Degree of Landscape Fragmentation in Switzerland

Quantitative analysis 1885–2002 and implications for traffic planning and regional planning

Condensed version

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Foreword

Across Switzerland and the rest of Europe, landscapes are being urbanised, fragmented and encroached on. The latest report by the European Environment Agency entitled *Urban sprawl – Europe's ignored environmental challenge* calls for urgent action and suggests the development of Europe-wide policies to curtail urban sprawl. This would also counteract continued landscape fragmentation.

There is a strong connection between the growth patterns of urban areas and the way in which the transport network is spatially structured. Transport routes are important contributors to economic development, but they also fragment the landscape. For people and animals, highways and high-speed railway lines, in particular, represent practically impassable barriers. For flightless insects and small animals, even little-used local roads are barriers. An important aspect here is the size of individual patches of undeveloped land, and to what extent, if any, these are connected to neighbouring patches. This is because each species of animal requires a minimum area in order for it to survive. Landscape fragmentation is a significant cause of falling animal populations, the endangering and loss of species, and the reduction in recreational areas in central Europe. Fragmentation also affects the individual character and recreational quality of landscapes.

This condensed report is aimed at all those working in politics, administration and planning who are involved in traffic and regional planning in Switzerland; it is also intended for interested members of the general public. The report summarises the most important data and insights arising from a detailed study. This study was supported by four federal offices (ARE, FEDRO, FOEN and FSO) and five other institutions.

The new measurements of the degree of fragmentation used in this study reflect an important factor affecting landscape quality. The time series generated by these indicators show whether, and how quickly, fragmentation is increasing, and how much the landscape quality is likely to be affected by this. The aim of this study was to determine the degree of landscape fragmentation in Switzerland and to track the changes over the past 120 years. Detailed calculations were also made for individual cantons and other divisions of Switzerland.

Continued cooperation between the Swiss Federal Roads Authority (FEDRO) and the Federal Office for the Environment (FOEN) has proved valuable on the subject of wildlife corridors and wildlife passages. This raises the hope that in future there could be increased focus on the other effects of landscape fragmentation, for example the relationship between urban development trends and landscape fragmentation, and that existing problems may be overcome.

Dr Gilbert Thélin
President of the Support Group

Summary

Over the last several decades, the fragmentation of landscapes in Switzerland has sharply increased in almost all parts of the country. The project presented here has provided a methodical basis and produced data on the degree of fragmentation in Switzerland. The project generated the time series from 1885 to 2002 for several levels of observation: for Switzerland as a whole, the biogeographic regions, the cantons and districts, and for the landscapes and natural monuments of national importance (BLN areas) as well as marshlands. The *effective mesh size* (m_{eff}) and the *effective mesh density* ($s_{eff} = {}^{1}/m_{eff}$) were used to measure the degree of fragmentation. The effective mesh size is a measure of the size of the „meshes“ that remain in the network of transport infrastructure and urban areas. The effective mesh density represents the number of meshes per 1000 km² of surface area.

The effective mesh size in Switzerland has decreased by 70 % since 1885 from 580 km² to 176 km². Correspondingly, the effective mesh density has increased by 230 % over this time period from 1.7 meshes per 1000 km² to 5.7 meshes per 1000 km². The fragmentation in the Central Lowlands and in the Jura is much greater than in the Alps. In the Central Lowlands the effective number of meshes per 1000 km² has risen by 280 %, from 24.6 to 92.8.

There is also a high variation among cantons in the degree of fragmentation: between 0.5 km² in Basel-City and 635 km² in Glarus. Mountain cantons have a much higher effective mesh size than cantons in the Central Lowlands and in particular much greater than the city cantons. The eight most fragmented cantons are Basel-City, Geneva, Thurgau, Aargau, Zurich, Zug, Schaffhausen and Basel-Country. In these areas the effective mesh size is under 10 km². The cantons with the largest effective mesh sizes are Glarus, Uri, Ticino, Nidwalden, Graubünden and Obwalden (all above 300 km²).

The degree of landscape fragmentation is a suitable indicator for representing the character of the landscape and the endangering of species and habitats (biodiversity). As this is a simple and easily understandable metric, this allows the effectiveness of schemes and targets for landscape development to be reassessed accurately. Similar studies on the degree of landscape fragmentation have also been performed using the same method in regions such as Baden-Württemberg, Hesse, Bavaria and South Tyrol.

A full version of the current abridged publication has been published by the Swiss Federal Roads Authority (Bertiller et al. 2007).

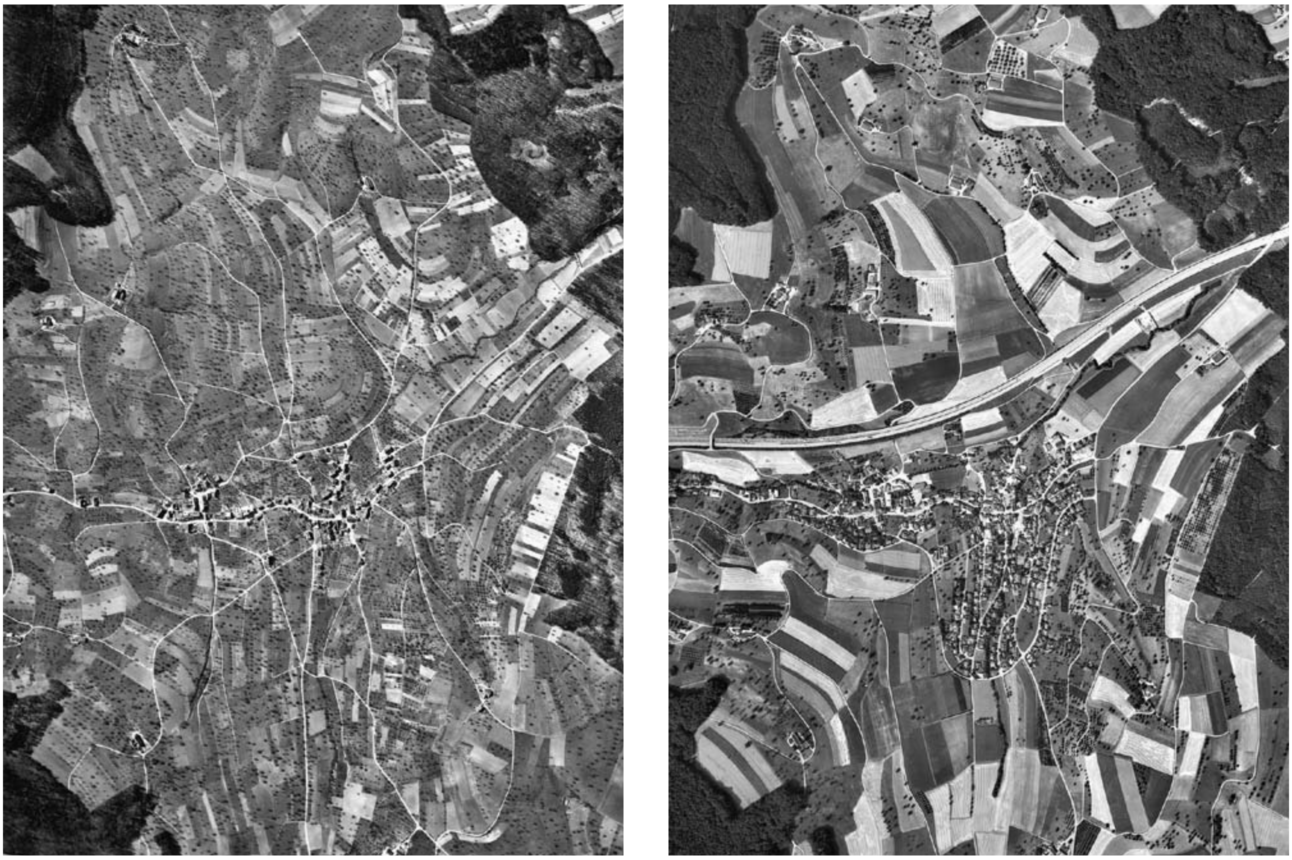
1 Introduction

1.1 Rising landscape fragmentation in Switzerland

The transport network in Switzerland has become increasingly dense, and urban areas have greatly expanded. As a consequence, the habitats of wild animals, recreation areas for people, and Switzerland's landscapes in general are being increasingly fragmented. The remaining and, as yet, unfragmented areas of landscape („landscape meshes") are becoming ever smaller. The research project into the „Degree of Landscape Fragmentation in Switzerland" shows how much landscape fragmentation has increased in the past 120 years.

Incremental changes to the landscape often go unnoticed by the public. Only after several decades can the full extent of the alterations be seen. Figure F1 shows a clear example from the canton of Basel-Country: within 40 years the settlement has expanded greatly; a motorway has been built; fruit trees and small structures have been removed; and small agricultural areas have been joined to form large parcels of land.

Urban areas in Switzerland more or less doubled between 1950 and 2000 (Jaeger et al., under prep.). Every year, new developments and transport routes claim an area equivalent to 2100 ha. As a result, the effective mesh size – which measures the size of remaining



F 1 Example of landscape change in Switzerland: with aerial photographs of Arisdorf (canton of Basel-Country) from 1953 (left) and 1994 (right). The fragmentation caused by the motorway and other large-scale landscape alterations are clear to see (photographs from Tanner 1999, © Federal Office of Topography swisstopo).

„meshes" in the network of transport routes and urban areas – has decreased, in Switzerland by 70 % since 1885 and by 47 % since 1935: in other words, from 580 km² in 1885 to 332 km² in 1935 and then to 176 km² in 2002.

Science and politics have recognised landscape fragmentation as an environmental issue for about 30 years. Therefore, the 1998 Swiss Landscape Concept set the following objectives: to minimise the barrier effects of new and existing transport infrastructures, to limit and concentrate buildings, infrastructure and other construction to a necessary minimum, and to create contiguous habitats. The Federal Council's *Sustainable Development Strategy 2002* aims at stabilising „the per-capita settlement area at the current level of around 400 m²", as uncoordinated expansion of built-up areas leads to the overdevelopment of the countryside and makes it more difficult to organise transport in a resource-saving manner.

The *Mission Landscape 2020*, drawn up in 2003, specifies targets for landscape fragmentation: „Unfragmented areas of 50 km² and above shall be preserved in their entirety (no class 1 or 2 roads) … areas that are less than 5 km² and free from buildings and infrastructures shall be preserved." In the Spatial Development Report 2005, a number of measures were put forward suggesting how urban development could be made more sustainable in the future. The 2006 sectoral plan for transport set the general objective of protecting landscapes from deterioration due to transport infrastructure.

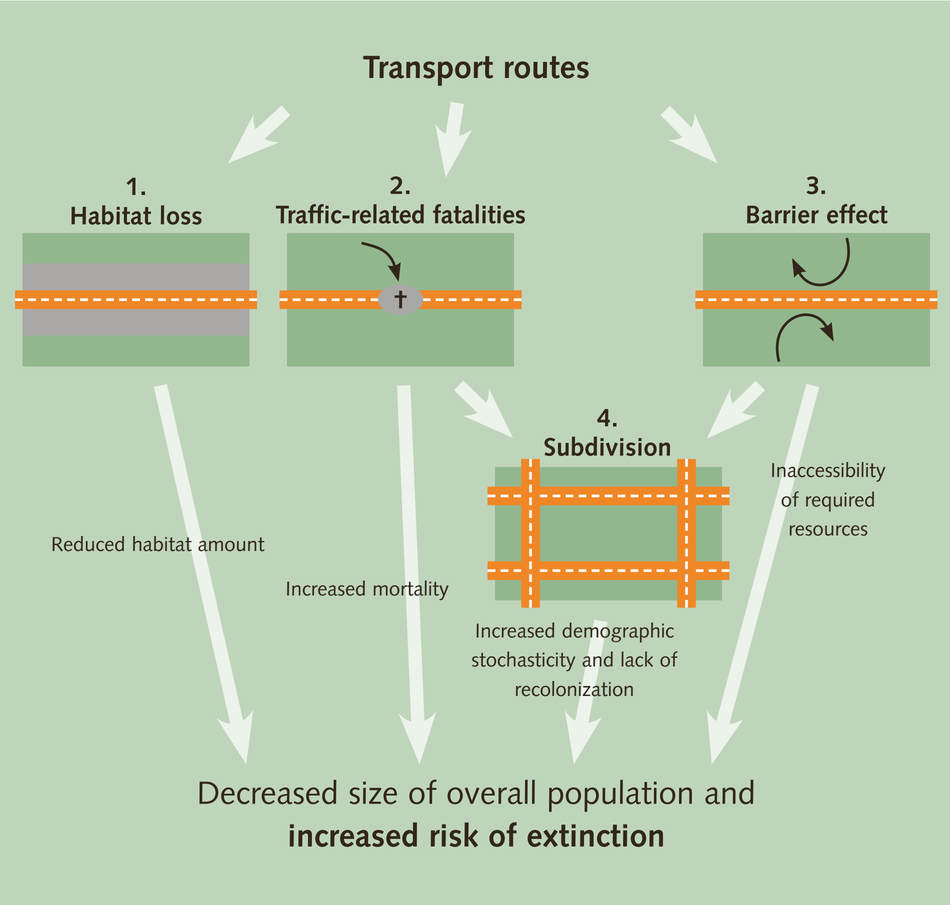
The present study supports the view that these and other measures need to be implemented more quickly and effectively in order to reduce continuing landscape fragmentation.

Numerous scientific studies provide evidence for the far-reaching consequences of habitat and landscape fragmentation. Along with the intensification of agriculture, high nitrogen input and changes in water balance, the landscape fragmentation that results from transportation and urban development is one of the most important causes of the decline and loss of animal populations and habitat diversity.

F 2 A motorway interchange divides the area into several small habitats. Swiss motorways are impassable for many wild animals because they are fenced in (photograph: Zurich Archaeology Department).

