Measuring and assessing urban sprawl: What are the remaining options for future settlement development in Switzerland for 2030?

Ulrike Wissen Hayek · Jochen A.G. Jaeger · Christian Schwick · Alain Jarne · Martin Schuler

Abstract Transformation of land use in and around European cities is proceeding as fast as never before, and urban sprawl is a reality in Europe. This process is coming along with significant landscape changes that can even lead to the loss of landscape identity. Is it possible to find indications of which regions are prone to urban sprawl in order to curtail undesired future settlement developments in time? To answer this question we used settlement development scenarios for Switzerland, and analysed their spatial implications using a set of four metrics, which allow for comparing the degree of urban sprawl in different regions. Two aspects were explored: (1) by how much settlement development could potentially increase in Switzerland, and (2) the suitability of the metrics as indicators for characterizing and assessing the development of urban sprawl. The results show that overall in Switzerland the urban permeation and dispersion of settlement areas is likely to increase (in all scenarios), but to different degrees. However, the results differ very much between the various types of settlement and between the cantons, and even a decrease in urban dispersion is possible. In combination with scenarios of settlement growth, the metrics provide useful evidence on regional characteristics such as the overall pressure of settlement development and likely transformations of the respective settlement types that should be taken into account in spatial development concepts. There is a need for calibration of the indicators on a regional level to define specific thresholds to limit urban sprawl.

Keywords: urban sprawl · settlement types · scenarios · urban permeation · dispersion · spatial planning

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Introduction

Settlement structures in combination with other landscape elements, e.g., water bodies, vegetation, and types of cultivation, can build unitary and comprehensive contexts with high informational content and stimulating orientation patterns contributing to the character of various landscape types (Kim and Pauleit 2007; Nohl 2001). Settlement development changes the view of a landscape significantly (Antrop 2004), and since the 1960s, it has frequently created conditions that are denoted as urban sprawl, i.e., particular types of scattered and fragmented peri-urban areas. Associated with these settlement structures are a number of negative effects, such as: loss of cultivated land and loss of biodiversity, irreversible loss of heritage values, aesthetic degradation, declining recreational quality of the landscape and reduced quality of life (Catalán et al. 2008; Ewing 1997; Frenkel and Ashkenazi 2007; Gagné and Fahrig 2007; Jaeger et al. 2007a, 2010a; Siedentop 2005). Affected landscapes often lose their identity (Nohl 2001).

Urban sprawl has been identified as an undesired trend in many countries. There are some examples of planning and land management systems that have been successful in urban containment and countryside stewardship, e.g. the Dutch system and to a lesser degree, the British system (Alterman 1997). However, most attempts to guide development activities in the direction of more desirable settlement patterns have had little success (Bengston et al. 2004; Kasanko et al. 2006; Ulfarsson and Carruthers 2006). Will urban sprawl become even worse in the future?

One difficulty in answering this question is that the future settlement development is difficult to predict. The combination of many factors may lead to completely different alternatives regarding where and how people decide to live and work, with spatial, economic and political dimensions being interconnected (Ulfarsson and Carruthers 2006). A second problem is that it is often not clear which degree of urban sprawl should be assessed as so harmful that further negative development should be strongly avoided. A common consensus on the evaluation of urban sprawl and what criteria should be applied is still missing (Siedentop 2005), even on a national level.

In this paper, we aim to overcome these difficulties by (1) using a set of alternative future settlement development scenarios for Switzerland, and by (2) analysing and assessing their characteristics and implications through the application of a set of new urban sprawl metrics. These metrics allow for a quantitative approximation of the description of landscape quality by indicating the anthropogenic pressure on the landscape (Jaeger and Bertiller 2006; Jaeger et al. 2010b). The following research questions were addressed:

- First, we asked by how much settlement will potentially increase in Switzerland by 2030 according to the four scenarios, and where the most substantial changes would be expected under these scenarios.
- The second question focussed on the evaluation of urban sprawl by asking if the metrics provide useful evidence for characterizing and assessing the nature of settlement dispersion.

The overall goal of this article is to assess the informative value of the new urban sprawl metrics in order to provide planners and decision makers with indications on settlement areas that are particularly exposed to urban sprawl, using Switzerland as an example.

Case Study Location and Research Framework

In Switzerland, the central settlement areas in the region between the Alps and the Jura mountains, the so called "Plateau" or “Mittelland”, have been steadily growing over the last century (Fig. 1). This development is continuing and there is an intense discussion on sustainable settlement development in Switzerland on all administration levels (Baccini and Oswald 1998; Schultz and Dosch 2005). For this reason, suitable instruments for the analysis and communication of the current trends and long-term perspectives are needed. This article documents the results from the collaboration of two research projects about the enhancement of methods for the analysis of spatial developments.

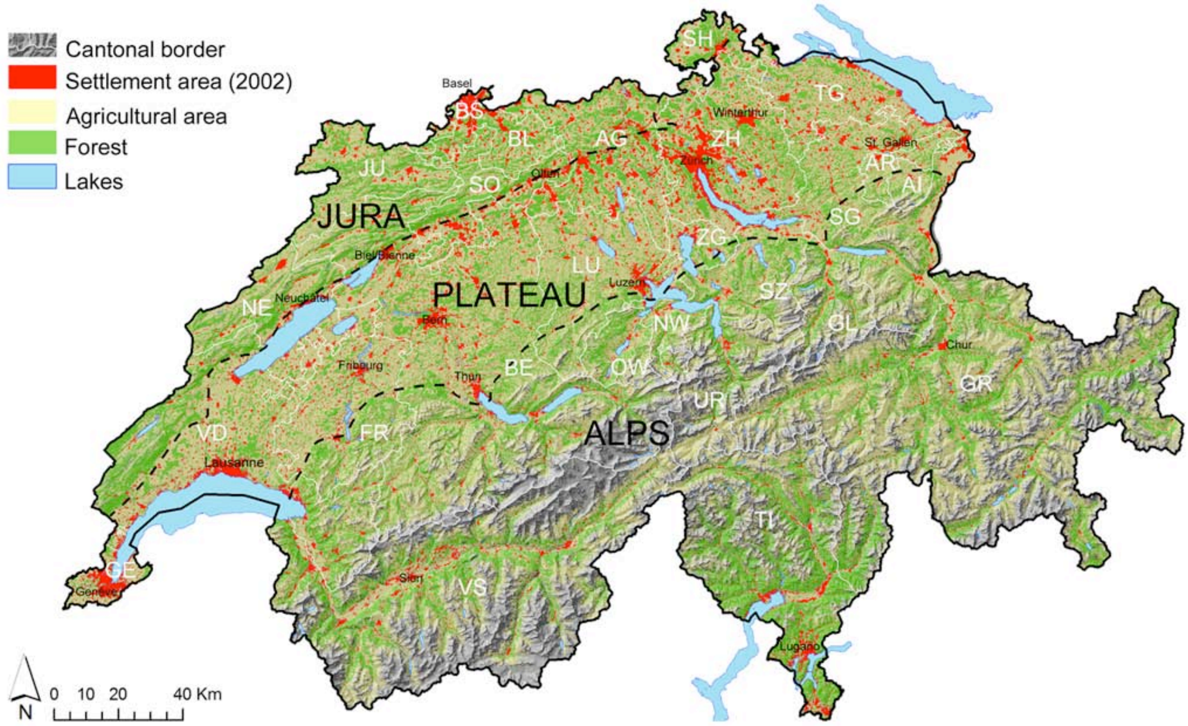

Fig. 1 Topographical characteristics of the settlement areas and their location in Switzerland (AG = Aargau; AR = Appenzell-Ausserrhoden; AI = Appenzell-Innerrhoden; BL = Basel-Landschaft; BS = Basel-Stadt; BE = Bern; FR = Fribourg; GE = Genève; GL = Glarus; GR = Graubünden; JU = Jura; LU = Luzern; NE = Neuchâtel; NW = Nidwalden; OW = Obwalden; SH = Schaffhausen; SZ = Schwyz; SO = Solothurn; SG = St. Gallen; TI = Ticino; TG = Thurgau; UR = Uri; VD = Waadt; VS = Wallis; ZG = Zug; ZH = Zürich)

In project A, we developed four alternative spatial scenarios of the built environment in Switzerland in 2030 and applied a suite of new metrics for quantifying the degree of urban sprawl developed by Jaeger et al. (2010b) to the scenarios. These scenarios point out causal relationships of how the future might be shaped based on today's situation and assumptions about the main future framework conditions (see below, Fig. 2). The study comprised a discursive approach to the development of qualitative scenarios and a modelling approach to show in a quantitative manner what Switzerland's spatial pattern may look like in the year 2030 under the four alternative scenario conditions (Perlik et al. 2008). The maps of the settlement distribution that are required as input data for the calculation of the metrics of urban sprawl were based on this settlement growth model.

Project B used the metrics to document the increasing degree of urban sprawl in Switzerland since 1935 and prepared nine scenarios for the future settlement development until 2020 and 2050 that were solely based on predictions of future population density and on certain assumptions about the spatial distribution of the new settlement areas (Jaeger et al. 2008). The results of the time series analysis and of two of these scenarios were used for comparison and a better understanding of the current situation and of the predicted developments in the four more complex scenarios from project A.

Four Alternative Scenarios: "Switzerland 2030"

Qualitative Scenarios

Scenarios of the built environment in Switzerland were developed in a workshop with national and international spatial-planning experts following the Global Business Network (GBN) matrix approach (Bishop et al. 2007). The participants of this workshop identified key driving forces of the settlement and infrastructure development: the interactivity of the Swiss norm and value system (including global influences) and the economic prosperity (of Switzerland and Europe). These two coincide with the driving forces called "territorial cohesion" and "competitiveness" that define the integrated scenarios developed by the European Spatial Planning Observation Network (ESPON) at the European level (ESPON 2006). Thus, the scenarios for Switzerland allow for a zoom-in from the European level down to the national level, displaying potential and spatially more differentiated developments. Both driving forces hold a large scope of possible developments. Their positive and negative extremes ("individualistic vs. cohesive" and "dynamic/risky vs. less dynamic/risk-avoiding") delineate four main scenarios (Fig. 2).

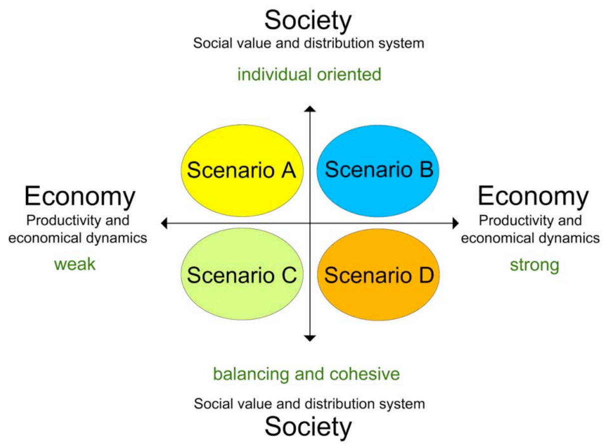

Fig. 2 The 4 scenarios that were analysed in this paper. The main two scenario dimensions "economy" and "society" delineate four quadrants defining four basic future framework conditions for Switzerland in the year 2030

Scenario A "Spatial Dispersion" combines a regulation regime that values individual property and vested rights very highly with an accumulation regime that ties back productivity. Cantons and communities strongly compete against each other. Scenario B "Metropolitan Expansion" combines a regulation regime that weighs individual property rights and high willingness to perform very highly with an accumulation regime of highest productivity, high dynamics, and global integration. The growth dynamic of the metropolitan regions Zurich, Geneva-Lausanne, and Basle continues and is not restricted. Scenario C "Urban and rural" combines a regulation regime of regional balance and cohesion with an accumulation regime whose productivity is tied back, e.g., due to economic recession. The metropolitan regions stop growing because of missing economic dynamics and reduced competition of regions. Scenario D "Spatial Equality" combines a regulation regime of regional balance and cohesion with an accumulation regime of high productivity, high dynamics, and global integration. The metropolitan regions are not growing further due to a reduced competition between regions.

