size (46.02 km$^2$) is more than twice as high as in Hesse and Baden-Württemberg in FG2, and by 20–40% higher (18.91 km$^2$) in FG3, suggesting lower fragmentation effects overall, but reiterating the result from the Lowlands of disproportionate impact of minor roads. The impact of minor roads is, arguably, variable depending on the object of concern, with particularly shy animal species likely to be most vulnerable, while other animals or, for that matter, plants, may show little or no response to minor roads. Thus, selection of the appropriate FG is critical to the management objectives.

The Alpine region $m_{eff}$ values using FG1 can be compared to South Tyrol, which is 485 km$^2$ (including municipal roads but excluding natural barriers) (Moser et al., 2007). South Tyrol is located east of Switzerland and has a landscape that is similar to the Central and Southern Alps. The Swiss Alps are clearly less fragmented than South Tyrol, as the $m_{eff}$ of the Southern and Northern Alps are more than 80% higher, and 160% higher in the Central Alps.

In some studies in Germany, the number and proportion of large contiguous areas $>50$ km$^2$ and $>100$ km$^2$ have been used to quantify landscape fragmentation (e.g., Gawlak, 2001). For example, the proportion of contiguous areas $>50$ km$^2$ in Baden-Württemberg is 5.3% (including municipal roads) and 9.0% (omitting municipal roads), respectively (Esswein et al., 2002), and is much lower than in Switzerland (see above). However, values for the number and proportion of large contiguous areas are not reliable as indicators of fragmentation for two reasons: 1) Fragmenting areas larger than 200 km$^2$ into two or more parts each of which is larger than 100 km$^2$ does not change the proportion, while the number of large patches even increases (deceivingly indicating an unchanged or improved situation, respectively); and 2) continued fragmentation affecting areas smaller than 100 km$^2$ or 50 km$^2$ are not taken into account at all.

### *4.3. Suitability of the effective mesh size as an indicator in the MONET and other monitoring systems of sustainable development*

The MONET system, in its first version (SFSO/SAEFL/ARE, 2004), includes two indicators of urbanisation, but one of these, urban sprawl, has been marked as "currently not feasible". Measures of landscape fragmentation using, for example, $m_{eff}$ provide a feasible alternative that includes aspects of urban sprawl as well as accounting for the distribution of transportation infrastructure. The relationship between landscape fragmentation and urban sprawl has yet to be investigated in detail but is clearly relevant to landscape planning.

Many monitoring systems still lack good indicators of urban sprawl and landscape fragmentation (e.g., Heinz Center, 2002). We have shown that $m_{eff}$ is highly suitable as an indicator in monitoring systems of sustainable development (Table 2).

Two weaknesses of the MONET indicator set, identified by the MONET Report (SFSO/SAEFL/ARE, 2004), are that, first, very few indicators provide interconnections between the 26 themes on social, economic, and ecological aspects, and second, few indicators are able to highlight differences among regions within Switzerland. Effective mesh size addresses both weaknesses, in that we have shown that $m_{eff}$ relates to five of the MONET postulates, and that the calculation of $m_{eff}$ values for five ecoregions and 26 cantons reveals large differences among them, indicating that $m_{eff}$ is adequately sensitive to landscape structure. Additionally, $m_{eff}$ is conceptually and mathematically straightforward and so can be, and indeed has been, applied easily to a wide variety of landscape scenarios (Esswein et al., 2002; Roedenbeck et al., 2005; Padoa-Schioppa et al., 2006; Moser et al., 2007).

### 4.4. The four FGs and options for their application

The four fragmentation geometries have been defined for different purposes and application contexts as outlined in Section 2.1. Accordingly, each of them has specific strengths and weaknesses. Different FGs will be appropriate depending on the context or objective of a study.