Landscape fragmentation means the destruction of established ecological connections between adjoining areas of the landscape, for example by dividing up habitats (Fig. F2). This not only impacts individual habitats but also whole ecosystems. In addition, it changes the landscape's appearance. Noise and air pollution also have a negative effect on the recreational quality of landscapes.

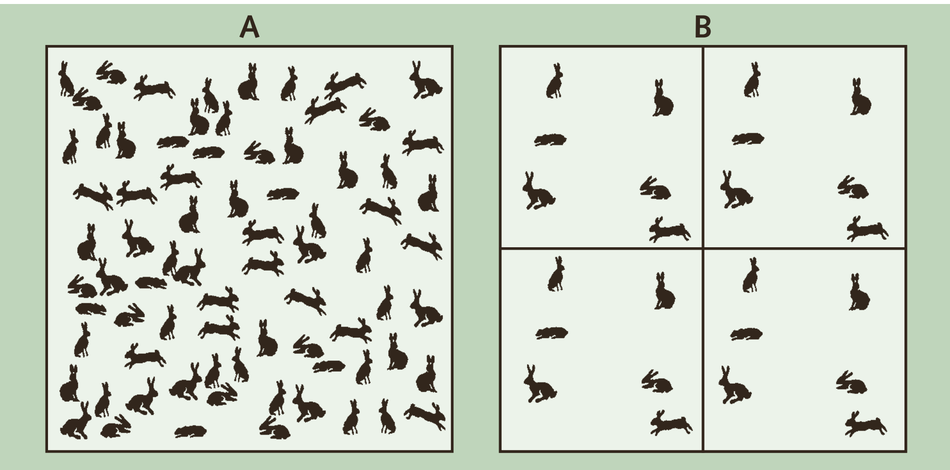
For animals that live on the ground, fragmentation means that sections of the population are isolated from each other (Fig. F3). Animal numbers are not only decimated by traffic, but also because the necessary (genetic) exchange between populations is prevented. This increases the risk of populations becoming extinct, as isolated populations are more sensitive to natural stress factors such as weather conditions (Fig. F4). Thus fragmentation lowers the resilience of animal populations; that is, their ability to regenerate in response



F 3 The four main effects of transport routes on animal populations (from Jaeger et al. 2005).

to disturbance. When a population becomes extinct in a habitat, barriers then prevent recolonization. Animal species that require large areas of space or live in low population densities, such as the lynx and pine marten, react most strongly to the isolation and reduction of their habitats. Concerning the isolation of populations: the smaller the remaining overall habitat, the more damaging the impact due to fragmentation.

The extent of the negative impacts of habitat fragmentation on animal and plant populations is often – as in the case of incremental landscape alteration – only evident decades afterwards. Even if all further landscape and habitat fragmentation stopped today, populations would still disappear over the coming decades due to previous interventions.



F 4 Impact of landscape fragmentation on animal populations. Transport routes divide up a population into a number of smaller populations with an increased risk of extinction: the number of individuals in the isolated populations (B) is lower than in the unfragmented landscape (A), and the risk of extinction is higher (modified graphic according to the Swiss Society for Wild Animal Biology 1995).

1.2 Objectives and issues for investigation

Natural landscapes and habitats are a limited, unrenewable resource. The motivation for the present study was the observation that landscape fragmentation is still continuing in spite of political targets and measures. How much has landscape fragmentation increased over previous decades? Where is fragmentation highest, where is it lowest? Until now there have been no reliable data to answer these questions. This project now allows definitive targets to be set in relation to habitat and landscape fragmentation and enables the effectiveness of measures to be evaluated at a later date.

The following questions were central to the study:

1. What is the extent of fragmentation in Switzerland today?

- What differences exist between biogeographic regions, cantons and districts?
- How does the degree of fragmentation in Switzerland differ compared to neighbouring countries?

2. How has the degree of fragmentation in Switzerland changed since 1885? When were the main surges in landscape fragmentation and what were their causes?

3. What specific issues can be analysed using the study's method?

– How fragmented are the BLN and marshland areas? Has fragmentation within the BLN areas increased more rapidly or more slowly than areas outside these zones?

– How fragmented would Switzerland's landscapes be in 2020 and 2050 if today's trends were allowed to continue unchecked?

4. How can the results from the analysis be applied to traffic planning and regional planning?

The results of the study will benefit environmental monitoring schemes, e.g. the Swiss environmental data network (NUD-CH) and biodiversity monitoring (BDM). In the latter programme, the Federal Office for the Environment monitors biodiversity trends in Switzerland.

The data is also of interest to the Swiss monitoring system for sustainable development (MONET), since such monitoring systems have, up until now, lacked an indicator of landscape fragmentation.

Another important aim of the project has been to make those involved in politics and administration more aware of the problem. The study therefore also proposes measures that should be adopted.

2 Methods

2.1 Effective mesh size and effective mesh density

In order to measure the degree of landscape fragmentation, Jaeger (2000) developed the „effective mesh size“. This metric expresses the probability that two points chosen randomly in a region are connected; that is, not separated by barriers such as transport routes or developed land. The more barriers fragmenting the landscape, the lower the probability that the two points are connected, and the lower the effective mesh size. Accordingly, the likelihood also decreases that animals or people will be able to move freely in the landscape without encountering such barriers, and therefore there is also a reduced chance that two animals from the same species will be able to find each other in a landscape, for example in order to breed.

To make it possible to compare values from various areas, the probability of being connected is converted into the size of a patch – the effective mesh size – by multiplying it by the total of the region investigated. The effective mesh size is given in square kilometres. If a landscape is fragmented evenly into patches that are the same size as the effective mesh size, then the probability of being connected is the same as for the fragmentation pattern under investigation (Fig. F5). This grid provides a clear demonstration of landscape fragmentation.

F 5 Barriers in the landscape (left) and the corresponding effective mesh size represented in the form of a regular grid (right).

The effective mesh size has received a great deal of interest from the European Environment Agency. It has already been used in places such as Germany, Italy, France, Canada and South America, with international interest continuing to increase.

Instead of talking about the *size* of meshes, it is also possible to talk about the *number* of meshes in an area, for example within an area of 1000 km². This number gives the effective mesh density s_{eff} (see Box 1 and Fig. F6).

An important strength of these two new measures lies in the fact that the spatial structure of complex networks, comprising transport infrastructure and urban zones, can be meaningfully described using one simple, understandable value. Unlike the traffic line density and average patch area, effective mesh size and density express changes in the spatial arrangement of transport routes.

Box 1: Definition of effective mesh size m_{eff} and effective mesh density s_{eff}

The definition of *effective mesh size* m_{eff} is based on the probability that two points chosen randomly in an area are connected and are not separated by any barriers. This leads to the formula:

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

where n represents the number of patches, A_1 to A_n the patch sizes from patch 1 to patch n and A_t the total area of the region investigated.

The first part of the formula gives the probability that two randomly chosen points are in the same patch. The second part (multiplication by the size of the region, A_t) converts this probability into a measure of area. This area is the „mesh" size of a regular grid pattern showing an equal degree of fragmentation and can be directly compared with other regions.

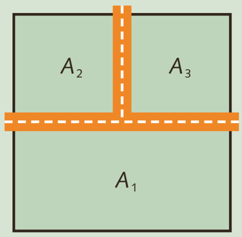
The *effective mesh density* s_{eff} gives the effective number of meshes per 1000 km², in other words the density of the meshes. This is very easy to calculate from the effective mesh size: it is simply a question of how many times the effective mesh size fits into an area of 1000 km². This is therefore expressed as:

$$s_{\mathrm{eff}} = \frac{1000\ \mathrm{km}^2}{m_{\mathrm{eff}}} \cdot \frac{1}{1000\ \mathrm{km}^2} = \frac{1}{m_{\mathrm{eff}}} .$$

The mesh density value rises if fragmentation increases (Fig. F6). So the two measures contain the same information about the landscape, but the mesh density is more suitable for spotting trends. A detailed description of both metrics can be found in Jaeger (2000, 2002).

Box 2: A simple example of calculating m_{eff} and s_{eff}

A landscape is fragmented by highways into three patches:



$A_t = 4\ \mathrm{km}^2$

The probability that two randomly chosen points will be in patch 1 (and therefore connected) is:

$$\left(\frac{A_1}{A_t}\right)^2 = 0{,}5 \cdot 0{,}5 = 0{,}25 .$$

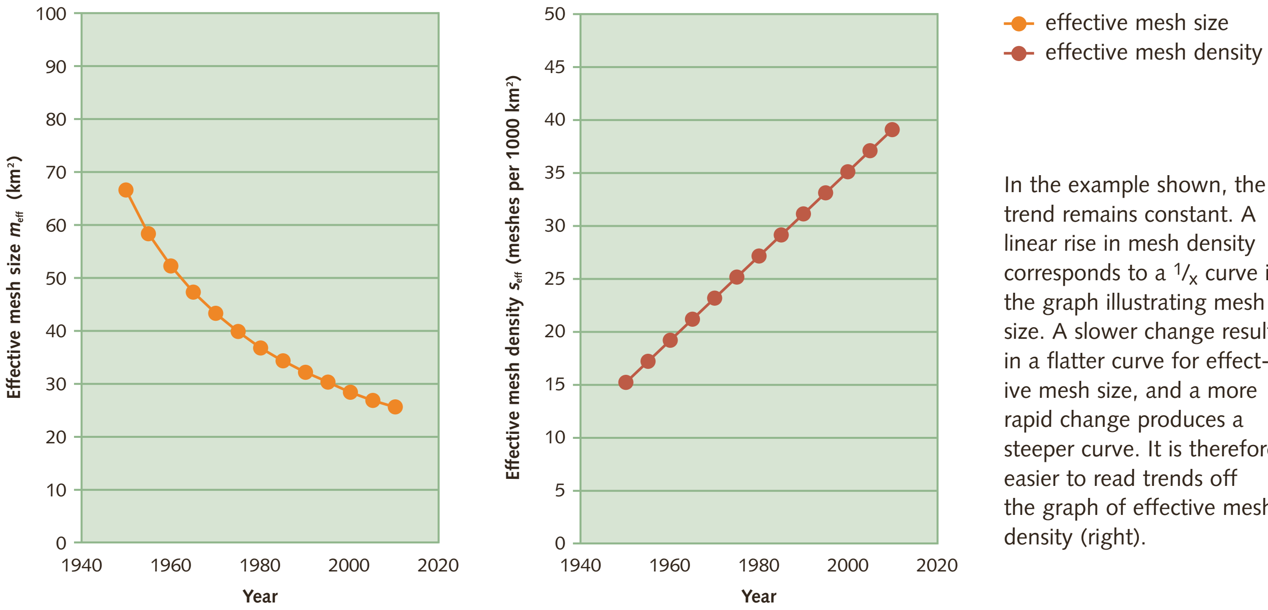
The corresponding probability is 0.25² = 0.0625 for both patches 2 and 3. The probability that the two points will be in patch 1 or 2 or 3 is the sum of the three probabilities which results in 0.375.

Multiplying this probability by the total area of the region finally gives the value of the *effective mesh size*: m_{eff} = 0.375 · 4 km² = 1.5 km².

The *effective mesh density* s_{eff} is then: s_{eff} = 666.7 meshes per 1000 km².

The relationship between mesh density and mesh size is such that a percentile increase in mesh density is different from a percentile decrease in mesh size. Figure F6 is a good example of this: here, the mesh size has decreased by 61.5 % (from 66.7 to 25.6 km²), and the mesh density has increased by 160 % (from 15 to 39 meshes per 1000 km²).

Hypothetical example illustrating the relationship between effective mesh size and the effective number of meshes per 1000 km² (= effective mesh density) F 6



In the example shown, the trend remains constant. A linear rise in mesh density corresponds to a $^1/_x$ curve in the graph illustrating mesh size. A slower change results in a flatter curve for effective mesh size, and a more rapid change produces a steeper curve. It is therefore easier to read trends off the graph of effective mesh density (right).

2.2 Fragmentation geometries and base data

In Switzerland, lakes and mountains play a major role in acting as natural barriers. For this reason, different fragmentation geometries (FGs) than the existing applications of mesh size had to be defined. Each FG handles anthropogenic and natural elements in a different way (Table T 1).

It has emerged that the impact of lakes and mountainous areas above 2100 m is, in many regions, so great that it would be inadvisable to compare them with regions that do not have lakes and mountains. Therefore, in geometry 4 (FG 4), lakes and mountainous areas above 2100 m are excluded from the area under investigation: thus the divisions of these regions were re-arranged so that they only include land areas below 2100 m. Clarification was also needed for some other

The four fragmentation geometries defined and explained T 1

		Allowance for natural barriers		
		None	Mountains (> 2100 m), lakes and rivers are considered barriers	Mountains (> 2100 m), lakes and rivers are excluded from the study area
Manmade barriers (motorways, railway lines, roads and developed land)	Up to class 2 roads	–	**FG 2**: Barriers including 2nd class roads	–
	Up to class 3 roads	**FG 1**: Pressure from civilization	**FG 3**: Barriers including 3rd class roads	**FG 4**: Land areas under 2100 m

Points in the time series and the base data used in the study of landscape fragmentation in Switzerland **T 2**

Year	Base data
2002	VECTOR25 (date range of records: 1996 to 2002)
1980	Map 1:100,000 (date range: 1977 to 1982)
1960	Map 1:100,000 (date range: 1957 to 1966)
1935	Map 1:100,000 (dates of originals: 1930 to 1936, and 1926 for Monte Rosa)
1885	Dufour map (dates of originals: 1884 to 1886, and 1869 for Mattertal)

issues. For example, if a transport route goes through a tunnel which is longer than 1 km, the landscape in this area is classed as unfragmented. Short tunnels are considered in the analysis as normal transport routes.

Every fragmentation geometry has its strengths and weaknesses. The most appropriate choice of an FG depends on a study's context and objectives. This condensed report only shows the results for FG 4 because this is the best one for comparing different regions. For a more detailed analysis of landscape fragmentation in the context of environmental impact assessment and strategic environmental assessment, a combination of all four FGs may be more appropriate than any single FG.