Quantitative Model of Settlement Growth

The four perspectives gave quite good images of Switzerland in 2030, but they were still spatially diffuse (Fig. 3). Therefore, a spatially explicit settlement growth model was used to translate the assumptions and causal relationships of the four scenarios into relative figures expressing the spatial tendencies in the distribution of population and jobs. The model is based on GIS data of a detailed settlement mapping of the year 2002 (1:25,000; minimum mapping unit of 15 m x 15 m) from the Swiss ordnance survey mapping, the designated building zones, and the size of the population and the number of jobs in each municipality in the year 2002 and in the year 2030 according to scenarios provided by the Swiss Federal Statistical Office (BFS 2006) and Ecoplan (2005). Further, people's preferences regarding an increase or decrease of densification in metropolitan, sub- or peri-urban, and peripheral areas under the four scenarios were integrated in the form of an expert-based index. This index summarizes spatially explicit assumptions about constraints in spatial settlement dispersion according to social and structural densification in the existing built-up areas.

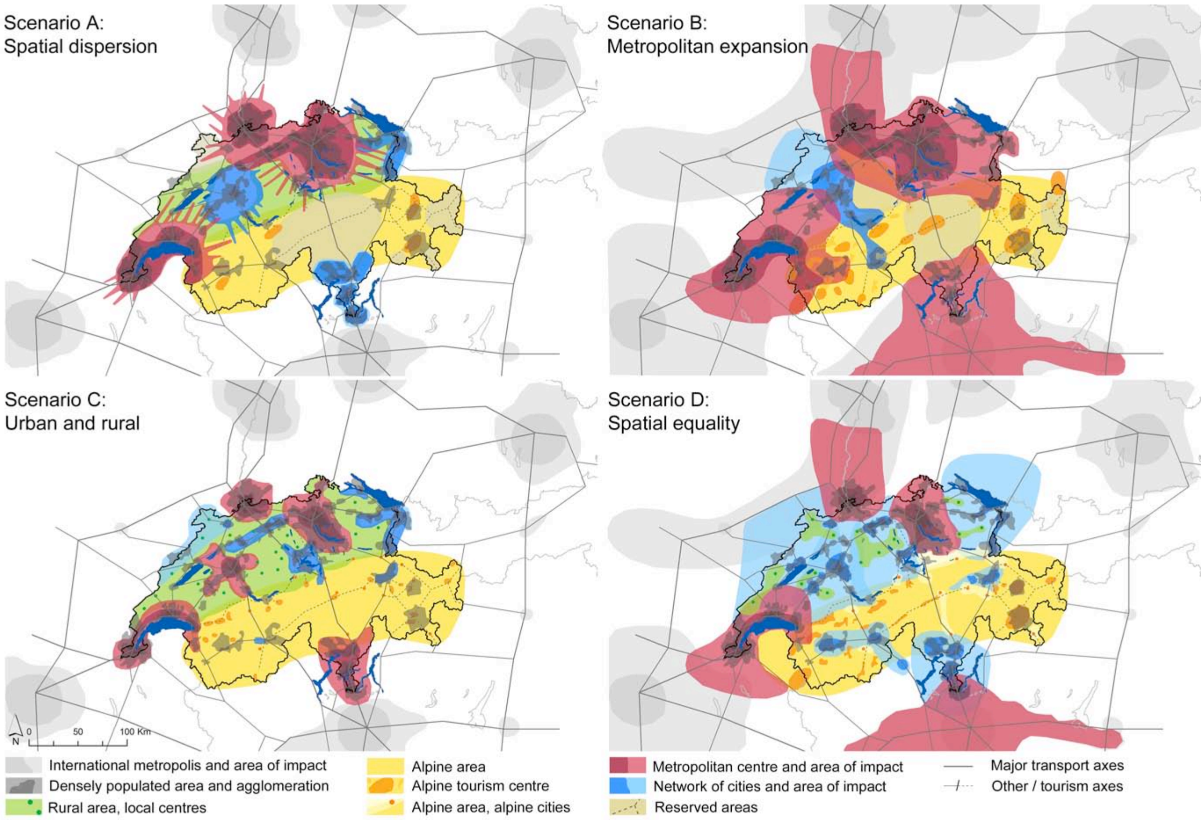

Fig. 3 The 4 scenarios in their different spatial characteristics. These visualizations of the respective spatial situation in Switzerland in the year 2030 are based on the elaborated scenario descriptions

The type of the model can be characterized as a combination of regional and typological spatial trends according to greater regions and municipality types. The modeling of the factor of gain (or loss) in population and jobs for each community within the timeframe of the scenarios was carried out in three steps: (1) defining tendencies in greater regions and in municipality types under the four scenarios in an expert workshop, (2) translating the tendencies into percentages of gain or loss in population and jobs, and (3) adjusting the percentages using the resulting spatially explicit map and the quantitative results from step 2. A "shift and share" approach (Steingrube 1998) was applied for the projection of the job's development until 2030 according to greater regions and municipality types.

Major advantages of this model are that it can integrate statistical data, spatially-explicit land-use data, and qualitative expert knowledge. However, it is a generalized urban growth model in so far as no principles on the shape of settlement development are taken into account. Thus, it is not possible to model an individual development pattern for each municipality according to its particular characteristics.

Whereas the predicted population increase is identical in all four scenarios (+ 11.7 %), the total amount of jobs differs: Scenario A: - 4.1 %; Scenario B: + 1.9 %; Scenario C: + 2.0 %; Scenario D: + 4.1 %. This was done for reasons of comparability of the four scenarios because in this way the structural effects of the distribution of jobs are reflected. This was a suitable approach for testing the results for their inner congruency. However, the modeling results are no prognosis but images depicting potential alternative spatial layouts of Switzerland in 2030 with quantitative means that allow for comparison between the scenarios.

Depending on the municipality type and according to the municipality's average value as of today, a certain amount of settlement area was assigned for every new person and job. Thus, the growth in settlement area according to the four scenarios was calculated for each municipality in Switzerland as shown in figure 4.

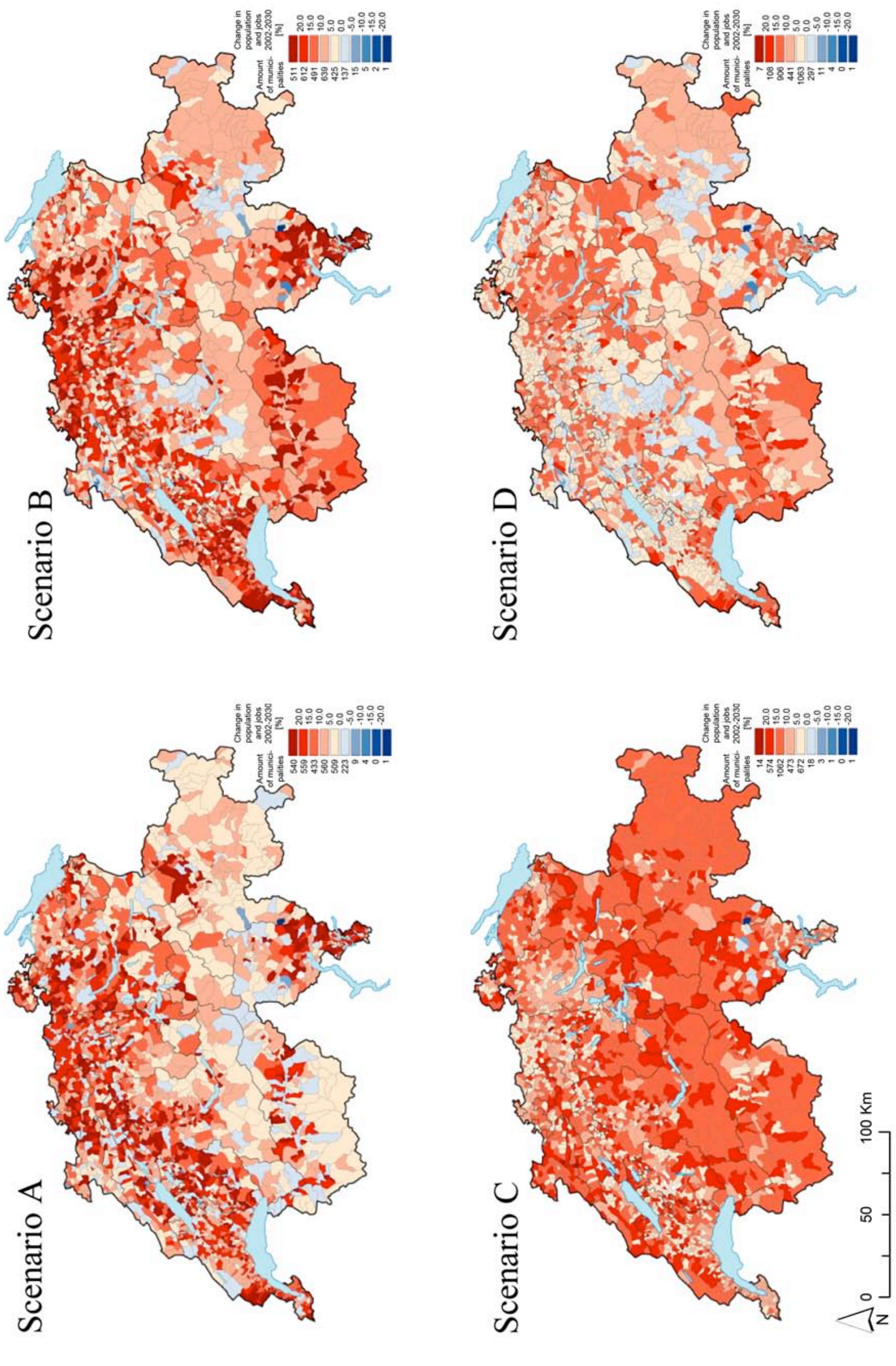

Fig. 4 Changes in the amount of population and jobs from 2002 to 2030 in percent under the four scenarios, calculated on the basis of the settlement growth model

Calculating Maps of the Future Settlement Distribution

A settlement distribution tool (see Section "Calculating Metrics of Urban Sprawl: Urban Dispersion, Total Sprawl, Urban Permeation, and Sprawl Per Capita") was applied to map the results of the settlement growth model. As an input for the program, the desired type of distribution (i.e., clumped or dispersed) and the excluded areas for distribution (e.g., not outside the designated building zones) have to be defined. According to the chosen parameters (Table 1) the tool distributes new settlement cells, with a defined size of 15m x 15m. The result were maps of the respective future situation in form of ASCII grid data files that can be transformed to raster files and displayed in Geographical Information System (GIS) programs, e.g., ArcMap (ESRI). The parameters were chosen by expert judgement in order to be as consistent as possible in the scenarios with regard to their initial qualitative description, and thus they differ between the scenarios.