FG1 considers only anthropogenic landscape elements as barriers. This approach is appropriate if the study aims to address the 'naturalness' of a landscape, or to species, such as migratory birds or raptors, that do not perceive lakes, large rives, or high mountains as barriers. FG1 would, for example, be suitable for assessing landscapes for recreation or the state of sites of conservation significance (BLN-areas). Values of $m_{eff}$ will, however, be highly sensitive to the extent of lakes and high mountains which are generally free of infrastructural and urban development. Interpreting $m_{eff}$ values according to FG1, particularly in cross-regional comparisons, should therefore take account of the extent of lakes and mountains.

FG2 and FG3 include natural and anthropogenic barriers and are appropriate for the many species that cannot cross lakes, large rivers, or high mountains, and whose access to resources on the other side of a lake may be restricted by a road that leads to the lake shore or riverbank. This combined barrier effect of natural and anthropogenic barriers cannot be observed in FG1, which cannot generate minimal values of 0 so long as areas occupied by lakes, rivers or mountains exist. In contrast, both FG2 and FG3 can, theoretically, have a minimum value of $m_{eff}$ as 0. The maximum value is, however, reduced by the natural barriers: regions with lakes and mountains may appear more highly fragmented than regions without these natural features regardless of anthropogenic barriers. For instance, Geneva's low $m_{eff}$ values according to FG2 (1.46 km$^2$) and FG3 (0.70 km$^2$) are partly due to Lake Geneva which covers 13% of the canton's area. A strong reason for including class 3 roads (i.e., using FG3 or FG4) is that the fragmentation effects of small roads may sum to a large impact that is otherwise not recognised. Comparing results from FG2 and FG3 reveals how much class 3 roads contribute to landscape fragmentation.

FG4 excludes natural features such as lakes and high mountains from consideration. Patches on different sides of a lake or high mountain would not be connected due to this removal, but areas covered by lakes and mountains are simply not included in the analysis. This approach allows for a more equitable comparative analysis of $m_{eff}$ values for regions that differ in area covered by lakes and high mountains. Under this scenario, if lakes and high mountains are, now or in the future, developed, this would not affect the $m_{eff}$ value. However, actual development of lakes and high mountains is highly unlikely.

A consequence of these differences is that ranking of the cantons changes among the four FGs (Fig. 3). Using all four geometries in parallel and comparing the values they produce may be the best strategy to combine their strengths and overcome the weaknesses of any single geometry used in isolation. We therefore suggest using them in combination, although with due respect to the management or assessment objectives.

Given that monitoring systems seek to include only one value for each indicator, precluding the use of multiple FGs, careful consideration may need to be given to geometry selection. For cultural and recreational objectives, FG1 and FG4 are more suitable than FG2 and FG3 because only anthropogenic land uses detrimentally affect recreational opportunities. For issues relating to biodiversity, FGs 2, 3 and 4 are more suitable than FG1 as lakes and high mountains present barriers to the movement of many plant and animal species. FG 1 is clearly more suitable for species that can cross lakes and mountains. FG4 would be the most suitable to apply to forest fragmentation as forests do not tend to grow above 2100 m, and certainly not on lakes. Within the MONET system, FG4 appears to be relevant for most topics.

An additional issue, unrelated to the MONET project, favours the choice of FG4: the presence of large lakes and high mountains confounds most large scale analyses of landscape fragmentation, and confuses regional comparisons. FG 4 avoids both these problems by simply excluding these natural features from the reporting unit.

The increasing number of data sets from various regions and countries that use $m_{eff}$ will allow comparisons among landscapes with similar and different characteristics. The resulting data pool may contribute to the development of quantitative limits, or objectives, to more effectively plan and control the future extent of landscape fragmentation (Jaeger, 2001) to take account of social and ecological impacts. The German Federal Environmental Agency has already used $m_{eff}$ for landscape planning, and has proposed targets accordingly (UBA, 2003; Penn-Bressel, 2005): for areas of $m_{eff} < 10\,km^2$, the $m_{eff}$ value must not be allowed to decline by more than 1.9% to 2015; areas of $10\,km^2 < m_{eff} < 20\,km^2$, the $m_{eff}$ value should not decrease by more than 2.4% to 2015; areas of $20\,km^2 < m_{eff} < 35\,km^2$, no more than a 2.8% decrease is allowed; and for areas where $m_{eff} > 35\,km^2$, $m_{eff}$ values should not decline by more than 3.8%. Hence $m_{eff}$ is now being used in landscape planning and decision-making.