Calculations were based on maps at a scale of 1:25,000 and 1:100,000 (Table T2). The maps are highly accurate and provide standardised cover for the whole of Switzerland and therefore the results have a similar level of accuracy.

The analysis of landscape fragmentation at earlier points in time required the digitisation of historical maps (Fig. F7). The project investigated a time series from 1885 to 2002 at five intervals (1885, 1935, 1960, 1980 and 2002). This is the longest time series so far that has been generated in any study of landscape fragmentation.

F 7 The same map extract at different points in time (left = 1885, centre = 1960, right = 2002). Reproduced with permission of swisstopo (BA071297).

3 Results

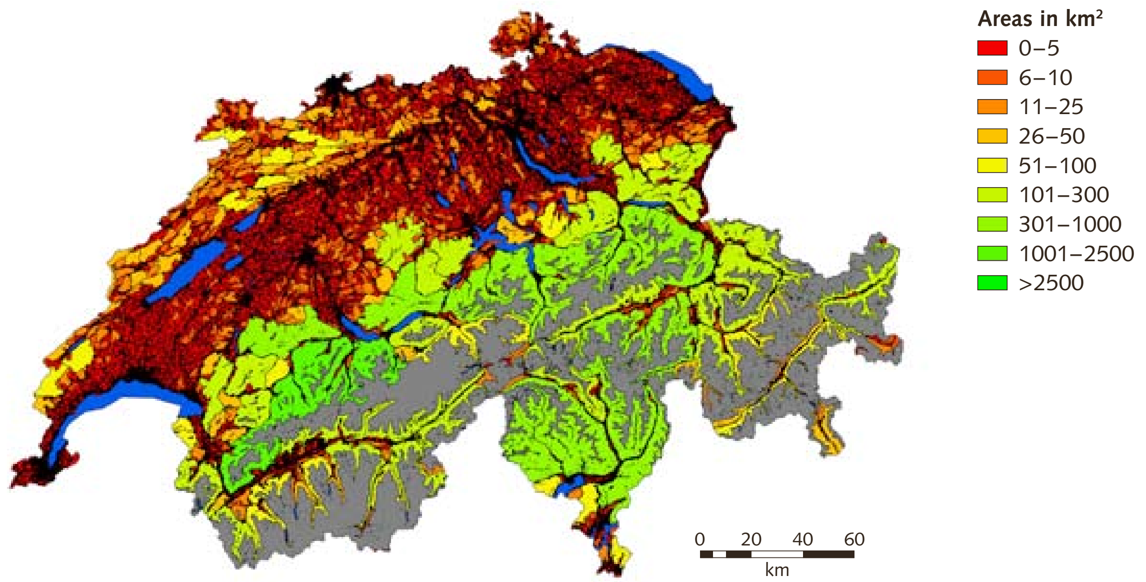
3.1 Current situation

The Central Lowlands and the Jura are among the most fragmented regions in central Europe (Fig. F8 and F9). The effective mesh size in the Central Lowlands calculated for 2002 is almost 11 km² (Fig. F9 and F10). This is the equivalent of 93 meshes per 1000 km². In the Jura it is 19 km², or 53 meshes per 1000 km². These values and all other figures mentioned relate to land areas under 2100 m (fragmentation geometry 4, see section 2.2).

valleys in the Alpine regions are by contrast very heavily fragmented, with effective mesh sizes that are, to an extent, smaller than in the Central Lowlands. The effective mesh size calculated for Switzerland as a whole is 176 km² (Fig. F9).

The number of large unfragmented areas (UFAs) above a certain size that still exist can be seen from the fragmentation map in Figure F11. It is often interesting to look at the minimum sizes of 50 km² and 100 km². An area of 100 km² would allow a person to enjoy a day walking without coming across any roads or railway

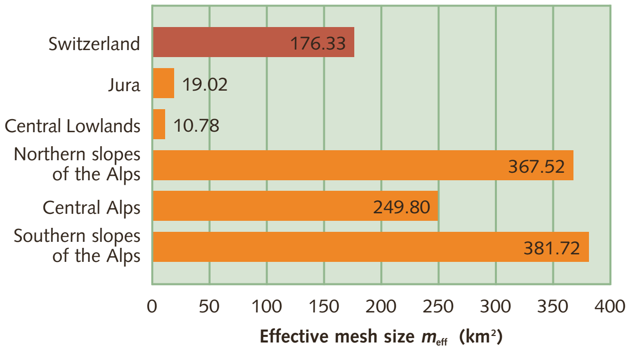
Fragmentation map of Switzerland in 2002 for land areas under 2100 m (FG 4) **F 8**



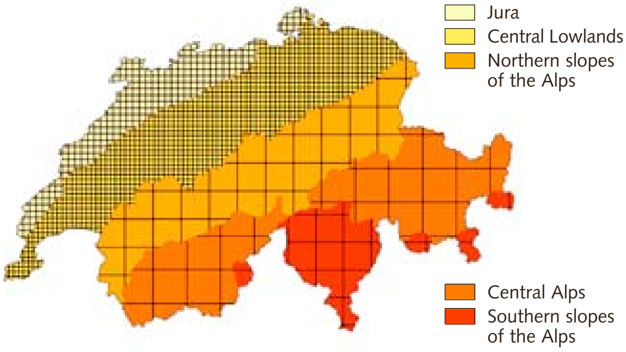
The comparison of eco-regions in Figure F10 illustrates how much the degree of fragmentation varies in Switzerland from region to region. The effective mesh size in the Alps is between 250 and 380 km², which is 20 to 35 times higher than in the Central Lowlands. The effective mesh size is smaller in the Central Alps than in the northern and southern foothills of the Alps. The

lines. But the total number of these large areas is rarely meaningful because the number can just as well increase through a very large area being divided into two less large areas (fragmentation increases) as it can through the removal of a barrier resulting in two smaller areas becoming a large area (fragmentation decreases). What is more meaningful is the proportion of large areas in

Effective mesh size in Switzerland and its five eco-regions in 2002 for land areas under 2100 m (FG 4) **F 9**



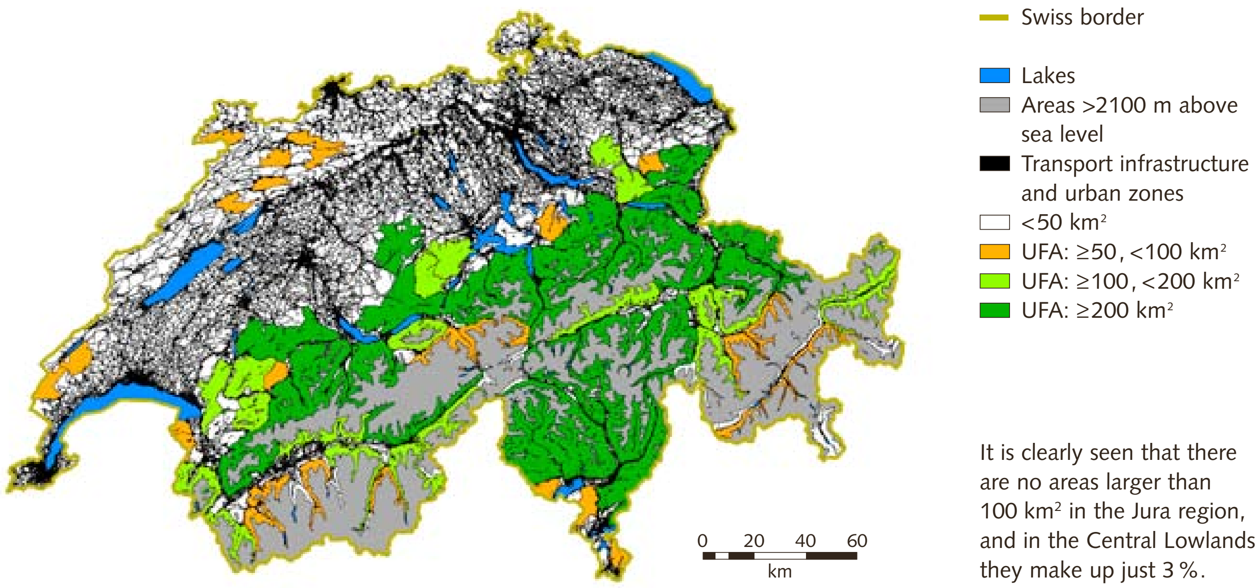
Schematic representation of effective mesh size in the five eco-regions in 2002 for land areas under 2100 m (FG 4) **F 10**



relation to the total land area. UFAs that are larger than 100 km² (excluding lakes and mountains above 2100 m) still make up a rather large share of the land area, coming in at 26 %. This is almost exclusively due to the large unfragmented areas in the Alpine foothills and the Alps. If lakes and mountainous areas above 2100 m are taken into account, this figure becomes 53 %. Today, there are no UFAs larger than 100 km² left in the Jura region (compared to 27 % in 1885) and in the Central Lowlands they make up just 3 % of the total region (Fig. F 11).

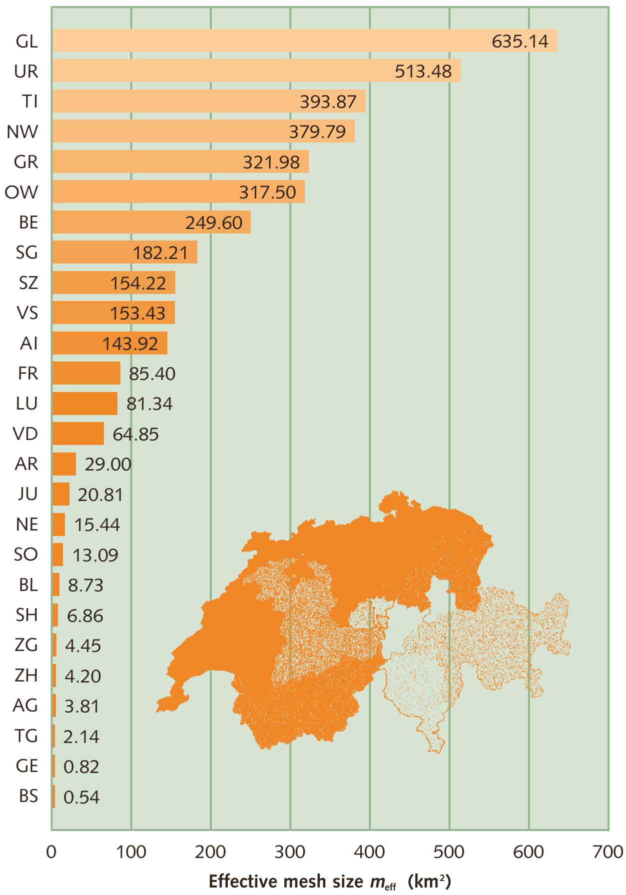
There is also a great variation between cantons in the degree of fragmentation: between 0.5 km² in Basel-City and 635 km² in Glarus (Fig. F 12). Mountain cantons have a much higher effective mesh size than cantons in the Central Lowlands and certainly much greater than the city cantons. The eight most fragmented cantons are Basel-City, Geneva, Thurgau, Aargau, Zurich, Zug, Schaffhausen and Basel-Country. In these areas the effective mesh size is under 10 km². The cantons with the largest effective mesh sizes are Glarus, Uri, Ticino, Nidwalden, Graubünden and Obwalden (all above 300 km²). The canton of Berne is spread across different eco-regions. Its effective mesh size is therefore influenced by the differing conditions in these eco-regions,

Map of large unfragmented areas (UFAs) from 50, 100 and 200 km² in 2002 **F 11**



It is clearly seen that there are no areas larger than 100 km² in the Jura region, and in the Central Lowlands they make up just 3 %.

Cantons ranked according to their current degree of fragmentation (2002) F 12



resulting in a value (250 km²) which is in between the extremes of mountain and city cantons.

In addition to figures for the five eco-regions and the 26 cantons, values were also calculated for 32 biogeographic regions, 181 districts, 163 BLN areas (Federal Inventory of Landscapes and Natural Monuments of National Importance) and 89 nationally important marshlands (see detailed report by Bertiller et al. 2007).

3.2 Time series from 1885 to 2002

The time series show that effective mesh size has decreased sharply in Switzerland since 1885 by a figure of 70 %. The size fell from 580 km² in 1885 to 332 km² in 1935 and then to 176 km² in 2002 (Fig. F 13). Correspondingly, the number of meshes per 1000 km² (the effective mesh density) has increased by 230 % since 1885, when the number was 1.7 meshes per 1000 km², rising to 3.0 meshes per 1000 km² in 1935 and then to 5.7 meshes per 1000 km² in 2002.

The following graphs display effective mesh size and effective mesh density side-by-side so that trends can be interpreted more easily. The effective mesh density is more suitable for spotting trends as rising fragmentation is represented by upward curves (cf. also Fig. F 6).

The five eco-regions

The values for effective mesh density for the Central Lowlands and the Jura have at all times been much higher than those for the Alpine eco-regions (Fig. F 14). Even during the early period between 1885 and 1935, the effective mesh density increased in all eco-regions. However, the southern slopes of the Alps and the Central Alps saw a lower rise than the other three eco-regions.