Table 1 Overview on the parameters chosen for the distribution of new settlement area cells under the four scenarios. Two runs of the ettlement distribution tool were required to distribute the new settlement cells for each of the scenarios A, B, and D. In the scenarios A and, 30% of the new settlement development were outside the designated building zones. Therefore, in the first run, 70% of the new settlement cells were distributed exclusively inside the building zones (but not in the already built-up area). In the second run of the tool, a decision was made about where the new settlement areas would not be allowed to be distributed, and the second option for the excluded areas was chosen for this

Characteristics	Parameters	Choice made under the scenarios			
		A	B	C	D
Distribution of settlement cells:	All clustered			x	x
	All dispersed	x	x		
Percentage of new settlement cells:	70% of new settlement cells	x (1st run)	x (1st run)		
	30% of new settlement cells	x (2nd run)	x (2nd run)		
Excluded areas for the distribution of new settlement cells:	1. All areas outside the building zones and already built-up area	x (1st run)	x (1st run)	x	x (1st run)
	2. Water bodies, forests, mountainous areas > 2100 m elevation, steep areas with slope >45°, unproductive areas	x (2nd run)	x (2nd run)		x (2nd run)

The principle of the separation of building zones and non-building zones is a central aspect of spatial planning in Switzerland. Basically, settlement development is not allowed outside the designated building zones. However, in the agriculture zone, buildings related to agriculture management or infrastructure services can be allowed by the canton (Gennaio et al. 2009).

In the settlement growth model, we kept with the regulation of the zones, but the principle was applied with differing strengths in the scenarios. This was necessary as prognoses showed that the current designated building zones would not suffice for accommodating all new settlement area in some regions. Assumptions had to be made regarding the extent to which the projected additional settlement areas could be located by either densification or spatial dispersion, thereby expressing norms and values accepted by the society in the different scenarios. In cases of high building development pressure, the allowance of building in the agriculture zone is higher in scenarios A and B (which are characterized by a society oriented towards the individual) than in scenarios C and D (where the society is more oriented towards balancing and cohesion). Consequently, scenarios A and B show a rather dispersed settlement development, whereas in scenarios C and D the settlement development results in rather compact patterns (Fig. 5). In scenarios A and B, the individualistically oriented society would prefer high levels of privacy, resulting in settlement patterns characterized by one-family homes or spacious flats, and thus a relatively high ratio of new settlement area per person. The developments of scenarios C and D, that are characterized by high solidarity, lead to less growth in the peri-urban areas and a densification of the built-up areas. This is quite well reflected in the maps, with the new settlement areas in scenario D showing even more areas filled up next to existing patches of settlement, as presented in figure 5 in the lower left image.

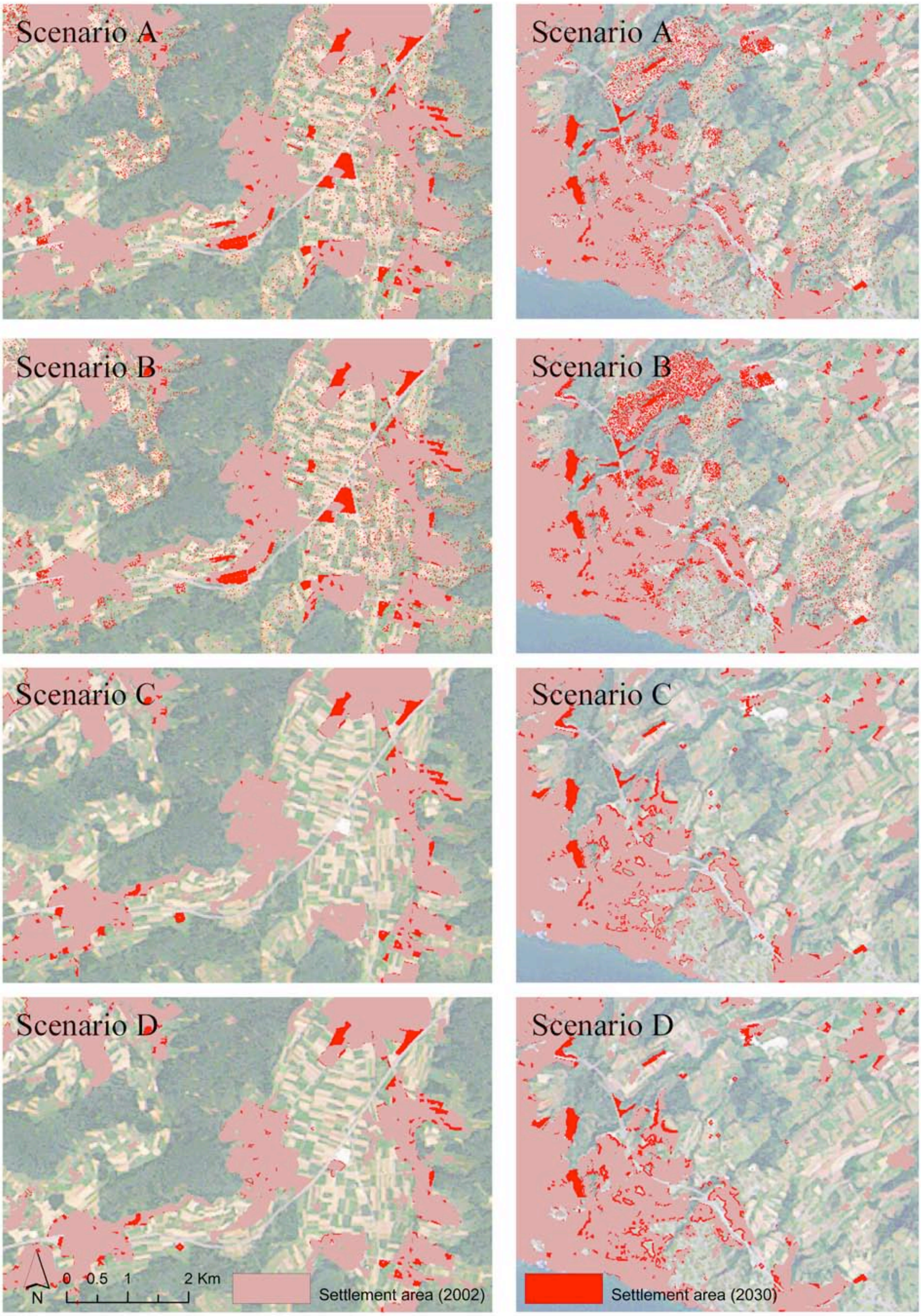

Fig. 5 Examples of settlement area distribution maps for the four scenarios in 2030 (red) with an overlay of the current situation in 2002 (rose). Left column: from Canton Aargau (settlement type 6); right column: from Canton Vaud (settlement type 1)

Methods

The ASCII grid data files with the spatial distribution of settlement areas based on the quantitative model for the four scenarios, as represented in the maps in figure 5, were used as input data for calculating the metrics of urban sprawl. The metrics are based on a definition of "urban sprawl" that describes it as a phenomenon that can be perceived visually. A landscape is the more affected by urban sprawl the more it is permeated by settlements. The "degree of urban sprawl" describes the proportion of built-up area and its dispersion. The more area is built up and the further the dispersion of settlements, the higher is urban sprawl (Jaeger and Bertiller 2006; Jaeger et al. 2007b; Jaeger et al. 2010a). All kinds of settlements were taken into account for calculating the degree of urban sprawl, regardless of their uses. Areas of transportation infrastructure outside of settlement areas were not included. The results were edited in tables and diagrams providing the values for the Swiss cantons and allowing for a comparison of the scenarios.

Calculating Metrics of Urban Sprawl: Urban Dispersion, Total Sprawl, Urban Permeation, and Sprawl Per Capita

Numerous measures of urban sprawl have been proposed in the literature (e.g., Ritsema van Eck and Koomen 2007; Schneider and Woodcock 2008; Torrens 2008; Tsai 2005). However, many existing metrics are limited in their suitability as measures of urban sprawl or difficult to interpret consistently, which can cause misunderstanding and misuse of these landscape metrics (Schneider and Woodcock 2008; Jaeger et al. 2010b). In order to systematically evaluate the consistency and reliability of metrics of urban sprawl, Jaeger et al. (2010a) defined 13 suitability criteria.

With these issues in mind, we calculated the degree of settlement dispersion and the degree of urban permeation of the landscapes using the URSMEC (URban Sprawl MEtrics Calculation) tool (Jaeger et al. 2008). The metrics characterize urban sprawl from a geometric perspective. Their calculation is based on all distances between any two points in the settlement areas within a chosen cut-off radius called "horizon of perception". We used these metrics because (1) they focus on the core phenomenon of urban sprawl, the degree of which increases with both increasing amount of urban area and increasing dispersion (Jaeger et al. 2010a), and (2) they meet the 13 suitability criteria developed by Jaeger at al. (2010a) ensuring that the behaviour of the landscape metrics can be evaluated and understood in a systematic way.

The metric "urban permeation" (***UP***) measures the degree to which a landscape is permeated by settlement areas, i.e., not only the total settlement area but including its degree of dispersion. The value of ***UP*** can be compared among landscapes of differing total size, and is measured in "urban permeation units" per km^2 of landscape area (UPU / km^2).

The second metric, urban dispersion (***DIS***) (in "urban permeation units" per m^2 of settlement area; UPU / m^2) is the average value of the effort function for two randomly chosen points within the settlement areas (where the effort function describes the "effort" required to connect two points as a function of their distance from each other). For a given total amount of settlement area, this is largest when the buildings are distributed evenly (e.g., in a gridded pattern) over the entire landscape, and lowest when the buildings are arranged close to each other in a circle. A random distribution of settlement areas would result in a value for ***DIS*** of 78.96 urban permeation units per m^2 of settlement area for a cut-off radius of 5 km.

TS (**t**otal **s**prawl; in "urban permeation units") is the average effort function summed up over all pairs of points when starting at one randomly chosen starting point within the settlement areas. Therefore, the relationship between ***TS*** and ***DIS*** is ***TS*** = ***DIS*** * size of settlement area (Jaeger et al. 2010b).

The metrics are related through (Jaeger et al. 2010b):

$$TS = DIS \ast \text{settlement area}$$

and

$$UP = DIS \ast \text{settlement area / size of the landscape}$$

$$= TS \text{ / size of the landscape}$$

and, consequently,

$$DIS = TS \text{ / settlement area} = UP \text{ / settlement area} \ast \text{size of landscape.}$$

Sprawl per capita (***SPC***) expresses the total sprawl (***TS***) in relation to the population:

$$SPC = TS \text{ / capita} = DIS \ast \text{settlement area / capita.}$$

The cut-off radius defines the scale at which settlement development is assumed to be experienced by a viewer, for example 2 km, 5 km or 10 km. The resulting values of the metrics are larger when a larger cut-off radius is chosen. It is important to be aware that a spatial point pattern can be clumped on one scale and dispersed on another scale at the same time (for an example, see Fortin and Dale 2005: 34). Therefore, the results will depend on the cut-off radius chosen. In this study, a cut-off radius of 5 km was chosen because of the settlement structure in Switzerland, exhibiting typical distances between the municipalities of usually more than 2 km. A 2 km cut-off radius would not show the effect of villages building a "chain" of settlement areas in the landscape as clearly. Using 10 km would not reveal relevant differences between the comparatively small Swiss cantons because effects of smaller distinctive structures within this larger radius would be dominated by patterns on the larger scale.