## 5. Conclusions

This study has shown that $m_{eff}$ is an effective, flexible, and readily interpretable indicator that is both sensitive and representative of landscape fragmentation. Calculation of $m_{eff}$ values for earlier landscape realities aims to establish a time series by which changes in landscape structure can be related to social, economic and ecological parameters, thereby providing a method by which the impact of infrastructural fragmentation can be assessed. Effective mesh size has now been applied to regions in

Germany, Italy, France, Canada, and the European Environment Agency is engaged in a cross-country and regional comparison using $m_{\mathrm{eff}}$. This is the first study to complete a country-level analysis, although the German Federal Office for Nature Conservation is currently working on a country-wide assessment of landscape fragmentation using $m_{\mathrm{eff}}$ (Schupp, 2005), as is Environment Canada (Kathryn Lindsay personal communication).

A variety of FGs can be defined, each being appropriate for different scenarios and objectives. FG 4 appears to be the most widely suitable because it relates to the highest number of topics of environmental indicator systems, e.g., as demonstrated above for the Monet system, but also more generally as it allows for easy cross-regional comparisons. The large differences in $m_{\mathrm{eff}}$ values for the various FGs (Figs. 2 and 4) demonstrate that a consistent definition of the fragmentation elements is crucial for appropriate interpretation of results, and comparisons among different studies should be done with careful consideration of the FGs.

Although for any single context there may be a single most appropriate FG, the combined application of several FGs generates the most informative and complete analysis. A comparison of the values and the ranked orders of regions for different FGs reveals important additional insights. Therefore, we recommend this combined approach for more detailed investigations of landscape fragmentation over the use of any single FG. We envisage considerable potential for application of this tool in the field of environmental impact assessments, and in particular on the level of strategic environmental assessments.

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## Appendix A. Attribution of fragmenting elements to the four fragmentation geometries

Comparisons among different studies should be done with caution regarding the definition of the FGs used. A consistent definition of the fragmenting elements is crucial for appropriate interpretation of the results obtained under the various FGs. To enable future studies to produce results that are directly comparable to the results reported here, Tables A1 and A2 give complete lists of the linear and two-dimensional fragmenting elements used in the four FGs of this study.

Table A.1
Linear fragmenting elements of the four fragmentation geometries

| Element | Objectval (in *VECTOR25*) | Included in fragmentation geometry | | | |
|---|---|---|---|---|---|
| | | 1 | 2 | 3 | 4 |
| *Roads* | | | | | |
| Highway | Autobahn | Yes | Yes | Yes | Yes |
| Highway (divided lanes) | Autob_Ri | Yes | Yes | Yes | Yes |
| 2nd cl. Highway (undivided lanes) | Autostr | Yes | Yes | Yes | Yes |
| Highway Exit/Access | Ein_Ausf | Yes | Yes | Yes | Yes |
| 1st cl. road (at least 6 m wide) | 1_Klass | Yes | Yes | Yes | Yes |
| 2nd cl. road (at least 4 m wide) | 2_Klass | Yes | Yes | Yes | Yes |
| 3rd cl. road (at least 2.8 m wide) | 3_Klass | Yes | No | Yes | Yes |
| 4th cl., narrow road (at least 1.8 m) | 4_Klass | No | No | No | No |
| 5th cl., path, trail, bicycle path | 5_Klass | No | No | No | No |
| 6th cl., footpath | 6_Klass | No | No | No | No |
| Suburban road (at least 4 m wide) | Q_Klass | Yes | No | Yes | Yes |
| Traces of historic road | Histweg | No | No | No | No |
| Tank road | PzPiste | No | No | No | No |
| Parklane | Parkweg | No | No | No | No |
| Stand-alone bridge | BrueckLe | No | No | No | No |
| Stand-alone bridge, covered | GedBruLe | No | No | No | No |
| Stand-alone footbridge | StegLe | No | No | No | No |
| *Railways* | | | | | |
| Freight railway | Gt_Bahn | Yes | Yes | Yes | Yes |
| Industrial track | I_Geleis | Yes | Yes | Yes | Yes |
| Nostalgic railway | MS_Bahn | Yes | Yes | Yes | Yes |
| Normal gauge railway: single track | NS_Bahn1 | Yes | Yes | Yes | Yes |
| Normal gauge railway: multiple tracks | NS_Bahn2 | Yes | Yes | Yes | Yes |
| Narrow gauge railway: single track | SS_Bahn1 | Yes | Yes | Yes | Yes |
| Narrow gauge railway: multiple tracks | SS_Bahn2 | Yes | Yes | Yes | Yes |
| Intercommunal tramway | Str_Bahn | Yes | Yes | Yes | Yes |
| Combination of tracks within the station area | Str_Bhof | Yes | Yes | Yes | Yes |
| *Hydrography* | | | | | |
| River | Fluss | No | No | No | No |
| River running subsurface | Fluss_U | No | No | No | No |
| Brook unclear direction of flow | Kanal | No | No | No | No |
| Single pressure pipeline | Druckl_1 | Yes | Yes | Yes | Yes |
| Multiple pipeline | Druckl_2 | Yes | Yes | Yes | Yes |
| Stream | Bach | No | No | No | No |
| Brook running subsurface | Bach_U | No | No | No | No |