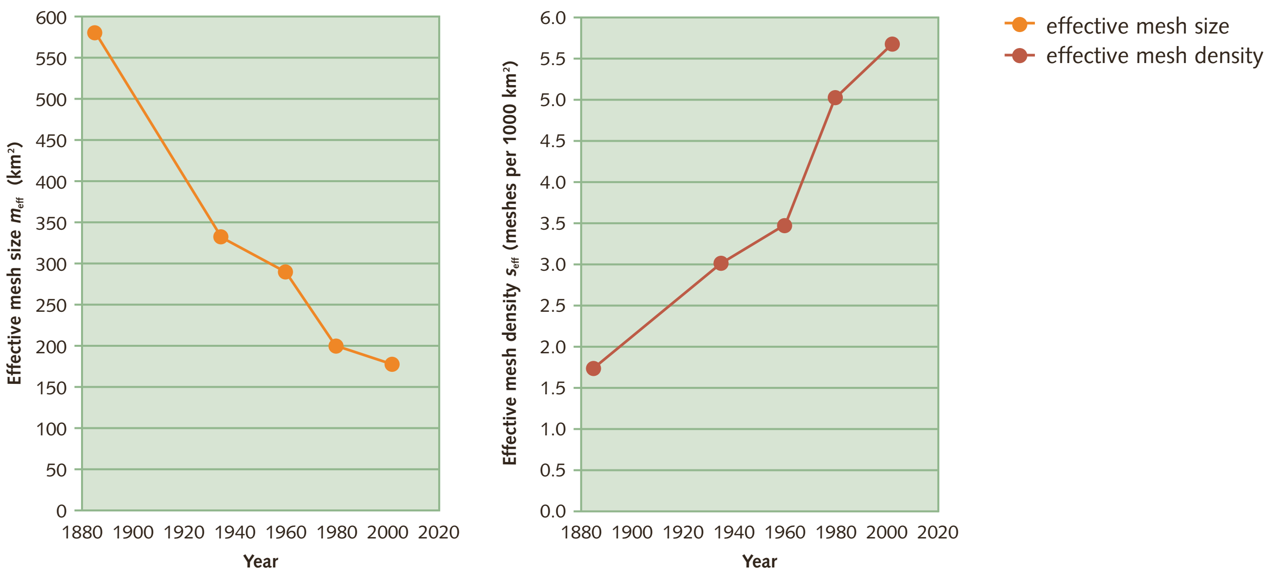
With the exception of the Jura region, the highest increase in effective mesh density occurred between 1960 and 1980 (Fig. F 14). Motorway construction in this period was one of the reasons for the accelerated rise in effective mesh size. This intensive construction phase saw the completion of the majority of Switzerland's main transport routes. That is why the curves for both effective mesh density and effective mesh size mostly flatten out to some degree after this period (Fig. F 14). In the Central Alps, however, the trend starting in 1960 is unabated.

The most remarkable change has occurred in the Jura region. There, the effective mesh density has increased steadily from 1935 to the present day, and there is no sign of any let-up.

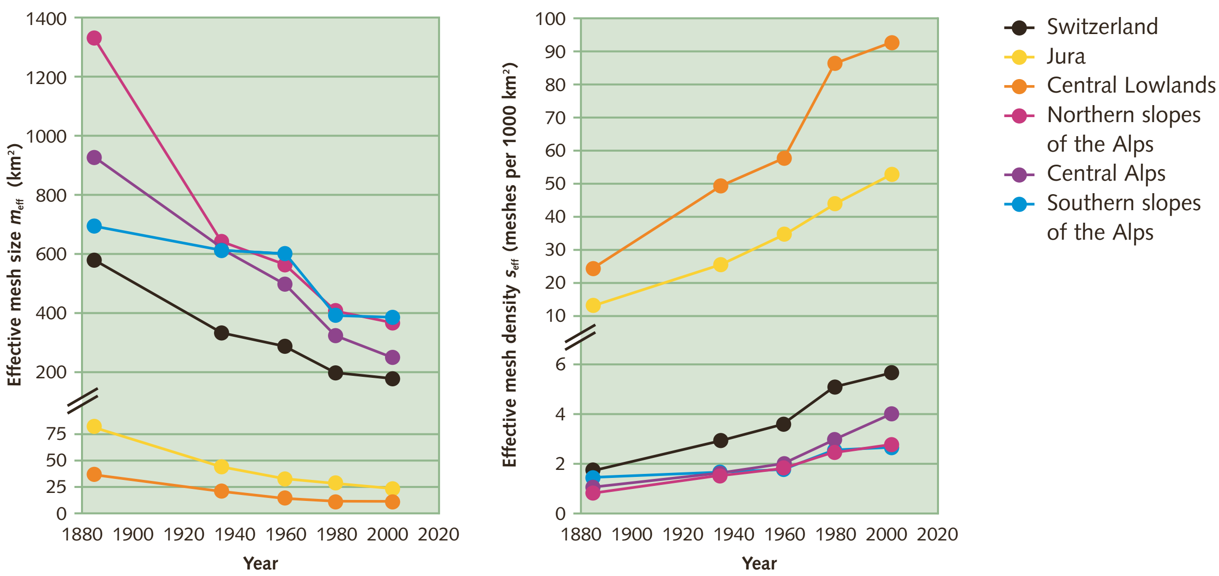
The first railway was built in Switzerland in 1856. Up until 1935 the railways were still growing rapidly, with the length of the rail network expanding by around 50 % between 1885 and 1935. Since then the rail network has only changed marginally. As a result, the road network has had far greater impact on the increase in landscape fragmentation since 1935 than the railways. If a comparison were made with a date before 1900, for example with the year 1850, the influence of the rail network would be much more apparent.

When interpreting the data, it is important to note that the road categories in 1885 and 1935 do not correspond very well to current categories in terms of their fragmenting effect, as the earlier roads had much less impact. Traffic volumes were lower, roads were narrower and less well stabilised. In reality, the rise in the extent of fragmentation is therefore even greater than that expressed by the differences in values over the decades. It is quite possible that a more exact method could be used to include these differences, but that would then require traffic volume data for earlier points in time – data which is not normally available.

Trends in effective mesh size and effective mesh density in Switzerland **F 13**



Trends in effective mesh size and effective mesh density in the five eco-regions **F 14**



Cantons and districts

There are large differences in the increase in landscape fragmentation since 1885 among the cantons. Figure F 15 shows the trends using different colours. Decreases in effective mesh size have been particularly great (over 50 %) throughout almost all of the Central Lowlands, and also in the Jura, Northern Alps and the western area of the Central Alps.

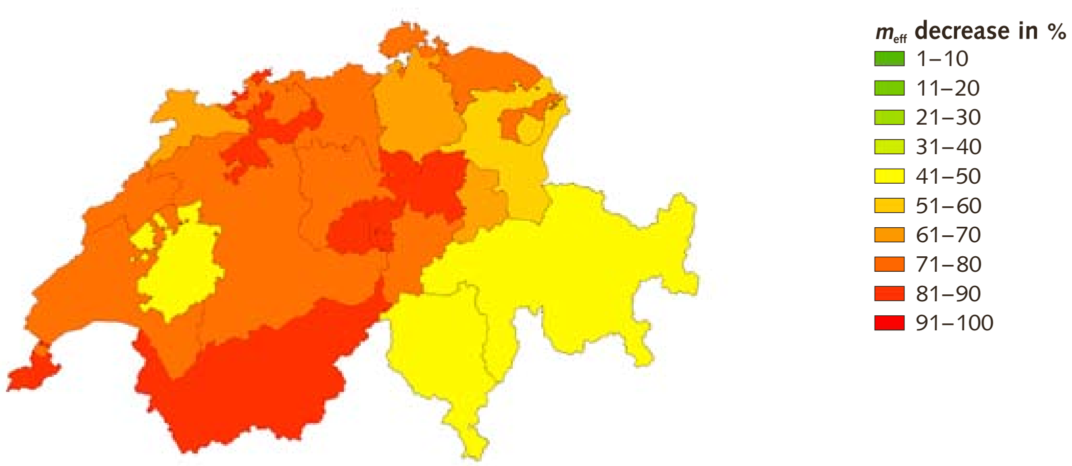
Generally speaking, almost all cantons have seen the construction of numerous transport routes. Urban development has expanded greatly in nearly all areas, thereby also contributing to higher landscape fragmentation. There are, however, significant differences between regions.

Over the time period studied, the curves for effective mesh density have, in all cantons, either increased continually or remained temporarily constant. Correspondingly, the curves relating to effective mesh size have had a downward trend across all periods. This demonstrates that the construction of new transport routes (including upgradings in road classification) has always outweighed the effect of dismantling of transport infrastructure.

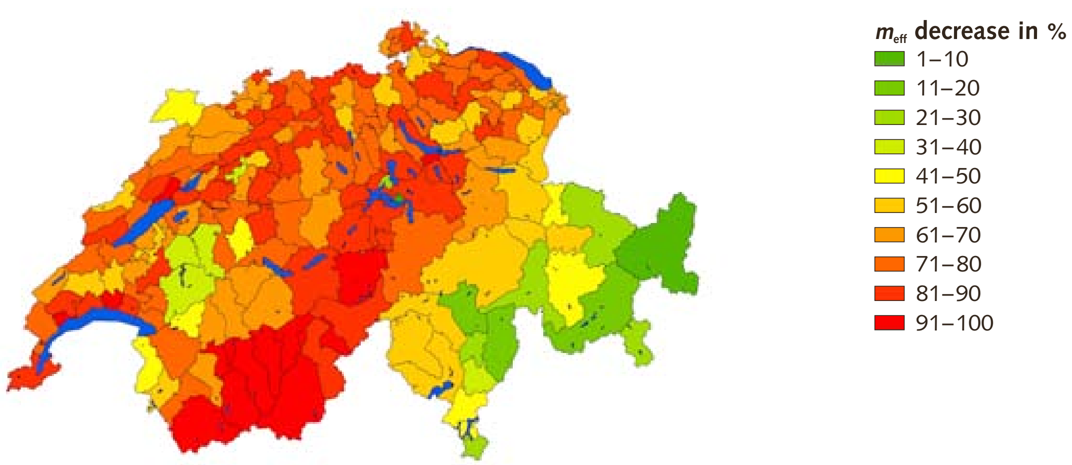
The two cantons of Aargau and Uri are good illustrations of the trends within cantons.

In Aargau the current patches are distinctly smaller than 120 years ago (Fig. F 17). Urban areas have grown considerably in large parts of the canton. The effective mesh density has more than tripled since 1885, and

Relative decrease in effective mesh size in the 26 cantons between 1885 and 2002 **F 15**



Relative decrease in effective mesh size in districts between 1885 and 2002 **F 16**

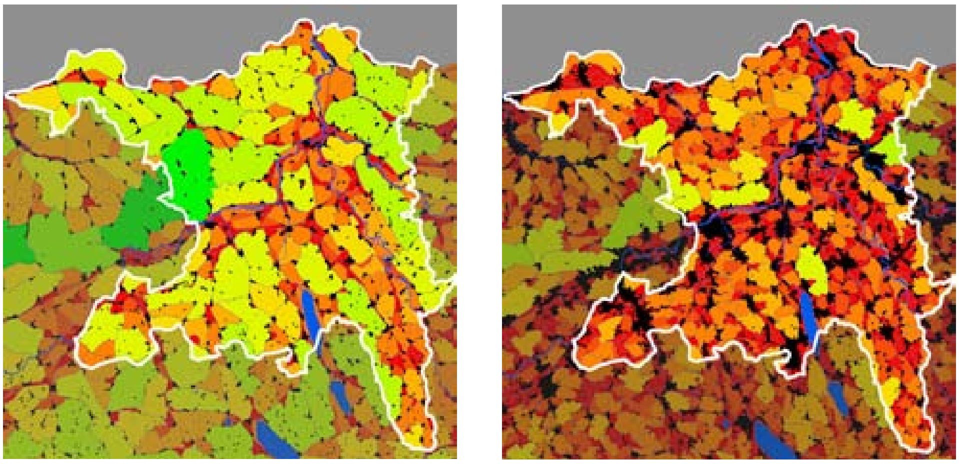


only six large areas now remain. The canton is currently one of the most fragmented regions in Switzerland. The curve of effective mesh density has increased relatively steadily, with a somewhat sharper increase between 1960 and 1980 (Fig. F18). A number of new transport routes were built in Aargau during this period.

The main reasons for the change were motorway construction (e.g. the construction of the A1 and A2 to Basel, Berne, Zurich and Lucerne), which was not bundled with existing transport infrastructure, together with the construction of class 2 and class 3 roads and road upgrades from class 3 to class 2. A slight drop-off in the trend can be seen, but a much more significant reduction is needed before a stable situation may be reached where the level remains constant.

The canton of Uri is characterised by high values in effective mesh size (Fig. F20). The canton has only relatively small valley areas. The percentage of land that is steep and mountainous is high, with 42 % of the canton's area lying over 2100 m. Uri's urban development is concentrated in the Altdorf region. Since 1885, the two large areas forming the west and east sides of the main valley have each been divided in two. There are relatively few class 3 roads, and as they only affect a small area they have had a relatively small effect on the degree of fragmentation.