The resulting files from the URSMEC tool were then used for calculation of the values for the investigated units (reporting units), i.e., Swiss cantons. The values of the metrics were calculated in a spreadsheet program (Microsoft Excel), for the various reporting units from the resulting ASCII file. In addition, the value of "total sprawl" (***TS***) per capita was calculated to express the differences in the cantons' total sprawl in relation to the human population densities (***SPC***). The results were then visualised in maps and diagrams (see below) and compared among the scenarios, with historical situations, and with two framework scenarios of settlement development that were based on extreme scenarios of population development until 2030, i.e., large growth, and low increase followed by decline, respectively.

Interpreting the Metrics with the Use of Qualitative Scenario Information

The interpretation of the quantitative results followed a step-wise approach, by first describing the graphs for the different metrics and deducing explanations for the differences in the values of the cantons from the qualitative scenarios and the quantitative settlement growth model. Secondly, the results were discussed with regard to two main aspects. The first aspect dealt with the dynamics of change in the settlement development. A comparison of the scenarios and of different regions was made to find out where the most substantial changes are under the different scenarios. Table 2 gives an overview of relevant characteristics of the Swiss cantons expressing their structural diversity that were taken into account for the interpretation of the results. Additionally, the metrics were related to six basic *types* of settlements (Fig. 6) to which the cantons were assigned based on their predominant settlement forms (Grosjean 1978). (Note the distinction between types and forms of settlement, with "types" referring to a larger scale than "forms"; Table 2). Thus, more general relationships could be revealed between the metrics and landscape structures, types of settlements, and cultural characteristics of the population. In addition, it was considered on this basis if the metrics can give useful indications of a region's inclination to urban sprawl.

Table 2 Characterisation of the 26 Swiss cantons with regard to their diversity in landscape structures, types of settlements, size of the area, and percentage of urban population. Note that a settlement type usually includes more than one settlement form

Settlement type	Canton	Abbr.	Landscape region	Predominant settlement forms	Canton's area (ha)	Settlement area (ha)	Urban population (% in year 2000)
1	Jura	JU	Jura	compact villages	83, 855	3, 736	29.9
	Neuchâtel	NE	Jura – Plateau	chains of villages; compact villages. farmyards; (city)	80, 293	4, 873	74.7
	Vaud	VD	Jura – Plateau – Alps	compact villages; city; compact villages in the valley – zone of scattered settlements – alpine farms	321, 203	21, 975	75.4
	Schaffhausen	SH	Jura – Plateau	compact villages; (city)	29, 842	2, 851	74.0
2	Ticino	TI	Alps – plain of the River Po	compact villages in the valley – alpine farms; city	281, 220	12, 759	86.2
3	Appenzell Ausserrhoden	AR	Alps	compact villages in the valley – zone of scattered settlements –alpine farms	24, 286	1, 669	52.9
	Appenzell Innerrhoden	AI	Alps		17, 252	429	0.0
	Schwyz	SZ	Plateau – Alps		90, 799	3, 679	79.4
	Glarus	GL	Alps		68, 530	1, 550	0.0
	Nidwalden	NW	Alps		27, 590	1, 154	87.1
	Obwalden	OW	Alps		49, 059	1, 257	0.0
	Uri	UR	Alps	compact villages in the valley. farmyards	107, 657	1, 334	0.0
4	Graubünden	GR	Alps	compact villages in the valley – zone of scattered settlements – alpine farms	710, 544	9, 109	49.6
	Wallis	VS	Alps	compact villages in the valley –alpine farms	522, 425	12, 929	56.7
5	Thurgau	TG	Plateau	compact villages. hamlets. farmyards; (city)	99, 102	10, 207	49.1
	St. Gallen	SG	Plateau – Alps	compact villages. hamlets. farmyards; city	202, 554	15, 066	66.6
	Zug	ZG	Plateau – Alps		23, 872	2, 177	95.5
	Luzern	LU	Plateau – Alps		149, 347	10, 954	51.7
	Bern	BE	Jura – Plateau – Alps		595, 944	31, 618	62.1
	Fribourg	FR	Plateau – Alps	compact villages. hamlets. farmyards; city; compact villages in the valley – zone of scattered settlements – alpine farms	167, 070	9, 895	56.1
6	Basel-Stadt	BS	Upper Rhine valley	city	3, 700	2, 694	100.0
	Genève	GE	Plateau	city; compact villages	28, 248	7, 484	99.2
	Zürich	ZH	Plateau	compact villages. hamlets. farmyards; city	172, 889	31, 998	95.0
	Aargau	AG	Plateau – Jura	compact villages; city	140, 366	21, 381	65.0
	Basel-Landschaft	BL	Jura – Upper Rhine valley		51, 754	8, 438	91.8
	Solothurn	SO	Jura – Plateau		79, 051	10, 511	77.4

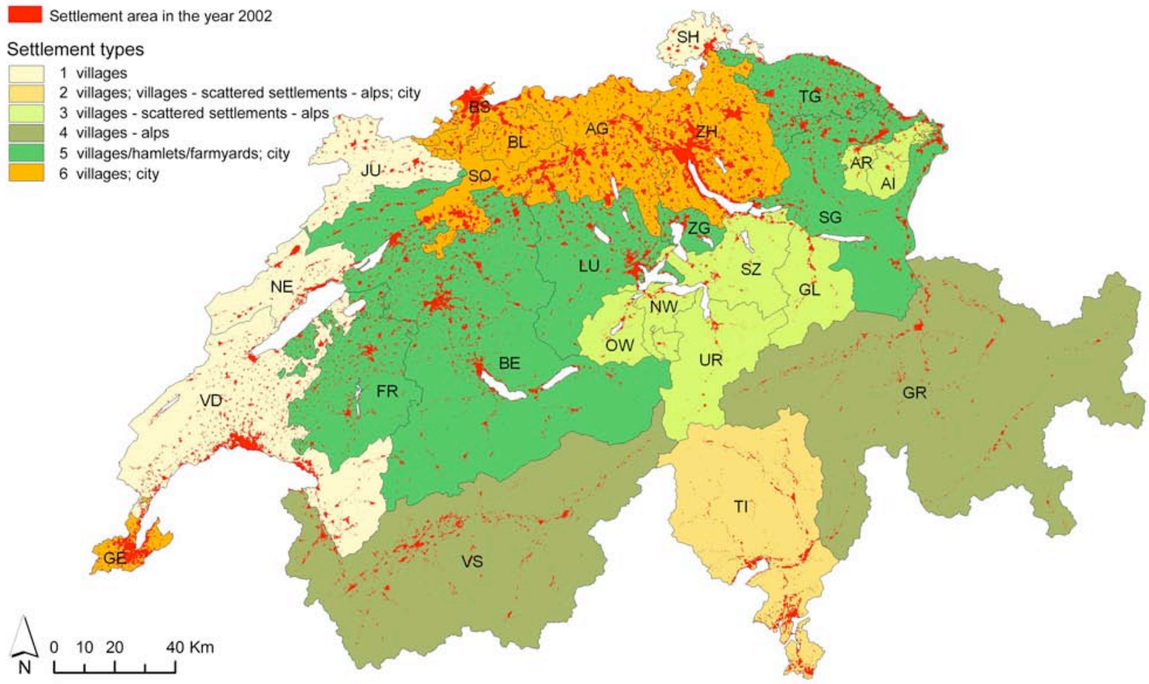

Fig. 6 Classification of the Swiss cantons with regard to the predominant settlement types (as outlined in Table 2)

Results

The following sections present the results with regard to the four metrics as shown in figures 7, 8, and 9. All values calculated for Switzerland and the 26 cantons are given in Tables 3, 4, 5 and 6.

Differences in the Increase of Urban Permeation Between the Scenarios

Urban permeation (***UP***) calculated for Switzerland in total (Fig. 7) exhibits a clear difference between the two scenarios with an individualistic society (scenarios A and B), with the urban permeation in scenario A "Spatial Dispersion" being slightly higher in most cantons.

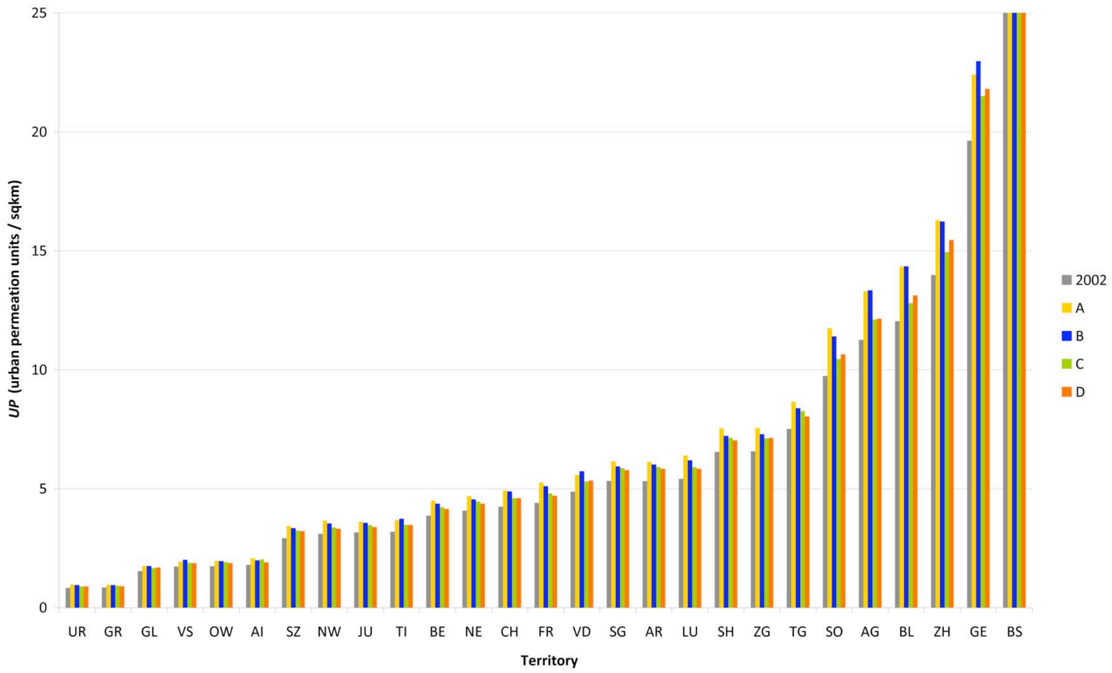

Fig. 7 Urban permeation (UP) of the 26 cantons in Switzerland in the year 2002 and in the year 2030 for the four scenarios (A, B, C, D) for a cut-off radius of 5 km. Shown are the values for Switzerland in total (CH) and the 26 cantons. Values for Basel-Stadt (BS): 50.5 UPU / km^2 (2002), 55.8 UPU / km^2 (A), 56.7 UPU / km^2 (B), 54.5 UPU / km^2 (C), 56.5 UPU / km^2 (D)

The values of urban permeation of the scenarios C and D, describing a society that aims at balancing and cohesion, are often similar (Table 3). Further, the difference between scenarios A and C (both in a stagnating economy) is of the same order of magnitude as the difference between scenario C "Urban and Rural" and the current situation (i.e., value for the year 2002). This means that the difference between the situation today and both scenarios is large. The increase in ***UP*** between today and the individualistic scenarios A and B is twice as large as between today and the social scenarios C and D.