Table A.2
Two-dimensional fragmenting elements of the four fragmentation geometries

| Element | Objectval (in *VECTOR25*) | Included in fragmentation geometry | | | |
|---|---|---|---|---|---|
| | | 1 | 2 | 3 | 4 |
| *Primary area classes* | | | | | |
| Rock | Z_Fels | No | No | No | No |
| River | Z_Fluss | No | Yes | Yes | No |
| Scree with Scrub | Z_GerGeb | No | No | No | No |
| Scree on Glacier | Z_GerGle | No | No | No | No |
| Scree | Z_Geroel | No | No | No | No |
| Scree in Forest | Z_GerWa | No | No | No | No |
| Scree in scattered Forest | Z_GerWaO | No | No | No | No |
| Glacier | Z_Glet | No | No | No | No |
| Airfield, grass strip | Z_GsPist | No | No | No | No |
| Airport, hard surface runway | Z_HaPist | Yes | Yes | Yes | Yes |
| Gravel pit | Z_KiGrub | No | No | No | No |
| Clay pit | Z_LeGrub | No | No | No | No |
| Lake | Z_See | No | Yes | Yes | No |
| Urban area | Z_Siedl | Yes | Yes | Yes | Yes |
| Quarry | Z_StrBru | No | No | No | No |
| Dam | Z_StauDa | Yes | Yes | Yes | Yes |
| Dam | Z_StauMa | Yes | Yes | Yes | Yes |
| Other areas | Z_Uebrig | No | No | No | No |
| *Facilities* | | | | | |
| Railway station | Z_BhArea | Yes | Yes | Yes | Yes |
| Airport area | Z_FlArea | Yes | Yes | Yes | Yes |
| Airport station area | Z_FlugBh | Yes | Yes | Yes | Yes |
| *Single objects* | | | | | |
| House | Geb_25_p | No | No | No | No |
| Water treatment plant | ARA | No | No | No | No |
| Antenna | Antenne | No | No | No | No |
| Lookout tower | AusTurm | No | No | No | No |
| Turning platform | Drehsch | No | No | No | No |
| Power plant | ElWerk | No | No | No | No |
| Port | Hafen | No | No | No | No |
| Chimney-stack | Kamin | No | No | No | No |
| Reservoir | Reserv | No | No | No | No |
| Landing pier | Schiffst | No | No | No | No |
| Radio transmitter | SendeAnl | No | No | No | No |
| Ruin | Ruine | No | No | No | No |
| Tower | Turm | No | No | No | No |
| Water tower | W_Turm | No | No | No | No |
| *High mountains* | | | | | |
| Elevations above 2100 m | — | No | Yes | Yes | No |

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