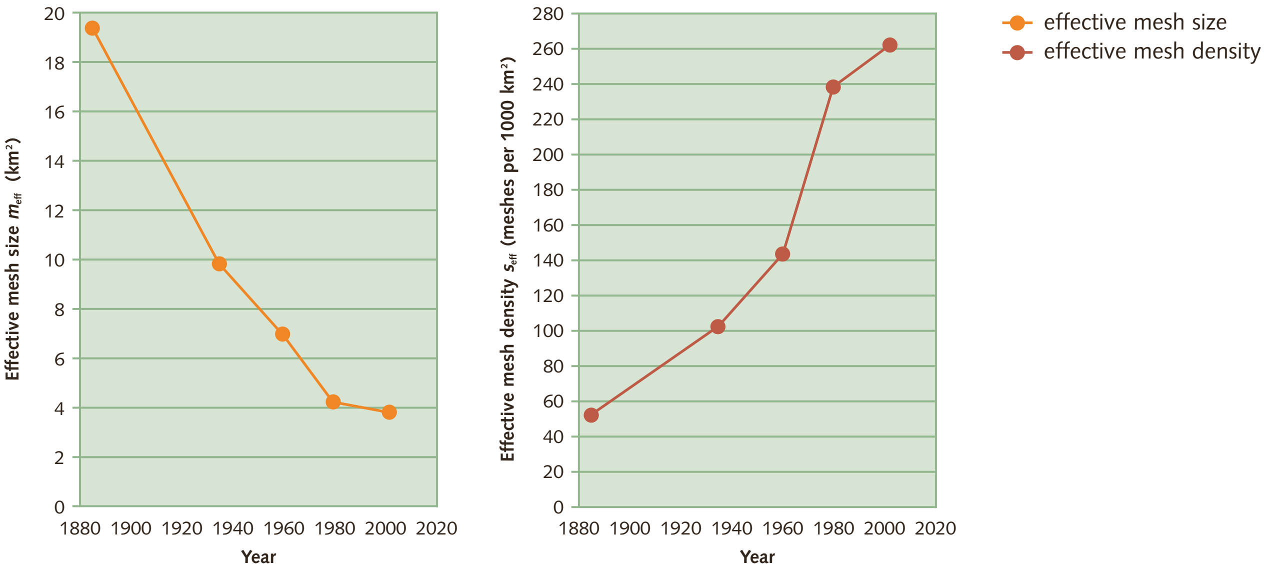
In contrast to most other cantons, Uri did not witness a more pronounced increase in fragmentation between 1960 and 1980 (Fig. F20). The rise in effective mesh density has continued unabated. However,



F 17 Canton of Aargau – situation of landscape fragmentation in 1885 (left) and 2002 (right)

Area in km²
- ≥0, <2
- ≥2, <3
- ≥3, <6
- ≥6, <10
- ≥10, <15
- ≥15, <25
- ≥25, <50
- ≥50, <75
- ≥75, <100
- ≥100

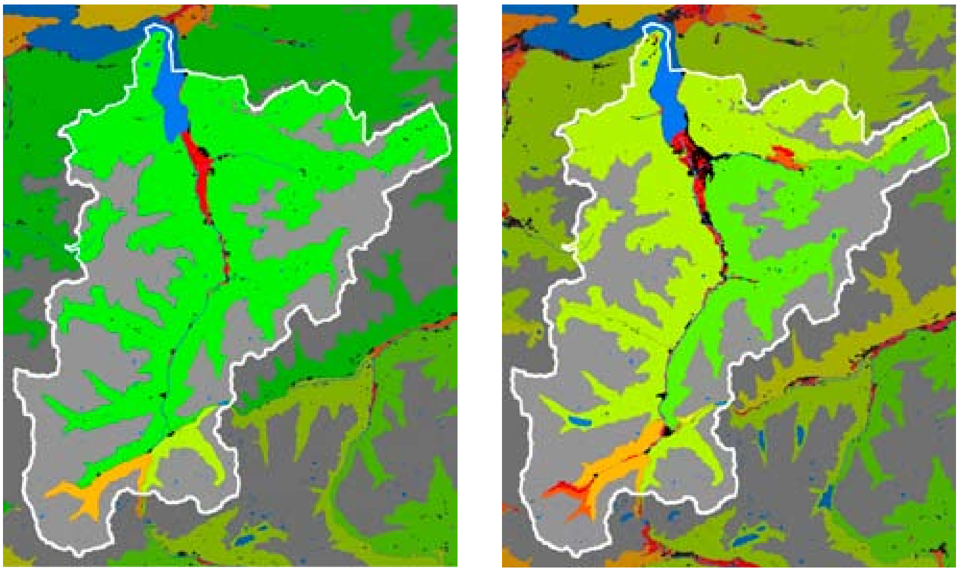
Trends in effective mesh size and effective mesh density in the canton of Aargau **F 18**



it is anticipated that the values will change little in the future as a result of major transport routes (class 2 roads and above), as all the important connections to the neighbouring cantons are already in place and only relatively few areas are suitable for new urban development. Yet there is still a possibility of a further rise due to class 3 roads.

The changes in effective mesh size between 1885 and 2002 in district areas are illustrated in Figure F16. The highest relative decreases occurred in the districts of Höfe, Hérens, Sierre, Solothurn, Sion, Leuk and Neuchâtel (with a decrease of more than 80 %).

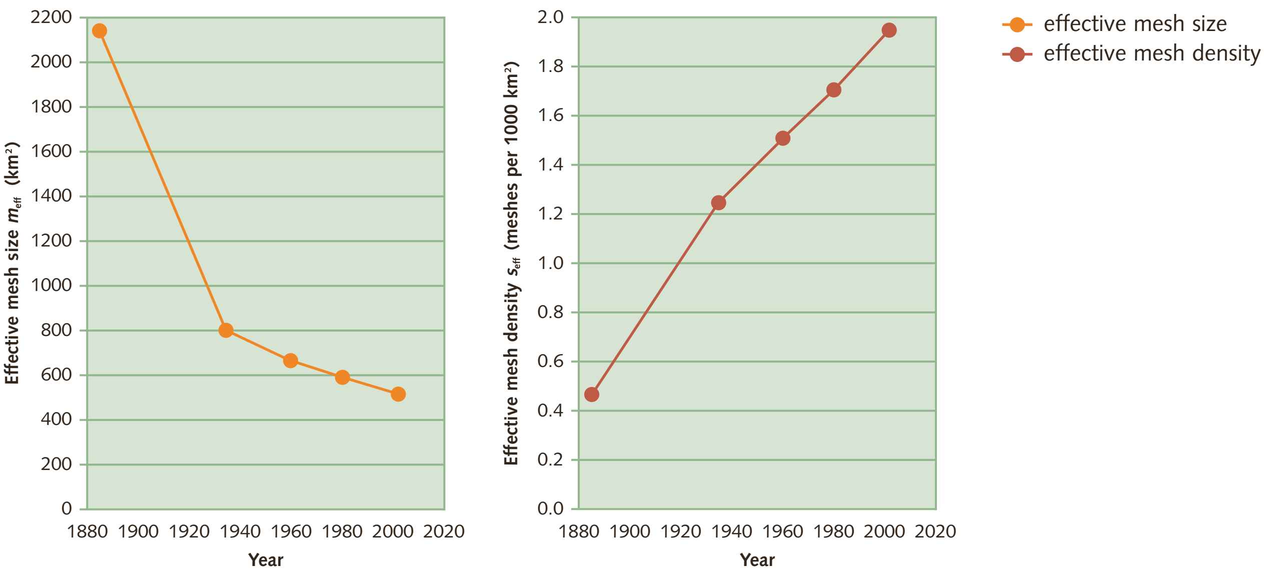
The proportion of unfragmented areas >100 km² (UFAs) is often considered when discussing landscape fragmentation. This value does, however, distort landscape fragmentation trends, as it does not take into account the division of very large areas into smaller areas which are themselves just above 100 km². The proportion of UFAs is also unable to represent the fragmentation of areas that are smaller than 100 km² which are nonetheless significant in terms of both ecology and scenic value. For these reasons, data for the changes in UFAs over time are not given.



F 19 Canton of Uri – situation of landscape fragmentation in 1885 (left) and 2002 (right)

Area in km²
- ≥0, <3
- ≥3, <6
- ≥6, <10
- ≥10, <25
- ≥25, <50
- ≥50, <200
- ≥200, <700
- ≥700, <1400
- ≥1400, <2800
- ≥2800

Trends in effective mesh size and effective mesh density in the canton of Uri **F 20**



3.3 Comparison with other countries

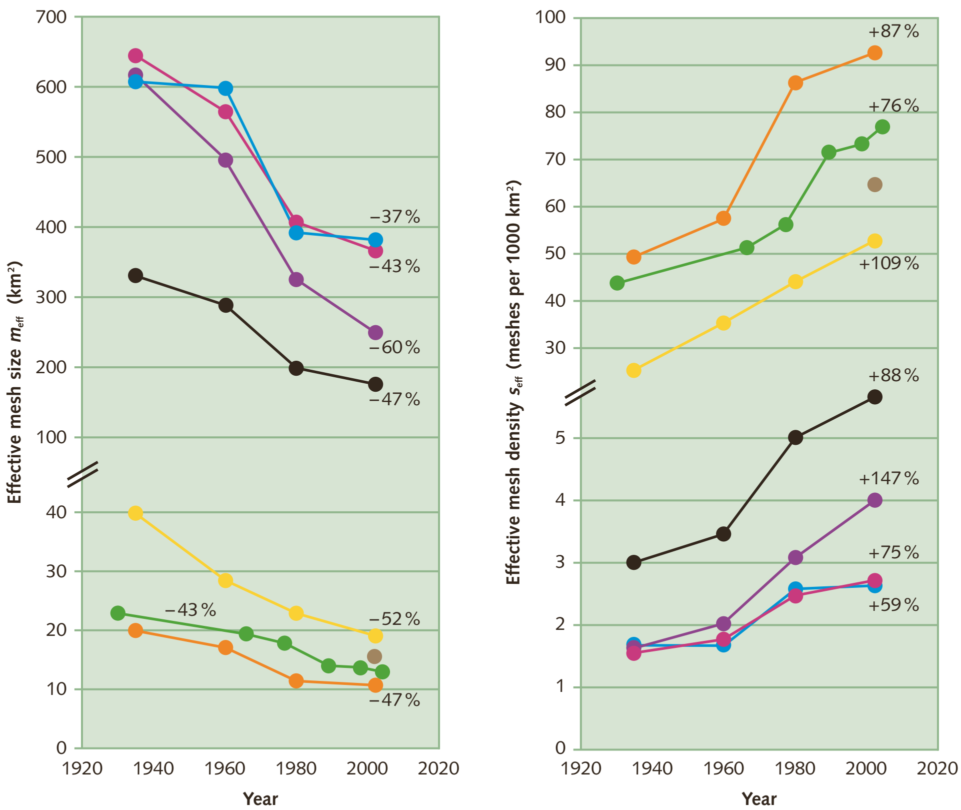
Considering that the Alpine region accounts for a large part of the country, Switzerland appears extremely fragmented when compared internationally. When Switzerland is compared with other countries on the basis of major transportation routes, it may seem at first glance to be far less fragmented, less than Germany, the Czech Republic and Austria (Fig. F22). However, this is due to the large areas in the Alpine region which have a positive effect on the effective mesh size for the whole of Switzerland. The Northern, Central and Southern Alps account for a good 60 % of the land area, with almost 23 % of the land area lying above 2100 m. However, in the Central Lowlands and the Jura region the landscape is much more fragmented than in the Alpine regions. The effective mesh size is much smaller in the Lowlands and the Jura region than in most other countries.

The effective mesh size for Switzerland as a whole is 176.3 km² – around twelve times larger than that for Baden-Württemberg (13.0 km²) and Hesse (15.6 km²). This is due to Switzerland's Alpine regions. There are no corresponding regions in Baden-Württemberg and Hesse. It is therefore only meaningful to compare Baden-Württemberg and Hesse with the Lowlands and the Jura region, as they have eco-regions comparable to these.

Baden-Württemberg has an effective mesh size of 13.0 km² and Hesse has 15.6 km², whereas the Lowlands only have 10.8 km² (Fig. F21). The Swiss Lowlands are much more fragmented due to the smaller class 3 roads than Baden-Württemberg and Hesse. In the Jura, effective mesh size is 19.0 km², which is 45 % larger than Baden-Württemberg and 20 % larger than Hesse (Fig. F21). The Jura region is therefore at a similar level to the German *Land* of Saxony, which has an effective mesh size of 18.2 km².

There have been similar, highly negative, trends over time, in the areas of Jura, Central Lowlands and Baden-Württemberg (Fig. F21). Compared to 1935, the effective mesh size in Switzerland has decreased between 37 % and 60 %, depending on the area (eco-region). Overall, Baden-Württemberg has seen a drop of 43 % since 1930, and the Central Lowlands experienced a fall of 47 % since 1935. The downward trend has therefore been greater in the Lowlands than in Baden-Württemberg.

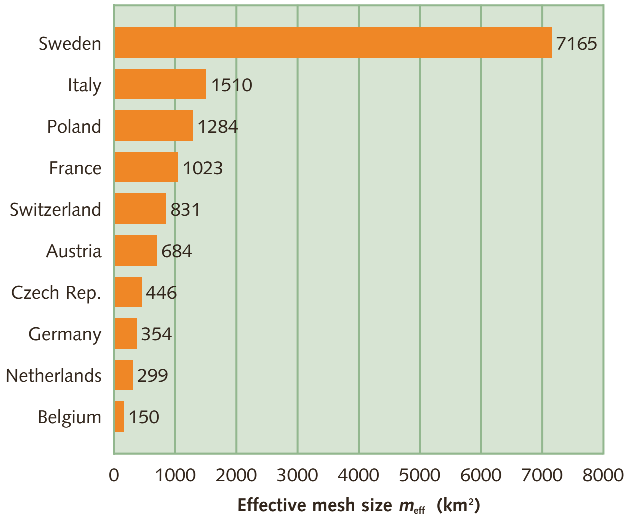
Comparison of fragmentation trends in Switzerland with those in Baden-Württemberg and Hesse **F 21**



- Switzerland
- Jura
- Central Lowlands
- Northern slopes of the Alps
- Central Alps
- Southern slopes of the Alps
- Baden-Württemberg
- Hesse

The graphs show values for effective mesh size (left) and effective mesh density (right) for Switzerland and its five eco-regions and also for Baden-Württemberg and Hesse. The Central Lowlands are much more fragmented than Baden-Württemberg, while the Jura region is much less fragmented. Over time, all areas have experienced strong downward (left) and upward (right) trends.

Landscape fragmentation through major transport routes and large agglomerations (>1000 ha) in a selection of European countries F 22



The above values are still provisional as the data used (GISCO road/rail data, 1998 version) is in some countries incomplete or unrepresentative. Reliable base data is therefore needed to improve the comparability of results between countries and to enable conclusions to be drawn at the European level. As the values represented here have been calculated differently, they do not match the values provided in the present report (source: European Environment Agency, project under preparation).