Table 3 Values of ***UP*** for a cut-off radius of 5 km. The values are given for Switzerland in total and all cantons for four time steps from 1935 to 2002, for the year 2030 under the four scenarios (A, B, C, D), and for the years 2020 and 2050 under the two framework scenarios low / high = low- or high-population-development scenario)

Urban Permeation (***UP***) in urban permeation units / km^2

Territory	1935	1960	1980	2002	A	B	C	D	2020 (high)	2050 (high)	2020 (low)	2050 (low)
CH	2.06	2.75	3.72	4.24	4.93	4.88	4.60	4.60	5.02	5.80	4.42	4.42
ZH	6.26	9.03	12.27	13.98	16.29	16.23	14.94	15.45	16.16	18.37	14.49	14.49
BE	2.26	2.87	3.56	3.87	4.50	4.37	4.22	4.15	4.55	5.22	4.03	4.03
LU	2.41	3.28	4.77	5.41	6.40	6.19	5.91	5.83	6.13	6.84	5.58	5.58
UR	0.49	0.64	0.75	0.83	0.97	0.95	0.90	0.89	1.15	1.46	0.90	0.90
SZ	1.37	1.92	2.57	2.92	3.43	3.34	3.24	3.21	3.64	4.36	3.09	3.09
OW	0.88	1.01	1.42	1.74	1.97	1.96	1.92	1.87	2.25	2.75	1.85	1.85
NW	1.26	1.51	2.50	3.10	3.65	3.54	3.37	3.32	4.08	5.06	3.32	3.32
GL	0.83	1.17	1.38	1.54	1.76	1.75	1.67	1.69	2.06	2.57	1.64	1.64
ZG	2.97	3.88	5.92	6.57	7.54	7.29	7.12	7.13	8.03	9.47	6.90	6.90
FR	2.37	2.74	3.65	4.40	5.26	5.11	4.79	4.70	5.12	5.85	4.57	4.57
SO	4.04	6.08	8.36	9.74	11.75	11.40	10.45	10.65	11.09	12.45	10.05	10.05
BS	35.09	46.94	52.12	50.48	55.77	56.66	54.51	56.50	56.07	57.22	53.86	53.86
BL	4.95	7.01	10.37	12.04	14.34	14.34	12.80	13.13	13.63	15.20	12.42	12.42
SH	2.87	4.17	5.67	6.55	7.54	7.22	7.14	7.03	7.72	8.90	6.82	6.82
AR	3.57	4.62	5.01	5.32	6.13	6.02	5.92	5.83	6.46	7.61	5.58	5.58
AI	1.07	1.33	1.68	1.79	2.07	1.99	2.03	1.90	2.70	3.61	2.00	2.00
SG	2.81	3.75	4.65	5.33	6.15	5.94	5.87	5.78	6.23	7.14	5.53	5.53
GR	0.51	0.56	0.77	0.85	0.97	0.95	0.92	0.90	1.18	1.51	0.92	0.92
AG	5.13	7.13	9.93	11.26	13.30	13.34	12.11	12.14	12.57	13.90	11.56	11.56
TG	4.66	5.80	6.51	7.51	8.65	8.38	8.27	8.04	8.12	8.73	7.66	7.66
TI	1.30	1.87	2.67	3.19	3.68	3.74	3.48	3.47	4.01	4.80	3.38	3.38
VD	2.16	2.73	4.20	4.88	5.58	5.73	5.31	5.35	5.78	6.69	5.08	5.08
VS	0.62	0.82	1.39	1.72	1.94	2.01	1.88	1.87	2.33	2.94	1.86	1.86
NE	2.15	2.76	3.66	4.08	4.69	4.55	4.46	4.37	5.12	6.14	4.32	4.32
GE	8.31	12.87	17.91	19.62	22.40	22.97	21.50	21.80	22.45	25.20	20.31	20.31
JU	1.82	2.17	2.78	3.16	3.61	3.56	3.47	3.39	3.69	4.23	3.29	3.29

Table 4 Values of DIS for a cut-off radius of 5 km. The values are given for Switzerland in total and all cantons for four time steps from 1935 to 2002, for the year 2030 under the four scenarios (A, B, C, D), and for the years 2020 and 2050 under the two framework scenarios (low / high = low- or high-population-development scenario)

Dispersion (*DIS*) in urban permeation units / m² of settlement area												
Territory	1935	1960	1980	2002	A	B	C	D	2020 (high)	2050 (high)	2020 (low)	2050 (low)
CH	73.34	73.37	73.82	73.85	74.44	74.40	73.90	73.94	74.93	75.54	74.03	74.03
ZH	75.74	76.26	76.81	76.92	77.25	77.26	76.99	77.07	77.39	77.68	77.01	77.01
BE	73.68	73.70	73.99	73.99	74.65	74.51	74.03	74.05	75.09	75.74	74.20	74.20
LU	74.87	75.16	75.12	74.97	75.61	75.43	75.01	75.02	75.81	76.34	75.18	75.18
UR	67.85	66.77	67.66	67.64	69.04	68.86	67.82	67.79	71.59	73.51	68.39	68.39
SZ	71.06	71.48	72.15	71.98	72.83	72.71	72.02	72.04	74.11	75.28	72.53	72.53
OW	68.94	68.48	67.72	67.84	68.93	68.93	67.90	67.91	71.29	73.23	68.61	68.61
NW	73.88	74.71	74.38	73.73	74.38	74.31	73.71	73.76	75.42	76.21	74.00	74.00
GL	66.88	67.17	67.75	68.04	68.99	68.94	68.14	68.21	71.73	73.59	68.46	68.46
ZG	71.82	72.06	72.96	72.88	73.35	73.33	73.00	72.99	74.43	75.30	73.15	73.15
FR	75.73	75.41	75.04	75.11	75.66	75.58	75.11	75.12	75.99	76.54	75.27	75.27
SO	74.58	74.69	75.20	75.16	75.80	75.73	75.22	75.25	75.86	76.33	75.27	75.27
BS	70.99	73.00	74.10	74.42	74.62	74.57	74.46	74.57	74.64	74.78	74.47	74.47
BL	75.07	75.26	75.70	75.77	76.25	76.27	75.78	75.89	76.28	76.59	75.86	75.86
SH	67.70	68.46	69.91	70.35	71.43	71.19	70.64	70.75	71.97	73.04	70.65	70.65
AR	76.25	76.62	77.34	77.62	77.90	77.74	77.51	77.56	78.09	78.29	77.68	77.68
AI	76.54	74.25	73.32	72.77	73.17	72.88	72.77	72.82	75.17	76.07	73.13	73.13
SG	72.82	72.54	72.83	72.85	73.58	73.48	72.95	72.93	74.09	74.85	73.09	73.09
GR	68.11	66.91	66.93	66.88	67.69	67.56	66.92	66.96	70.45	72.09	67.56	67.56
AG	75.30	75.32	75.73	75.75	76.25	76.26	75.81	75.84	76.22	76.57	75.84	75.84
TG	75.06	74.41	74.24	74.16	74.68	74.57	74.26	74.11	74.54	74.84	74.23	74.23
TI	71.46	71.10	72.09	72.19	72.75	72.83	72.28	72.32	73.95	74.81	72.49	72.49
VD	72.30	72.13	73.28	73.35	73.87	73.93	73.37	73.40	74.48	75.14	73.53	73.53
VS	70.99	69.90	71.05	71.17	71.83	71.94	71.28	71.24	73.35	74.17	71.47	71.47
NE	67.99	67.51	68.24	68.47	69.36	69.19	68.67	68.62	71.09	72.51	69.06	69.06
GE	74.12	75.06	75.77	75.87	75.93	75.98	75.96	75.96	76.16	76.31	75.93	75.93
JU	72.21	71.98	72.04	71.74	72.38	72.29	71.73	71.71	73.09	74.00	72.01	72.01

Table 5 Values of settlement density. The values are given for Switzerland in total and all cantons for four time steps from 1935 to 2002, for the year 2030 under the four scenarios (A, B, C, D), and for the years 2020 and 2050 under the two framework scenarios (low / high = low- or high-population-development scenario)

Settlement Density (settlement area / territory's area) in %												
Territory	1935	1960	1980	2002	A	B	C	D	2020 (high)	2050 (high)	2020 (low)	2050 (low)
CH	2.8	3.7	5.0	5.9	6.62	6.57	6.23	6.23	6.82	7.80	6.08	6.08
ZH	8.3	11.8	16.0	18.5	21.08	21.00	19.40	20.05	21.22	23.98	19.15	19.15
BE	3.1	3.9	4.8	5.3	6.03	5.87	5.70	5.60	6.13	6.97	5.50	5.50
LU	3.2	4.4	6.4	7.3	8.46	8.21	7.88	7.77	8.19	9.07	7.54	7.54
UR	0.7	1.0	1.1	1.2	1.41	1.38	1.32	1.32	1.62	2.00	1.33	1.33
SZ	1.9	2.7	3.6	4.1	4.72	4.59	4.50	4.46	4.91	5.79	4.25	4.25
OW	1.3	1.5	2.1	2.6	2.86	2.84	2.82	2.75	3.15	3.75	2.70	2.70
NW	1.7	2.0	3.4	4.2	4.91	4.76	4.57	4.50	5.39	6.62	4.47	4.47
GL	1.2	1.7	2.0	2.3	2.55	2.54	2.45	2.47	2.88	3.50	2.41	2.41
ZG	4.1	5.4	8.1	9.1	10.28	9.95	9.75	9.77	10.89	12.69	9.54	9.54
FR	3.1	3.6	4.9	5.9	6.95	6.76	6.38	6.26	6.80	7.70	6.13	6.13
SO	5.4	8.1	11.1	13.3	15.50	15.05	13.89	14.15	14.96	16.66	13.69	13.69
BS	49.4	64.3	70.3	72.8	74.74	75.98	73.21	75.77	77.20	81.70	73.84	73.84
BL	6.6	9.3	13.7	16.3	18.81	18.80	16.89	17.30	18.29	20.31	16.77	16.77
SH	4.2	6.1	8.1	9.6	10.55	10.14	10.11	9.94	10.98	12.44	9.89	9.89
AR	4.7	6.0	6.5	6.9	7.86	7.74	7.63	7.52	8.28	9.73	7.20	7.20
AI	1.4	1.8	2.3	2.5	2.83	2.73	2.79	2.61	3.61	4.76	2.75	2.75
SG	3.9	5.2	6.4	7.4	8.36	8.08	8.04	7.92	8.54	9.67	7.70	7.70
GR	0.7	0.8	1.1	1.3	1.43	1.41	1.37	1.34	1.69	2.11	1.38	1.38
AG	6.8	9.5	13.1	15.2	17.44	17.50	15.98	16.01	16.87	18.55	15.62	15.62
TG	6.2	7.8	8.8	10.3	11.59	11.24	11.13	10.85	11.06	11.83	10.48	10.48
TI	1.8	2.6	3.7	4.5	5.06	5.13	4.82	4.80	5.54	6.57	4.78	4.78
VD	3.0	3.8	5.7	6.8	7.55	7.75	7.23	7.28	7.97	9.12	7.11	7.11
VS	0.9	1.2	2.0	2.5	2.69	2.79	2.64	2.63	3.24	4.02	2.66	2.66
NE	3.2	4.1	5.4	6.1	6.77	6.57	6.50	6.37	7.32	8.60	6.37	6.37
GE	11.2	17.1	23.6	26.5	29.50	30.23	28.30	28.70	30.11	33.78	27.36	27.36
JU	2.5	3.0	3.9	4.5	4.99	4.93	4.83	4.73	5.10	5.76	4.61	4.61

Table 6 Values of SPC for a cut-off radius of 5 km. The values are given for Switzerland in total and all cantons for four time steps from 1935 to 2002 and for the year 2030 under the four scenarios (A, B, C, D)

Sprawl per Capita (*SPC*) in urban permeation units per person								
Territory	1935	1960	1980	2002	A	B	C	D
CH	20,948.50	17,806.29	21,059.95	24,035.23	24,979.13	24,764.96	23,339.07	23,338.60
ZH	17,532.89	16,393.34	18,896.80	19,365.16	20,160.88	19,992.35	18,905.22	18,914.68
BE	21,582.92	21,028.96	23,606.55	24,099.90	25,032.86	24,850.75	23,223.87	23,455.14
LU	19,017.56	19,354.21	24,073.39	23,067.28	23,779.99	23,567.56	22,303.07	22,268.52
UR	22,793.79	21,606.98	23,733.47	25,722.54	26,680.18	25,971.71	24,514.77	25,156.20
SZ	19,886.89	22,389.82	23,962.73	20,595.69	21,071.22	21,012.76	20,330.55	19,928.15
OW	22,251.24	21,518.99	26,954.24	26,310.64	27,727.33	26,872.33	24,904.64	25,180.98
NW	23,122.47	18,768.46	24,111.41	22,976.71	22,918.27	23,000.60	22,605.61	21,818.50
GL	15,881.83	19,996.35	25,699.81	27,546.96	28,946.01	28,763.55	25,908.78	26,852.86
ZG	20,636.28	17,618.41	18,592.71	15,679.07	15,659.79	15,944.94	15,445.69	14,936.45
FR	27,655.38	28,770.98	32,883.14	30,423.49	31,373.86	31,346.66	29,607.25	29,625.26
SO	22,145.33	23,939.41	30,301.68	31,507.88	32,580.99	32,894.89	30,277.01	30,950.37
BS	8,374.95	7,700.14	9,458.12	9,931.14	11,061.67	10,507.90	9,593.51	10,167.95
BL	25,129.33	22,575.64	22,987.50	24,028.66	24,548.79	25,149.49	23,024.20	23,371.43
SH	16,709.26	18,840.58	24,392.95	26,622.88	27,856.29	27,315.49	25,992.99	26,031.05
AR	17,685.08	22,922.54	25,553.48	24,135.48	25,102.39	24,783.18	23,608.24	23,821.97
AI	13,211.14	17,776.62	22,592.49	21,162.74	21,777.48	21,206.61	20,134.65	20,800.65
SG	19,885.44	22,385.67	24,046.95	23,823.26	24,717.27	24,623.69	23,398.31	23,197.34
GR	28,519.65	26,859.07	33,188.80	32,183.67	33,019.02	32,942.23	30,389.10	30,962.34
AG	27,757.23	27,726.04	30,750.20	28,857.99	29,852.71	29,864.43	27,940.56	28,206.01
TG	33,963.24	34,542.95	35,085.90	32,532.03	33,587.72	33,151.09	31,469.69	31,626.31
TI	22,931.71	26,823.72	28,218.19	29,240.19	29,729.69	29,754.47	28,433.46	28,357.54
VD	20,930.27	20,404.13	25,500.44	24,442.85	25,538.91	25,077.52	23,873.35	23,651.76
VS	23,699.78	24,203.73	33,174.45	33,043.24	34,648.70	33,479.86	31,661.44	31,688.12
NE	13,886.26	15,029.72	18,564.55	19,498.82	20,523.65	20,135.08	19,095.37	19,027.27
GE	13,693.59	14,017.26	14,485.12	13,391.50	14,184.38	14,027.36	13,371.27	13,080.43
JU	27,363.65	28,627.06	35,918.08	38,882.61	39,735.53	39,284.72	36,798.07	37,807.48

Differences in Urban Permeation Between the Scenarios and Today

The cantons can be ranked by their differences in urban permeation between each scenario and today ($\boldsymbol{UP}_{\text{scenario}}$ - $\boldsymbol{UP}_{\text{today}}$). The results were related to the settlement types (see Fig. 6) and characteristic attributes of the respective cantons (Table 2). The overall pattern in the differences in ***UP*** is almost the same in all scenarios: cantons with a very high percentage of urban population in the year 2002 (Table 2) and with urbanised areas comprising compact villages and cities (settlement type 6) show a disproportionately high growth in urban permeation compared to today (e.g., BS, GE, ZH, BL, AG, SO). These are the metropolitan centres and agglomerations. Lower growth ratios in ***UP*** than the Swiss (CH) average value are found in cantons that are mainly characterized by tourism, agriculture or their location in the mountainous area (e.g., UR, OW, GL, NW, SZ, GR, VS). Most of them predominantly show settlement forms with compact villages in the valleys and a zone of scattered settlements followed by a zone of only periodically inhabited individual alpine farms (Table 2), and a total amount of settlement area that is far below the Swiss average (settlement type 3).

Differences Between the Scenarios

The general pattern on the national level in that scenarios A and B differ always from scenarios C and D, is also true for all cantons, but the difference is not always very strong. Therefore, we calculated the differences in the increase in urban permeation and in population increase between scenario A "Spatial Dispersion" and scenario C "Urban and Rural" as a percentage (Table 7). Cantons that are at least partly situated in the Alps or in the Jura mountains (AI, VS, AR, OW, SZ, SG, JU, NE, VD) are in the group with rather low differences in the increase of ***UP*** (16%-39%), and they belong mainly to settlement type 1 (compact villages) or 3 (scattered settlements). The highest differences between scenarios A and C in the increase of ***UP*** (58%-67%) were observed for the cantons of settlement type 6, which are situated in the metropolitan regions of northern Switzerland (SO, AG, BL, ZH). In contrast, the two remaining cantons of settlement type 6 (BS and GE) show moderate differences

(24% and 32%). The differences in the increase in population in all cantons of settlement type 6 (aside from canton BS) are comparatively moderate (21%-34%).

Table 7 Relative difference (%) in the increase of urban permeation (***UP***) and in the increase in population from 2002 to 2030 between the scenarios A and C. Shown are the values for Switzerland in total (CH) and the 26 cantons. All values of ***UP*** are given in UPU/km2

Territory	***UP*** 2002	Population in 2002	***UP*** A	Population in A	***UP*** C	Population in C	Relative difference in the increase of ***UP*** from 2002-2030 between A and C	Relative difference in population increase from 2002-2030 between A and C
CH	4.24	7,288,010	4.93	8,142,887	4.60	8,142,887	47 %	0 %
ZH	13.98	1,247,906	16.29	1,396,580	14.94	1,365,837	59 %	21 %
BE	3.87	957,197	4.50	1,071,356	4.22	1,082,533	45 %	10 %
LU	5.41	350,504	6.40	401,647	5.91	395,604	50 %	12 %
UR	0.83	34,777	0.97	39,203	0.90	39,419	52 %	5 %
SZ	2.92	128,704	3.43	148,046	3.24	144,782	38 %	17 %
OW	1.74	32,427	1.97	34,929	1.92	37,765	26 %	113%
NW	3.10	37,235	3.65	43,983	3.37	41,137	51 %	42 %
GL	1.54	38,183	1.76	41,635	1.67	44,056	41 %	70 %
ZG	6.57	100,052	7.54	114,948	7.12	109,937	44 %	34 %
FR	4.40	241,706	5.26	279,881	4.79	270,530	54 %	24 %
SO	9.74	244,341	11.75	285,032	10.45	272,755	65 %	30 %
BS	50.48	188,079	55.77	186,548	54.51	210,233	24 %	*
BL	12.04	259,374	14.34	302,305	12.80	287,678	67 %	34 %
SH	6.55	73,392	7.54	80,737	7.14	81,984	40 %	17 %
AR	5.32	53,504	6.13	59,269	5.92	60,859	26 %	28 %
AI	1.79	14,618	2.07	16,407	2.03	17,374	16 %	54 %
SG	5.33	452,837	6.15	504,384	5.87	507,969	35 %	7 %
GR	0.85	187,058	0.97	208,355	0.92	214,178	43 %	27 %
AG	11.26	547,493	13.30	625,329	12.11	608,575	58 %	22 %
TG	7.51	228,875	8.65	255,319	8.27	260,329	34 %	19 %
TI	3.19	306,846	3.68	347,975	3.48	344,374	41 %	9 %
VD	4.88	640,657	5.58	701,609	5.31	713,820	39 %	20 %
VS	1.72	272,399	1.94	291,782	1.88	310,558	24 %	97 %
NE	4.08	167,949	4.69	183,647	4.46	187,698	38 %	26 %
GE	19.62	413,673	22.40	445,840	21.50	453,918	32 %	25 %
JU	3.16	68,224	3.61	76,142	3.47	78,986	31 %	36 %

* In canton Basel-Stadt (BS) the population decreases in scenario A by 1% from 2002 to 2030, whereas in scenario C the population increases in the same period by +12 %.

Influence of the Scenarios on the Dispersion of the Settlement Areas

Included in the urban permeation value is the dispersion (***DIS***) of the settlement areas (***UP*** = ***DIS*** * settlement area). This metric is convenient for comparing the cantons in combination with the development of the density of settlement area (percent settlement area of a canton's area; Fig. 8). Figure 8 shows the values corresponding to Tables 4 and 5 for the historic development from 1935 to 2002 and for six scenarios for Switzerland in total and for a selection of seven cantons. The values for two general trend scenarios from project B are given as reference for the four more complex scenarios. The selected cantons represent cantons with different degrees of urban permeation and different types of settlements (Fig. 6).

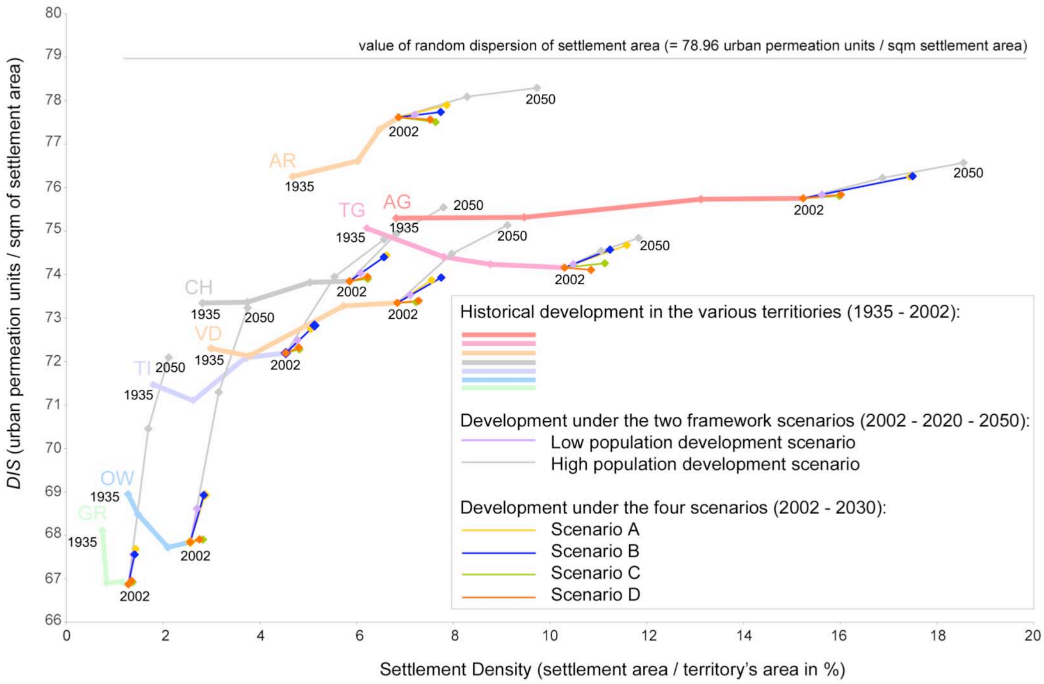

Fig. 8 Development of settlement density and dispersion of the settlement area in Switzerland in total (CH) and in 7 cantons, i.e., Appenzell-Ausserrhoden (AR), Aargau (AG), Thurgau (TG), Vaud (VD), Ticino (TI), Obwalden (OW), and Graubünden (GR), from 1935 to 2002, up to the year 2030 under the four alternative scenarios, and up to 2020 and 2050 under two framework scenarios