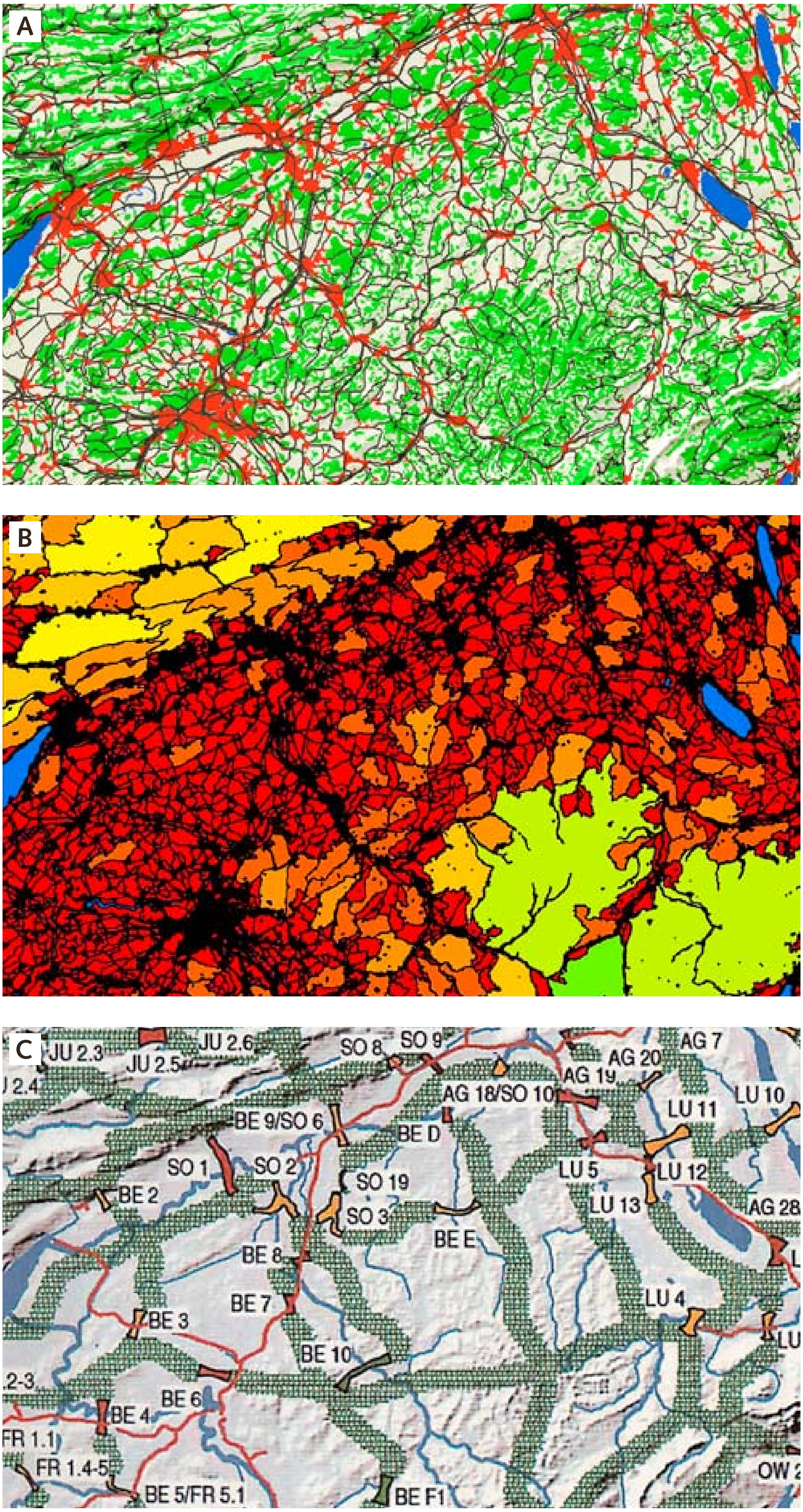
3.4 Landscape fragmentation and wildlife corridors

The ecological network and the wildlife movement corridors have been particularly affected by landscape fragmentation. The ecological network can be superimposed on the fragmentation map in order to highlight the areas of conflict. This provides information on the locations where wildlife passages or the dismantling of transport routes are desirable.

The large-scale ecological network for wild animals consists of wildlife corridors and trans-regional connections for wildlife movement (Fig. F23). Wildlife corridors are the sections in the ecological network that are delineated by permanent boundaries, e.g. through urban development. They provide a trans-regional network that links populations' habitats. They enable genetic exchanges to take place between and within populations, allow populations to make their usual journeys across the landscape, e.g. seasonal migration, and facilitate active dispersion in order for new habitats to be claimed or for previous habitats to be recolonised. Switzerland has a leading role in Europe in identifying wildlife corridors and making plans on how to restore and protect them. Of the 303 wildlife corridors of trans-regional importance that have been identified, 28 % are classed as intact, 56 % as damaged, and 16 % as largely severed (Holzgang et al. 2001). The recovery plans for wildlife corridors include the construction of 15 new wildlife passages by 2013, adding to the current total of 23.

Motorways act as impassable barriers. For traffic safety reasons, Swiss motorways are fenced off. The overlaying of wildlife movement network on the fragmentation map takes into account not only motorways, but numerous other relevant barriers (Fig. F23). The relevant question here is what additional conflicts arise as a result of the fragmenting effect of smaller transport routes. Figure F23 clearly shows that animals have to overcome numerous barriers; for example, when journeying from the Jura to the Alpine region. The overlaying process can be carried out for each of the five time points, starting in 1885, and this helps determine where and how fast the state of each wildlife corridor has changed over the decades.

For areas containing trans-regionally important wildlife corridors, the effective mesh size should no longer continue to decrease. For the wildlife corridors that have been judged as damaged or severed, it is particularly important that unnecessary transport infrastructure is removed or that these wildlife corridors are tunnelled



F 23 Map extracts for superimposing the Swiss ecological network (according to Holzgang et al. 2001) on the fragmentation map. A section from the Central Lowlands is shown.

A. Map of urban areas and transport infrastructure
B. Fragmentation map
C. Large-scale network of wildlife movement corridors

- Settlements
- Forest
- Lakes
- Transport routes

Areas in km²

- 0–5
- 6–10
- 11–25
- 26–50
- 51–100
- 101–300
- 301–1000
- 1001–2500
- >2500

Status of wildlife corridors of trans-regional importance

- Intact
- Damaged
- Largely severed
- Trans-regional network for wildlife movement
- Motorway
- Lakes and watercourses

under. As a consequence, the effective mesh size will begin to grow again in these areas. Urban development in these areas should be prevented from expanding, e.g. by establishing urban separation belts.

3.5 Trend projections for the years 2020 and 2050

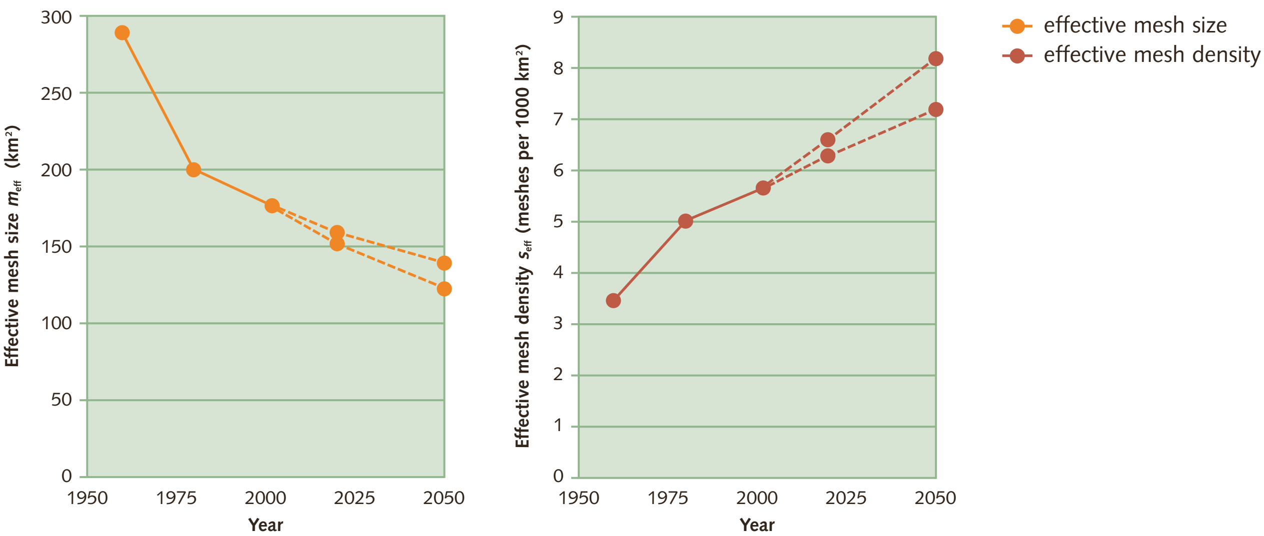
How fragmented will Switzerland be in the years 2020 and 2050? This section looks at this question with the help of trend projections. By projecting effective mesh density trends from the period between 1960 and 2002, values for effective mesh density and effective mesh size in 2020 and 2050 were estimated (Fig. F 24). A minimum value and a maximum value were generated which illustrate the trend spread since 1960. This means that the greater the trend changes between 1960 and 2002, the farther apart the projected maximum and minimum values. The calculation of m_{eff} for Switzerland in 2020 is between 151 km² and 159 km². The decrease when compared to today is expected to be between 10 % and 14 % for 2020 and between 21 % and 30 % for 2050 (today m_{eff} is 176 km²).

When interpreting these figures, it should be considered that many important ecological processes (e.g. adaptation to new habitat conditions) take place over long time-scales. The extrapolated data indicate continued drastic and rapid change in the landscape, especially when compared to these lengthy processes.

Underpinning the extrapolation of the current trend is the assumption that traffic levels will continue to rise in Switzerland. „All traffic predictions assume continued massive growth in all forms of transport. Passenger transport is calculated to increase by 20 to 40 per cent by 2015. In terms of goods transport, tonne-kilometres are expected to double by 2020" (Stremlow et al. 2003: 134). A continued rapid rise in urban development is also anticipated, with no let-up foreseen, assuming that there are no major alterations in urban development policy.

Of course, a projection is not a guarantee that a trend will actually continue in the predicted way. As far as national routes are concerned, construction will hardly continue at the present rate. Therefore it could seem, at first glance, that the projection is unrealistic. But when looked at again it becomes clear that a further significant rise in landscape fragmentation *can* be expected (e.g. due to the construction of class 3 roads, by-passes, and the second stage of the Rail 2000 project). This projection allows interesting comparisons to be made. One very interesting option would be to calculate effective mesh density based on currently planned transport infrastructure. This would allow much more accurate statements to be made about expected changes in landscape fragmentation. A comparison could then be made with the projection made above

Forecast values for effective mesh size and effective mesh density in Switzerland for 2020 and 2050 based on the current trend of landscape fragmentation **F 24**

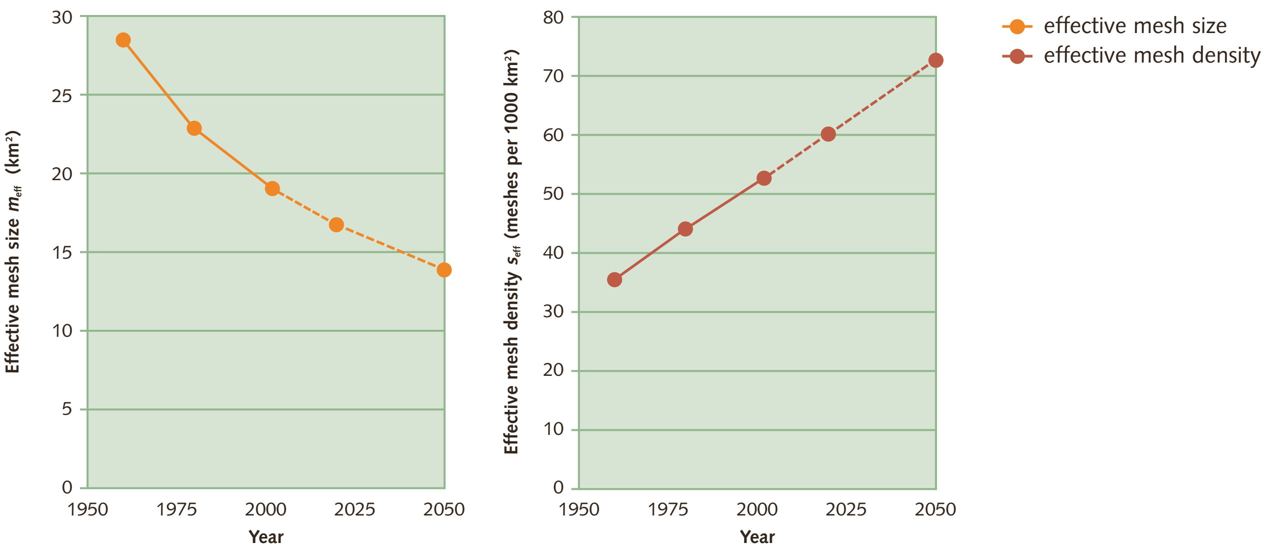


in order to judge whether or not the trend is likely to slow down (and by how much). A follow-up project should be undertaken to determine the degree of fragmentation based on current plans for by-passes and large-scale projects.

Out of the five eco-regions, the Jura region has the strongest downward trend in m_{eff}. If the trend in the Jura continues, then a figure of 16.7 km² will be reached by 2020 and 13.9 km² by 2050. There has been a distinct trend in the Jura since 1960 and therefore the high and low values are close together (Fig. F25). In the Central Lowlands it is likely the value will drop below 10 km² either before or shortly after 2020.

If the trends observed are set to continue, the effective mesh size will carry on falling in all cantons over the next 45 years. For example, the canton of Valais will drop to between 113 and 132 km² by 2020 and between 83 km² and 107 km² by 2050. The canton of St. Gallen ranks in the middle, with its mesh size lying close to the size for Switzerland as a whole (176 km²). St. Gallen is expected to see a decrease from the current 182 km² to 138 km² by 2050, in other words a larger drop than for Switzerland overall (155 km²). Cantons such as Fribourg, Lucerne and Vaud, with values of 65 km² and 85 km² will experience a drop to a level of between 45 km² and 65 km² by around 2050. Cantons with overlapping ranges may see their ranking change, e.g. Zug and Zurich (it is likely that Zug will overtake Zurich in terms of fragmentation from 2030). A change in ranking for the remaining cantons is rather unlikely.

Forecast values for effective mesh size and effective mesh density in the Jura eco-region for 2020 and 2050 based on the current trend of landscape fragmentation **F 25**



4 Implications

4.1 Application of results in spatial and environmental monitoring

The current study provides a comparative basis for further investigations. This study uses data over a very long time series (from 1885) for effective mesh size and density, and which were gathered according to standardised criteria. As a result, values calculated now and in the future can be compared with changes over a time period of more than one hundred years, enabling the identification of any trend variations.

The aims of environmental monitoring are to recognise, understand and document changes in the environment. Its results are not only relevant for animal populations, but concern the character and appearance of the landscape as well as noise pollution and the quality of recreational areas. The time series used in this investigation should be adopted nationally by existing monitoring systems. These systems include the monitoring system for sustainable development (MONET), biodiversity monitoring (BDM, to be used as an indicator of the effect of „road density“), landscape monitoring, the environmental data network (NUD), and NISTRA (sustainability indicators for road infrastructure projects). The MONET system lists 17 selection criteria which new indicators need to meet. The effective mesh size method fulfils all these criteria. The present data on landscape fragmentation have already been included in the new report by the FOEN and FSO *(Environment Switzerland 2007)* and in the FSO's short guide (*Swiss Environmental Statistics: A Brief Guide 2006* and *2007*).

At a cantonal level, existing monitoring systems (e.g. in the canton of Aargau) or reports on spatial development in the cantons could be broadened by use of indicators of effective mesh size and mesh density. The data should therefore be adopted in environmental reporting for the cantons. The present fragmentation analysis provides a basis for cantonal concepts for preserving and linking habitats as well as for evaluating and improving the quality of landscapes. In addition to the impacts on wildlife corridors and wildlife habitats,

Box 3: Applying the method

The method of effective mesh size and effective mesh density can be used at any level, e.g. at cantonal level, as a localised instrument of analysis for the following purposes:

1. Quantitative data on planned future development reveal the extent to which planned transport routes will increase fragmentation, e.g. in comparison to previous trends. This takes into account the cumulative effects of several construction projects (including the expansion of urban areas) on the effective mesh density.
2. The various planning options for transport infrastructure and urban areas can be compared with each other with respect to their impacts on the effective mesh density. Here, consideration should not just be given to individual development projects. Instead, the cumulative effects of all planned future developments and their interactions should be taken into account. The method can be broadened to encompass the issue of landscape quality. Among the possibilities here are: the inclusion of stepped values for landscape character or recreation-al quality; the inclusion of noise bands; the inclusion of stepped values for the ecological quality of affected patches, and the inclusion of wildlife passages and probabilities of crossing success of transport routes.
3. The extent to which each category of transport route contributes to the total degree of fragmentation can be determined. Such values can, for example, indicate threat levels for the remaining ecological networks, since smaller transport routes may signal where expansion could be envisaged in the future if traffic levels rise.
4. Using this method, specific suggestions can be put forward for the removal of transport routes, which would have an especially positive effect on effective mesh size.
5. It would be interesting to look at the extent to which regions are fragmented in relation to human population density and economic productivity (and other relevant factors), to see in which regions economic growth is paralleled by a rise in landscape fragmentation and where it has been independent of the degree of fragmentation.

cantonal landscape development concepts and structure plans should also take account of the effects of fragmentation on landscape quality and character. Such effects will not be balanced out or reversed by constructing wildlife passages.

The present data on landscape fragmentation would enable the effectiveness of national and cantonal measures to be checked in terms of fragmentation. It can then be analysed whether the postulates submitted have received attention and the intended objectives have been reached. Assessing the effectiveness of BLN areas with respect to landscape fragmentation is an example of how it is possible to evaluate current measures. This example shows that BLNs were more effective with regard to fragmentation than with regard to urban sprawl (see also the detailed report by Bertiller et al. 2007).

Indicators of the state of the landscape, of its variety and character are, on the whole, rarely available. There is therefore a case for using figures on the degree of fragmentation in landscape-related analyses and evaluations at a national and cantonal level. The suitability of results for use in planning generally depends upon how closely associated they are with the affected landscape functions and their sensitivity. The next step would therefore be for a detailed data study to be performed for the individual biogeographic regions, cantons and districts in relation to their landscape functions and their sensitivity.

Continuing on from the current time series, fragmentation in Switzerland should be calculated at regular intervals (e.g. every 4 to 6 years). Because the digital database (VECTOR25) is updated periodically this would involve relatively little time and expense.

Future research is still needed to investigate various issues, e.g. fragmentation of the landscape due to power lines. It would also be of great interest to establish the correlations between the degree of fragmentation and the occurrences and sizes of wildlife populations.

Given that the negative effects of habitat fragmentation and isolation usually only become apparent after several decades, it is probable that further population losses will be incurred in the coming decades as a result of landscape alterations that have already taken place.

If a decline in populations is documented, it may already be too late to take measures to stabilise the situation. The consequences of fragmentation up until now, which will become apparent over the course of the next few decades, should therefore be thoroughly investigated to determine time lags.

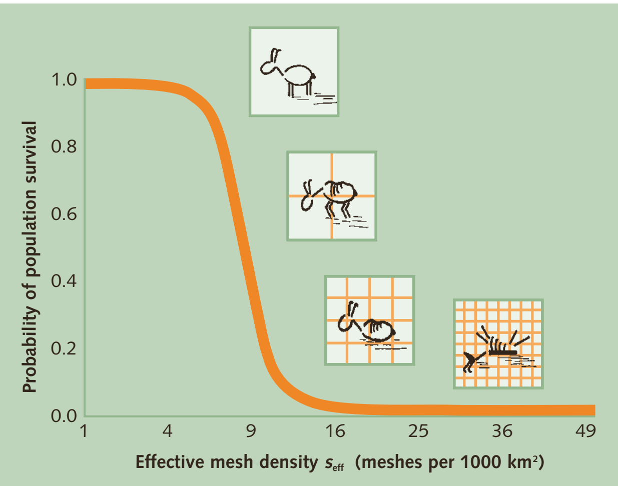
4.2 Recommendations for controlling landscape fragmentation

Data on the degree of fragmentation enable the assessment of environmental objectives

Measures on controlling and lowering landscape fragmentation can only be implemented effectively if there is an awareness of the problem, and specialist knowledge is made available. The authorities, experts and the public must therefore be made aware of the fragmentation problem and be informed about suitable measures. The setting of thresholds could play an important role here. There is a basic distinction between the issue of improving habitats for animal populations and the issue of evaluating the quality of the landscape (e.g. the character of the landscape). What is important is not only the protection of the remaining unfragmented areas, but also the prevention of further fragmentation where the landscape is already highly fragmented.

Previous research has demonstrated that there are thresholds of fragmentation (Fig. F26). It has been calculated, using a simulation model, that a population's chances of survival depend on the number of roads. According to the results, the threshold depends on the species and on road traffic volumes. Furthermore, the increasing number and severity of barriers reduces genetic exchange (not accounted for in the model in Fig. F26). The chances then increase that related individuals will breed with each other (inbreeding). This lowers the ability of the species to adapt to changing environmental conditions, thereby decreasing the population's chances of survival.

What do these thresholds mean for traffic planning and nature conservation? If current animal populations have so far survived all the new road building in a landscape, this does not imply that the populations will also be able to withstand further transport routes. When the threshold has been reached, it is highly likely that the next new route built will bring about the populations' extinction.



F 26 Landscape fragmentation thresholds for the survival of wildlife populations (adapted according to Jaeger and Holderegger 2005; specific values depend on the species and road traffic volumes).

Box 4: Recommendation for limiting fragmentation

The Federal Environment Agency in Germany has issued recommendations for limiting landscape fragmentation based on the effective mesh size (Penn-Bressel 2005; Table T3). In response to fragmentation predictions, the Agency has drawn up action plans for limiting fragmentation and/or curtailing the rate of increase in Germany. Large unfragmented areas are to be preserved and enlarged. In areas which are already highly fragmented, the trend is to be slowed down.

By 2015 the reduction in effective mesh size in highly fragmented areas should, compared to the starting point, be at least half the rate of the expected outcome had the situation been left unchecked. The following specific aims were set:

„a) The number and total area of each, as yet, unfragmented, low-traffic areas above 140, 120, 100, 80 and 60 square kilometres shall not decrease further and instead will be increased through defragmentation measures so that their current proportion of 20.6% of Germany's territory will be raised to 23% by 2015.
b) The degree of fragmentation of highly fragmented regions shall be limited by additional criteria [in Table T3]“ (Penn-Bressel 2005: 132).

The authors of the current publication support this recommendation.

Values for limiting landscape fragmentation in highly fragmented regions in Germany, as put forward by the German Federal Environment Agency **T 3**

Starting point at the end of 2002: effective mesh size m_{eff}	Goal to be reached by 2015: decrease in effective mesh size m_{eff} to be less than
<10 km²	1.9 %
10–20 km²	2.4 %
20–35 km²	2.8 %
>35 km²	3.8 %

There is currently only limited reliable data on another vital question concerning what volume of traffic makes a transport route impassable for a certain species. Ecological factors, such as the spatial distribution of habitats or a population's birth and mortality rates also influence the thresholds. It is difficult to consider the effects of all these factors, as this requires data for different habitat types over long time periods which can be gathered only rarely.

This is why the exact thresholds for a population or a species are largely unknown. This makes it all the more essential that a precautionary approach is adopted that guides landscape fragmentation in the desired direction. Future research projects should fill the remaining gaps in knowledge.

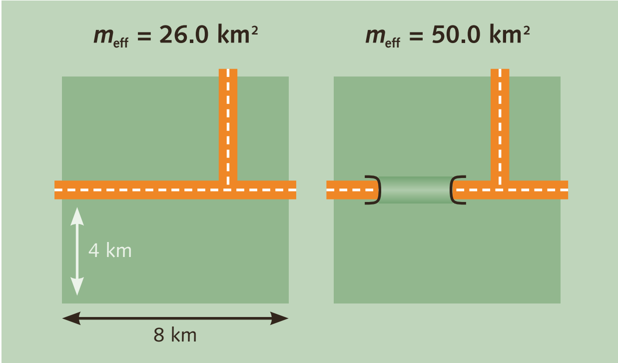
Traffic and urban planning measures

- *Preserving and restoring wildlife movement corridors*

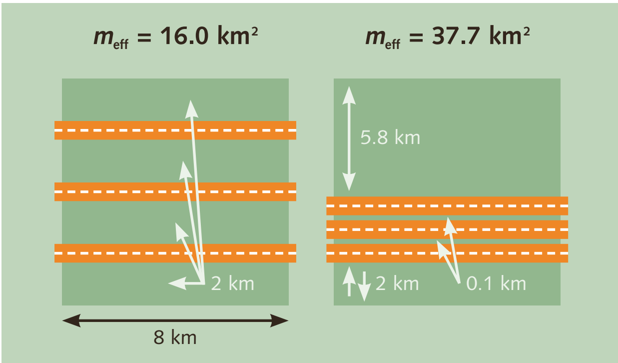
Existing transport routes can be made more permeable for wildlife through various measures: tunnels (Fig. F27), crossing structures such as wildlife passages and underpasses, or by raising roads up on pillars so that wildlife can cross underneath. The larger the areas linked together, the more effective the measures will be. Therefore the neighbouring areas and the interactions with other measures should be taken into account when planning. The restoration of damaged or severed wildlife corridors is a significant step in preserving and recreating the opportunities for large mammals and other species to migrate and disperse. The Swiss Federal Roads Authority (FEDRO) and the Federal Office for the Environment (FOEN) have drawn up a joint programme. Among the things envisaged in this programme is the creation of 15 new wildlife passages along motorways and major roads by 2013. Steps to reduce barriers that prevent the spread of wildlife should always be linked to improvements of the ecological conditions and the landscape. The cantons and local authorities could play an important role in implementing this.

- *Bundling of transport routes*

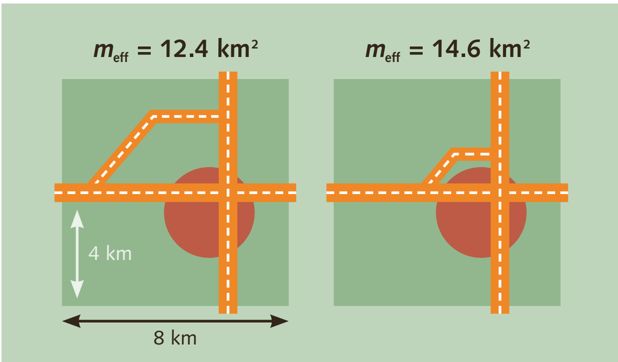
The tighter that transport routes are bundled together, the larger the remaining unfragmented areas of land. If, for example, a railway line is already present, any new road should be planned to run as close and parallel to the line as possible (Fig. F28). Wildlife passages could



F 27 Effect of tunnelling on the effective mesh size. Thanks to the road being routed through a tunnel (right) the effective mesh size in this example has increased from 26 km² (left, no tunnel) to 50 km².



F 28 Effect of bundling transport routes on the effective mesh size. The bundling of transport routes (right) causes the effective mesh size to increase when compared to the standard distribution of routes across the landscape (left).



F 29 Effect of by-pass location on the effective mesh size. Effective mesh size is larger if the by-pass is drawn tighter around the settlement (right), than if the road is built farther away (left).

then be organised so that all the transport routes could be crossed over or under in one go.