Historic Development of Dispersion in the Examples

The seven example cantons show rather different patterns in the historic development of the dispersion of settlement area. Overall, dispersion has increased significantly and continuously in the last 40 years in Switzerland. A distinctive continuous increase in dispersion and settlement density is obvious for canton Aargau (AG) (settlement type 6), where the establishment of industry took place at a rapid pace, which in turn caused intense residential developments for workers in the suburban area and building of transportation infrastructure (Schuler et al. 2007). In canton Appenzell-Ausserrhoden (AR), characterized by scattered settlements (settlement type 3), the dispersion of the settlement areas escalated most rapidly between 1960 and 1980 with further increases up to today. The remaining selected cantons show a decrease in the dispersion of settlement area between 1935 and 1960 with differing developments afterwards. For example, in canton Thurgau (TG), where the settlement structure has been dominated by villages, hamlets, and farmyards as well as some smaller cities (settlement type 5), the dispersion of the settlement areas decreased continuously, while the density of settlement area increased. This example demonstrates that it is possible to decrease the dispersion of settlement area, and that such developments do actually take place.

Degree of Dispersion in Switzerland for the Scenarios

The curve for Switzerland in total is not surprising and shows that the values for scenarios A and B, with an individualistic society, are rather similar; and so are the values for scenarios C and D, with societies characterized by high solidarity (Fig. 8). In contrast, the difference between scenarios A/B and scenarios C/D is rather large. When comparing these values to those of the framework scenarios, it is noticeable that the values of the scenarios A and B are below the values of the high population development scenario in 2020. Scenarios C and D show higher values with regard to the growth in settlement area but lower values regarding its dispersion when compared to the low population development scenario in 2020 and 2050.

Degree of Dispersion in Different Settlement Types

The mean ***DIS*** value was calculated for the settlement types. In all scenarios, cantons of settlement type 1, characterized by compact villages, exhibit a higher relative increase in the mean ***DIS*** value than the other types but there is a high difference in the cantonal ***DIS*** values (SH and NE very high; VD and JU low). The interesting point in the development of the curve of canton Graubünden (GR), as an example of the alpine settlement type comprising villages in the valley and individual alps on the slopes (settlement type 4), is that the dispersion values for the scenarios A "Spatial Dispersion" and B "Metropolitan Expansion" equal the value of the low-population framework scenario. In contrast, the curves belonging to the cantons AG (settlement type 6) and TG (settlement type 5) have in common that the values for the scenarios A and B are higher than the value of the high-population framework scenario for 2020 and they are more or less following the trend of this scenario. The curve of canton AR (settlement type 3) shows a wide angle between the curves of the scenarios. Peculiar features of scenarios C "Urban and Rural" and D "Spatial Equality" are that they have a relatively high increase of settlement density that is nearly as high as in the individualistic scenarios A and B, and that both the economically stagnating scenario C and the dynamic scenario D still have a lower dispersion value than today.

Differences in sprawl per capita

Many cantons with relative low urban permeation show very high values of total sprawl in relation to the size of the population in the canton. Figure 9 displays the ranking of the cantons with regard to sprawl per capita (***SPC*** = ***TS*** / capita = ***DIS*** * settlement area / capita).

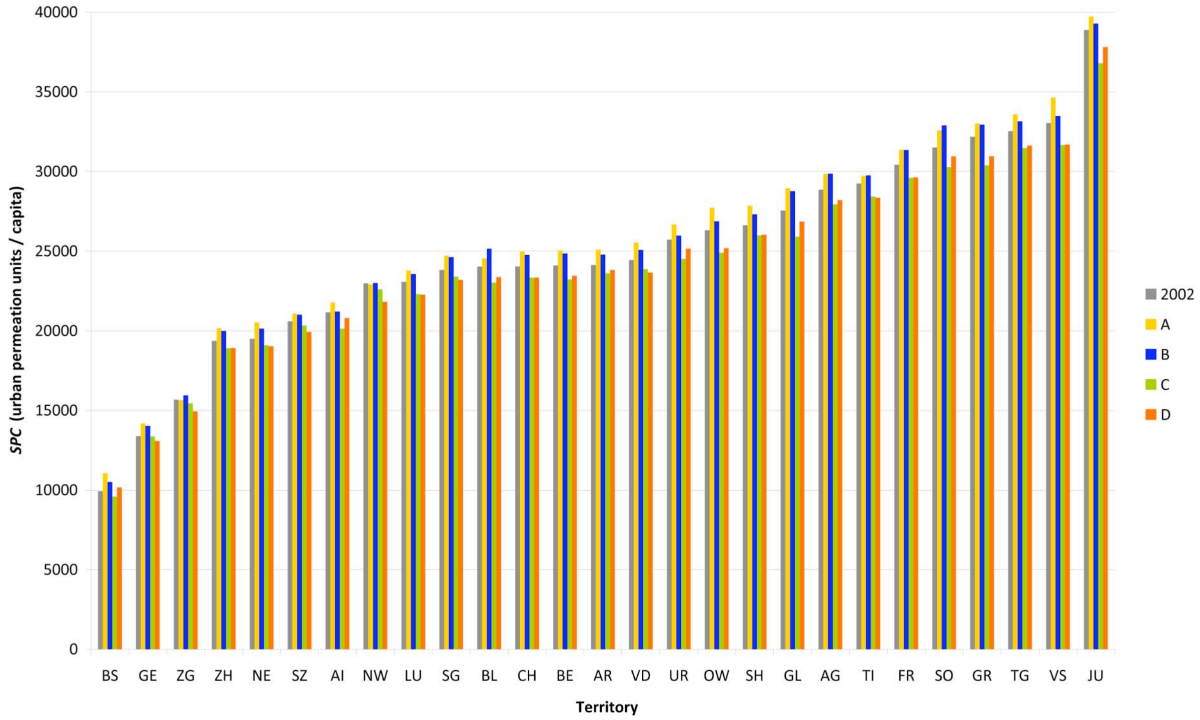

Fig. 9 Sprawl per capita (SPC) in the year 2002 and in the year 2030 under the four scenarios for Switzerland in total and the 26 cantons

The general pattern for today and all scenarios is that the metropolitan centres (BS, GE, ZH) as well as the cantons ZG and NE, both showing rather high percentages of urban population, have the lowest figures in sprawl per person. Cantons with scattered settlements (settlement type 3) and high percentages of urban population as of today (SZ, NW) show a much better sprawl per capita ratio than cantons of this settlement type with no urban population (UR, OW, GL). Canton TI (settlement type 2) is characterized by comparatively high values of ***SPC***. Cantons with the highest values of sprawl per capita for today and all scenarios include JU (settlement type 1), VS and GR (settlement type 4), TG and FR (settlement type 5), and SO (settlement type 6).

The individualistic scenarios A and B lead to an increase in sprawl per capita in nearly all cantons, whereas in the scenarios C and D with high solidarity, almost all cantons exhibit a decline in ***SPC***.

Discussion

The following interpretation compares the scenarios in order to understand their impacts on the settlement development and the factors promoting or reducing urban sprawl. First, the most substantial changes under the four scenarios and the differences between the scenarios with regard to the values of the metrics are discussed. Second, the values of the metrics are evaluated in order to find indications on regions in Switzerland that are particularly exposed to urban sprawl.

Most Substantial Changes in Settlement Development Under the Four Scenarios

Changes in the Metrics Regarding Switzerland in Total

The lower values of the dispersion of settlement areas in the individualistic scenarios A and B in relation to the high-population framework scenario (see Section "Degree of Dispersion in Switzerland in Total"), indicate that the scenarios A and B describe a less extreme development. In contrast, the dispersion values in the social scenarios C and D are lower than in the low-population framework scenario. This is an indication that these two scenarios are somewhat more extreme. Overall, the trend of further increase of dispersion towards a random distribution is continued in all scenarios because the dispersion values of all scenarios are higher than in the year 2002.

Changes in the Metrics Regarding Different Settlement Types

Settlement type 1: Compact Villages in the Jura Mountains In comparison to the other settlement types, the values of the metrics of settlement type 1 are rather low to moderate. Further, the mean increases in *UP* and settlement density are rather low to moderate for this settlement type in all scenarios. However, compared to the other settlement types there is a relatively high increase in the mean *DIS* value, even under the social scenarios C and D. This means that further settlement development tends to higher dispersion of built-up area for this settlement type. But according to the scenarios C "Urban and Rural" and D "Spatial Equality", the quite low dispersion values for canton VD show that a development in cantons of settlement type 1 can take place in a rather "low landscape consuming" manner. Thus, even in a dynamic economy with more building activity a development can be guided in a direction that does not cause a higher dispersion of settlement areas than today.

Settlement type 2: Italian Switzerland The metrics show moderate values for settlement type 2 as compared to the other settlement types – except for the value of *SPC*, which is rather high. The specific spatial structure of canton Ticino, including zones in the Alps that are only periodically inhabited, causes relative high values in settlement area per person and thus leads to a high *SPC*. High population growth in scenario B "Metropolitan Expansion" leads to a notably high increase in *UP* and settlement density in comparison to the other settlement types, whereas the dispersion of settlement areas (*DIS*) increases only moderately and *SPC* increases rather little. Even in scenarios C "Urban and Rural" and D "Spatial Equality", there is still a moderate increase in settlement density and *UP*, and *DIS* rises comparatively strongly in scenario D. Overall, these results point towards further urbanisation. Today, the rate of land use change from agricultural land to settlement area in Ticino is partly as high as in the metropolitan regions (Schuler et al. 2007).

*Settlement type 3: Landscapes with Widely Scattered Settlements ("Streusiedlungen")*For these cantons, the values of *DIS* turned out to be moderate to high, while the values of the other metrics were lower than the ones of the other settlement types. This comparatively high degree of dispersion is a consequence of the historical settlement structure which is related to the specific style of dairy farming in these regions. Therefore, in terms of more recent types of urban sprawl it cannot be called urban sprawl, especially as on average the percentage of settlement area is rather low. However, when compared to the other settlement types, the scenarios describe a relatively high increase in settlement density and thus a pressure of settlement development in the cantons of settlement type 3. Settlement development in the designated building zones has a strong influence on the *DIS* values in these cantons. Even a reduction of settlement dispersion, i.e., densification, is possible in the social scenarios C "Urban and Rural" and D "Spatial Equality" (see AR as an example).

Settlement type 4: Alpine Regions with Agriculture and Tourism Cantons of settlement type 4 have rather low to very low values of the metrics when compared to the other settlement types, except for the high values of *SPC* that are caused by a traditionally low population density. In all scenarios, the increases in *UP* and settlement density are relatively low. This may be an indication that this settlement type is not likely to have a significant settlement development in the future. *SPC* decreases in the social scenarios C and D the most among all settlement types, which demonstrates that the designated building zones lead to a lower dispersion of settlement area. In addition, the higher solidarity in theses scenarios supports a positive population development in these cantons, contributing to lowered values in *SPC*, too. The relatively low increase in *UP* and high increase in *SPC* in scenario A "Spatial Dispersion" can be attributed to continuous population loss in this scenario, i.e., in an individual-oriented society with a stagnating economy.