In general an upgrade of existing routes should, however, be preferred over the construction of new routes at another location. This would apply even if the newly constructed route were to be bundled with existing routes. However, upgrading routes increases their barrier effect, especially if this is coupled with a rise in traffic volume. But this effect is generally less damaging than the fragmentation of large patches located near bundled transport routes. If traffic volume falls, for example due to new routes in other locations, then the affected routes should be downgraded accordingly, e.g. by being narrowed.

If by-passes and other transport routes are sited close to developed areas, the fragmentation effect is lower compared to the construction of by-passes away from settlements (Fig. F29). The purpose of this measure is to preserve unfragmented areas that are as large as possible and to lessen the fragmenting impact of any new transport routes.

- *Oasis concept*

A new, innovative idea for designing transport infrastructure is the so-called *oasis concept*. This means that areas suitable for recreational use *(oases)* and small communities will be kept free from trans-regional traffic. Road traffic will be concentrated onto a small number of roads located a clear distance from communities, which will in turn be connected by access roads. Current roads that route traffic directly from community to community will then be dismantled.

The major advantages of this concept lie in the fact that communities are freed from through-traffic and that it halts the trend of continually building new by-passes around. This concept may prompt new ideas for the planning of new roads, and can also be applied to roads dedicated to agricultural purposes, as part of continued restructuring in the agriculture sector.

- *Dismantling of transport infrastructure*

Transport infrastructure which is no longer needed, due to the construction of new routes or changing requirements, should be removed. This process should be encouraged particularly where existing infrastructure lies in an area of major animal movement corridors (e.g. amphibian migration). Removal is essentially the more effective, the larger the areas that will be rejoined. Consideration should not only be given to the patches directly bordering the transport route. Instead, account should also be taken of the combined effect of a series of measures.

When it comes to trans-regionally important wildlife corridors, the effective mesh density must no longer continue to increase. It is particularly important in the case of wildlife corridors considered damaged or severed, that unnecessary transport infrastructure is removed or that transport routes are tunnelled under or bridged over. Likewise built-up areas should be prevented from expanding in these areas.

- *Limiting urban areas, and internal urban development*

In order to preserve open space in the countryside, it is necessary to limit the size of urban areas. Regional planning legislation requires cantons and local authorities to treat land sparingly in their guidelines and land-use planning, and to preserve areas that are valuable and important for recreation as well as areas for agriculture. Cantons and local authorities can fulfil this obligation by limiting the growth of built-up areas, encouraging development within urban areas (e.g. through the use of brownfield sites and consolidation) and promoting compact design in previously developed zones as well as qualitative assessments of urban districts. Limiting lines and breaks in development would ensure clear open spaces are left between built-up areas. In addition to being important in shaping the landscape and structuring built-up areas, open spaces are particularly significant in providing linking corridors for animals and plants as well as local recreation areas.

Regional planning instruments can also contribute to preventing landscape fragmentation and urban sprawl. Through use of intercommunal land, several local authorities, for instance, can contribute jointly to spatial development which both saves land and has a lower fragmenting effect. In the case of residential and industrial land, coordinated re-use of previously developed zones (land recycling) can make a major contribution to reducing the need for land. Measures such as providing ecological links in the landscape, enhancing the quality of lakes and watercourses, and increasing structural diversity alongside and within woodland, contribute greatly towards making qualitative improvements in the ecological links in the region while also raising the scenic and recreational quality of the landscape.

Measures at a strategic level

- *National strategy for defragmentation*

At a national level there are already numerous regulations and instruments that can be used either directly or indirectly to promote defragmentation, for example the BLN areas or the Swiss Landscape Concept. Since there is now a method available which can concretely illustrate the degree of fragmentation within an area, the task of defragmenting should be expanded to be included in existing instruments at a national level. Appropriate objectives and measures should be elaborated according to jurisdiction.

One preferred option is to include defragmentation in the revision of the Swiss Landscape Concept (LKS) and make it binding for federal offices by stating what measures should be taken and where and how they should be implemented. A process of nationwide documentation and coordination is recommended to produce an overview of measures at a national level and to enable regional strengths and shortcomings to be recognised more easily. Defragmentation should also increasingly find its way into planning criteria and instruments at the cantonal level, for example in cantonal structure plans and landscape development concepts. The cantons of Berne and Thurgau have already proven to be good examples in this respect.

- *Long-term regional development and transport policy*

Regional development and transport policy can provide important directions for future options in landscape fragmentation. Large-scale urban sprawl generates more traffic than dense development. Urban sprawl also conflicts with the aim of using land sparingly and in an organised way.

Within the scope of the National Research Programme 54 on the subject of the „sustainable development of the built-up environment", the same research team is working on a project that is investigating the degree of urban sprawl in Switzerland. This essentially entails developing new regional development and transport concepts that have a lower impact on fragmentation and which put more emphasis on the conservation of open space and biodiversity than has previously been the case. Better use must be made of the designated zones for development in the future. The regional planning report published by the Federal Office for Spatial Development (ARE) in 2005 recommended new economic and financial instruments, for example land certificates.

In the long term, objectives should be drawn up on how future sustainable and low-fragmenting transport systems are to be developed and what the likely requirements will then be to enable the necessary restructuring of the built environment. Traffic planning should become more target-oriented and less demand-oriented. Such considerations should be included in the ongoing process of the Swiss spatial concept, in the continuing work on the sectoral plan for transport, and in the Federal Council's sustainability strategy.

Guiding concepts for the landscapes in Switzerland should be drawn up to this end that including the identification of regionally and nationally important unfragmented areas and priority areas for defragmentation. To make these guiding concepts more tangible, it would be appropriate to adopt benchmarks or targets for the degree of landscape fragmentation.

In order to evaluate the impacts of any new fragmentation, it is increasingly necessary to consider the network effects beyond the individual construction, in other words a Strategic Environmental Assessment (SEA) is recommended to determine the cumulative impacts. Here the application of the effective mesh size and mesh density method will come in useful. The development of new long-term concepts for a restructured transport system which is not dependent on fossil fuels should also take into consideration the effects on fragmentation.

According to the current forecasts, Switzerland will only see slight population growth in the future. This gives foundation to the argument that the need for land for urban development and transport infrastructure will stagnate or even decrease in the foreseeable future. If the number of urban developments further increases, and becomes more scattered, it will be more difficult and costly to maintain the supporting infrastructure.

Appendix

Information about the project

The project entitled *Degree of Landscape Fragmentation in Switzerland: Quantitative analysis 1885–2002 and implications for traffic planning and regional planning* was conducted by the authors in 2005 and 2006. It was given financial support by the SBT Research Centre of the Swiss Federal Roads Authority (FEDRO) and by the Federal Office for the Environment (FOEN) (research number: FEDRO 2004/012). Along with FEDRO and FOEN, the support group of the project also comprised the Federal Office for Spatial Development (ARE), the Federal Statistical Office (FSO), the Ornithological Station at Sempach, the Zurich Office for Landscape and Nature, the Zurich Office for Underground Civil Engineering, the Swiss Federal Institute for Forest, Snow and Landscape Research, and one planning office.

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Values for the cantons and eco-regions of Switzerland

Values of effective mesh size and effective mesh density for Switzerland, the 26 cantons and the 5 or 10 eco-regions from 1885 to 2002 (for FG 4: land areas under 2100 m) **T 4**

	Effective mesh size (km^2)					Effective mesh density (meshes per 1000 km^2)				
	2002	1980	1960	1935	1885	2002	1980	1960	1935	1885
Switzerland as a whole	176.33	199.69	289.15	331.79	579.72	5.67	5.01	3.46	3.01	1.72
Canton										
Zurich	4.20	4.37	5.13	5.78	13.31	238.10	228.83	194.93	173.01	75.13
Berne	249.60	264.46	388.59	430.95	894.30	4.01	3.78	2.57	2.32	1.12
Lucerne	81.34	82.94	148.98	226.27	296.73	12.29	12.06	6.71	4.42	3.37
Uri	513.48	587.06	663.98	802.87	2143.66	1.95	1.70	1.51	1.25	0.47
Schwyz	154.22	166.71	326.84	396.61	1051.40	6.48	6.00	3.06	2.52	0.95
Obwalden	317.50	324.91	448.25	735.26	1792.70	3.15	3.08	2.23	1.36	0.56
Nidwalden	379.79	390.79	424.54	638.62	2262.19	2.63	2.56	2.36	1.57	0.44
Glarus	635.14	760.46	886.00	908.30	1783.35	1.57	1.31	1.13	1.10	0.56
Zug	4.45	4.57	7.14	22.02	36.25	224.72	218.82	140.06	45.41	27.59
Fribourg	85.40	98.38	124.53	128.52	149.81	11.71	10.16	8.03	7.78	6.68
Solothurn	13.09	15.07	23.98	34.66	78.12	76.39	66.36	41.70	28.85	12.80
Basel-City	0.54	0.55	0.70	1.63	3.40	1851.85	1818.18	1428.57	613.50	294.12
Basel-Country	8.73	9.96	16.98	19.53	40.50	114.55	100.40	58.89	51.20	24.69
Schaffhausen	6.86	9.07	20.02	24.49	33.08	145.77	110.25	49.95	40.83	30.23
Appenzell-Ausserrhoden	29.00	29.70	31.61	36.20	129.05	34.48	33.67	31.64	27.62	7.75
Appenzell-Innerrhoden	143.92	145.18	161.62	164.76	294.16	6.95	6.89	6.19	6.07	3.40
St. Gallen	182.21	214.29	256.95	261.59	434.91	5.49	4.67	3.89	3.82	2.30
Graubünden	321.98	403.68	448.29	460.50	562.01	3.11	2.48	2.23	2.17	1.78
Aargau	3.81	4.20	6.99	9.81	19.41	262.47	238.10	143.06	101.94	51.52
Thurgau	2.14	2.32	2.86	3.36	10.72	467.29	431.03	349.65	297.62	93.28
Ticino	393.87	401.22	661.82	672.78	750.26	2.54	2.49	1.51	1.49	1.33
Vaud	64.85	75.88	142.44	149.85	279.78	15.42	13.18	7.02	6.67	3.57
Valais	153.43	192.57	492.40	731.60	1266.79	6.52	5.19	2.03	1.37	0.79
Neuchâtel	15.44	18.97	30.94	37.69	67.93	64.77	52.71	32.32	26.53	14.72
Geneva	0.82	0.96	1.47	1.79	6.02	1219.51	1041.67	680.27	558.66	166.11
Jura	20.81	25.97	25.90	29.11	54.02	48.05	38.51	38.61	34.35	18.51
Enclaves of Büsingen and Campione	9.41	9.97	10.24	10.76	14.56	106.27	100.30	97.66	92.94	68.68
Eco-region (5 main regions)										
Jura	19.02	22.81	28.40	39.78	77.94	52.58	43.84	35.21	25.14	12.83
Central Lowlands	10.78	11.57	17.32	20.17	40.71	92.76	86.43	57.74	49.58	24.56
Northern slopes of the Alps	367.52	406.46	565.11	643.56	1328.80	2.72	2.46	1.77	1.55	0.75
Central Alps	249.80	325.33	496.58	616.62	925.38	4.00	3.07	2.01	1.62	1.08
Southern slopes of the Alps	381.72	390.68	596.25	608.37	690.22	2.62	2.56	1.68	1.64	1.45
Eco-region (10 subregions)										
High Rhine and Lake Geneva region	2.82	2.92	4.77	6.46	15.23	354.61	342.47	209.64	154.80	65.66
Jura and Randen	19.67	23.55	29.06	40.79	82.22	50.84	42.46	34.41	24.52	12.16
Northern Alps	396.68	439.53	602.73	681.46	1424.99	2.52	2.28	1.66	1.47	0.70
Eastern Central Alps	309.29	414.60	461.58	476.30	610.75	3.23	2.41	2.17	2.10	1.64
Eastern Central Lowlands	3.13	3.48	4.75	6.86	20.74	319.49	287.36	210.53	145.77	48.22
Southern Alps	450.27	463.73	689.20	700.03	732.05	2.22	2.16	1.45	1.43	1.37
Southern Ticino	349.05	354.50	559.19	570.43	664.40	2.86	2.82	1.79	1.75	1.51
Prealps	171.62	184.28	272.73	309.22	513.61	5.83	5.43	3.67	3.23	1.95
Western Central Alps	162.00	204.71	545.60	819.89	1431.31	6.17	4.88	1.83	1.22	0.70
Western Central Lowlands	3.67	4.40	7.17	8.26	17.52	272.48	227.27	139.47	121.07	57.08

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Neuchâtel 2005, 99 pages, CHF 23.00 (excl. VAT) – order number: 002-0500

Nationale Schutzgebiete und ihre Nutzung, Swiss Environmental Statistics no. 13
Neuchâtel 2004, 31 pages, CHF 9.00 (excl. VAT) – order number: 141-9413

General information on environmental statistics:

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Landscapes in Switzerland are becoming more fragmented

The wildlife habitats and recreational areas for people have become increasingly fragmented in Switzerland over the past decades. This has been caused by the increasing density of the transport network and the expansion of residential and industrial areas. As a consequence, the remaining *meshes* in the landscape continue to become smaller. This has numerous detrimental effects on the landscape, on wildlife, and on recreational quality. Many animals such as amphibians are either unable to cross transport routes or do so with heavy losses.

- How can the fragmentation of the landscapes in Switzerland be expressed in figures?
- What are the differences between cantons? Where is fragmentation highest, where is it lowest?
- How much has fragmentation increased over previous decades?
- What periods saw the sharpest increase?
- What are the current trends?

This study answers these questions and more. In order to calculate the degree of fragmentation, the project uses the metrics of *effective mesh size* and *effective mesh density*. These metrics quantify the likelihood of any two points chosen randomly in an area being connected to each other.

The results demonstrate how much landscape fragmentation has increased in Switzerland in the last 120 years. This development is likely to increase further, so long as no effective measures are taken to control landscape fragmentation.

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