Settlement type 5: Cantons Comprising Several Settlement Forms All values of the metrics for settlement type 5 are moderate to high when compared to the other settlement types. The average increases for this settlement type in *UP* and settlement density are very high in the economically stagnating scenario A "Spatial Dispersion" and very low in the dynamic scenario B "Metropolitan Expansion", while the mean values of *DIS* and *SPC* increase moderately in both scenarios. Thus, the economy has a rather high influence on the changes in settlement patterns. Due to heterogeneous developments in the different cantons of settlement type 5, the other values exhibit large variability (and are only on average on a medium level). Most remarkably, the mean value of *SPC* of all cantons of this settlement type decreases by the lowest amount among all settlement types in scenario C "Urban and Rural", although all new settlement areas are located within the designated building zones (where a stronger decrease would seem reasonable). This may indicate that a creeping development towards urban sprawl is taking place in these cantons.

Settlement type 6: Metropolitan Agglomerations Settlement type 6 comprises the metropolitan areas (BS, GE, ZH, AG, SO, BL) of Switzerland and is characterized by very high values of the four metrics. Only *SPC* assumes very heterogeneous values among the cantons that belong to this settlement type, with the metropolitan centres offering the best values in *SPC* due to high population densities and much higher population than any other part of Switzerland. However, it seems to be only a matter of time when the development of *DIS* in the agglomerations (e.g., AG) will reach the state of the extreme scenario with the highest possible degree of dispersion. The dispersion values of all six scenarios are quite close together, and the scenarios are most strongly distinguished by the amounts of settlement area.

The scenarios have very severe impacts on the settlement development in the cantons belonging to settlement type 6. This is demonstrated by the highest relative differences between scenarios A and C, and B and D, for these cantons. In these cantons, a better economic situation also has a strong impact on the development of the urban permeation. This is underlined by higher values in ***UP*** for the economically dynamic scenario D "Spatial Equality" as compared to the values for scenario C "Urban and Rural" (stagnating economy). Additionally, the higher predicted growth in ***UP*** in each of the four scenarios in all urbanized areas as compared with rural regions displays the strength of these economical centres to attract people and jobs. However, the degree of these effects may be exaggerated due to the generalizations applied to the settlement growth model in so far as the amount of additional population is the same in all scenarios. Nevertheless, the exceedingly high percentages in the difference in ***UP*** between the scenarios A and C for cantons belonging to settlement type 6 (ZH, SO, BL, AG) reflect the tendencies towards urban sprawl in these cantons and show that they depend clearly on the peoples' norms and values with regard to social and spatial densification and to a minor degree, on the increase in population.

A rather extreme example of the spatial impacts of the peoples' norms and values is also given by the canton Basel-Stadt (BS). In the individualistic and economically weak scenario A, the population density in the city centres decreases, and due to the limited area available for further settlement development in canton Basel-Stadt, the total amount of inhabitants decreases, while the value of ***UP*** increases. In contrast, a population increase of about 12 percent from 2002 to 2030 in canton Basel-Stadt under the conditions of the social scenario C, aiming at social and spatial densification, can lead to less increase in ***UP*** than in the individualistic scenario A.

Indications for Regions Inclined to Urban Sprawl

The metrics highlight the differences among the Swiss cantons and among the settlement types. When applied to the scenarios, do they also indicate if a certain development should be evaluated as negative, resulting in spatial patterns that manifest as urban sprawl? The discussion of this aspect needs to link knowledge about the historical development of the settlement areas in certain cantons and characteristics of the landscape structure with the results of this study (see Table 8).

The cantons characterized by compact villages in the Jura mountains (settlement type 1) seem to be of low to moderate risk of urban sprawl according to the developments described by the scenarios that lead to moderate values of ***UP***. However, the disproportionate *increase* of the ***DIS*** values for the cantons NE and SH indicates that the ongoing trends may lead to undesirable sprawling settlement patterns in the long term.

According to the scenarios, the metrics reflect the process of continuing urbanisation in the canton Ticino very well (settlement type 2). Urban development is concentrated on a small part of this canton because of large unproductive areas in the mountains that cannot be used neither for agriculture nor for settlement development. The main issue is by how much ***UP*** and settlement density could increase without causing problems regarding mobility, the quality of the cultural landscape for tourism and recreation (Catalán et al. 2008), or other ecosystem services (Walz et al. 2007).

Table 8 Main tendencies of the future growth of the built-up area in the six settlement types with regard to their exposure to urban sprawl, based on the interpretation of the metrics urban permeation (UP), dispersion (DIS), and sprawl per capita (SPC) for the scenarios (A, B, C, D)

	Lowest increase, or decrease, of the metrics				Highest increase of the metrics			
Settlement type	*UP*	*DIS*	*SPC*	Main tendencies	*UP*	*DIS*	*SPC*	Main tendencies
1 Compact villages in the Jura mountains	D	C/D	C	moderate settlement development	A	A	A	overall tendencies of sprawling
2 Italian Switzerland	D	C	D	reduced *SPC*, even in the dynamic scenario D	B	B	B	intensified peri-urbanisation with large extension of built-up areas
3 Landscapes with scattered settlements	D	C/D	C	decrease in *DIS* in cantons with high % of urban population	A	A	A	active settlement development and high increase in *DIS*
4 Alpine regions with agriculture and tourism	D	C/D	C	effective reduction of *SPC*	B	A	A	very high increase of *SPC* in scenario A
5 Cantons with several settlement forms	D	C/D	D	moderate settlement development in scenario D	A	A	A	very high building activities and *SPC* remains rather high
6 Metropolitan agglomerations	C	C/D	C	very effective reduction of settlement activities in scenario C	B	A/B	A	continuing peri-urbanisation with steadily increasing *DIS*

A densification of settlement areas as identified in scenarios C and D would contribute to a change in the character of the landscape in the cantons belonging to settlement type 3 (widely scattered settlements). In particular, as the amount of new settlement areas is rather high (as compared to the gains of other settlement types in these scenarios), this possible development should be carefully assessed. The historical characteristic scenery with scattered (but still contained) settlements is rated as one of the most important economic resources of these cantons as they highly depend on tourism. Today, the percentage of urban population is already high in some of these cantons. Continuing functional urbanisation by using former farms as restaurants (Atrop 2004) and using new buildings predominantly for residential purposes can accelerate the transformation process.

The cantons in the alpine regions dominated by agriculture and tourism show quite similar results (settlement type 4). The location of the designated building zones supports a rather compact settlement development in the valleys. However, the low increases in ***UP*** and settlement density suggest that a high increase in settlement development is not likely in these cantons. The quality and use of the buildings are significant for the sustainability of future settlement development in the alpine regions. Today, many secondary homes, with their owners being only temporarily present, already cause several problems, e.g., high infrastructure costs or “ghost villages” (Cede and Steinicke 2007).

Cantons of settlement type 5 (mixed settlement forms) are mainly characterized by huge flat areas of agricultural land. A steadily growing settlement development has been recognised there in the past (Schuler et al. 2007). In the scenarios, this trend is shown to continue with various strengths. However, as the cantons comprise several settlement forms, the metrics assume rather moderate values. These increases are not significant enough to unambiguously evaluate the risk of urban sprawl in these cantons at this scale. Therefore, an assessment should be carried out on a finer scale to take into account the differences among the landscapes and settlement patterns within the cantons.

Landscapes with settlement structures of type 6, situated on the Swiss central plateau, are under comparatively high pressure of increased urbanisation in all scenarios. The ribbon of built-up areas, that dominates half of the landscape in this region, could easily get even more solid and impermeable. Particularly, competing rather than collaborating cantons as described in scenarios A and B seem to support a large growth in settlement area here.

Scenarios A and B outline a future settlement area distribution that is rather unlikely to come true with regard to the spatial pattern of the settlement areas. It is probably too dispersed and disregards some relevant mechanisms of settlement development. However, the scenarios demonstrate very clearly what an extreme development would mean as it leads to further consumption of cultivated landscape. They sketch situations in which agricultural land is effectively treated as a repository for settlement growth with no real other values (Catalán et al.

2008). This development would be very undesirable as the maintenance of important landscape functions and landscape identity is neglected.

This discussion elucidates that the application of the metrics to scenarios is useful to provide an indication if certain developments should be evaluated as negative as the metrics quantify the degree to which settlement patterns manifest as urban sprawl. However, the reporting units for this analysis need to be chosen at appropriate scales. The results should also be discussed in combination with indicators of urban growth pressure such as land-market activity measures (Pond and Yeates 1994) and other economic, cultural, technological, political, and environmental driving forces (Hersperger and Bürgi 2009).

Conclusions

Our results show that Switzerland has strong tendencies of continued urban sprawl, but these trends are not equally severe in all parts of Switzerland. The metrics help gain insights about the impacts of the scenarios on the spatial pattern of the settlement areas and compare them to the situation of today. Obviously, there is no single one settlement development scenario among our four scenarios that could support the lowest increases, or even decrease, of the metrics in all settlement types with the same effectiveness. Thus, the various settlement types need different strategies for managing their future growth of settlement area.

However, the results do not yet reveal what quantitative limits (based on the metrics) should be set in order to ensure a sustainable settlement development. Focussing on particular cantons, it has become obvious that the landscape structure, the related socio-historically evolved settlement forms, and the locations of the designated building zones have great influence on the values of the metrics, and that limits or thresholds based on the metrics need a region-specific calibration. It will depend on an evaluation and appreciation of the resulting landscapes if detected processes should be permitted, changed, or stopped.

The scenarios are not suitable for directly deriving policy recommendations from the simulation results because of the large number of scenario-related assumptions and generalizations. However, due to their inner consistency, the scenarios demonstrate potential spatial developments that provide thought-provoking impulses. In scenario C, the population remains more or less where it is today and the consumption of resources is stabilized. Thus, a lowered demand in further build-up area is a very reasonable option for the future. However, scenario D describes a cohesive development (with a strong economy) which is often equated with decentralized settlement growth and urban sprawl. In contrast, metropolitan growth as in scenario B is often equated with densification and thus reduced urban sprawl. Our scenarios show that this equation is not correct in such general terms. They support the hypothesis that cohesive regional development is not accompanied by high rates of land consumption but demands relatively little new build-up areas. This result is supported by Alterman's (1997) findings: Containment of urban growth strongly depends on a nation's shared norms and values for land development.

As the metrics provide for rather abstract (quantitative) information, the resulting landscape conditions should be studied through 3D landscape visualisations as a next step to aid understanding and communication on all planning levels from the outset on. By integrating visual and non-visual landscape information, these instruments show high potential for assisting in the analysis of landscape change and evaluating the character of possible future landscapes (Higgs et al. 2008; Wissen et al. 2008).

The new urban sprawl metrics are suitable to highlight anthropogenic pressures on the landscape. However, human action is one important aspect among others (e.g., physical forms and societal values) which in their combination shape a landscape (Stephenson 2008). In order to further increase the understanding of landscape change, the metrics should be combined with additional indicators, e.g., for the assessment of the view and the ecological impairment of potential future landscapes and for testing the effects of alternative patterns based on societal values (Grêt-Regamey 2007; Nassauer and Corry 2004; Walz et al. 2007).

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