Greening metropolitan growth:

*Integrating nature recreation, compactness and spaciousness
in regional development planning*

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Abstract

This paper reports findings on; analyses of landscape morphology by density and green space distribution of the Stockholm county region; correlations between morphology and socio-economic data and; assessments of two regional development scenarios for 2030 modelled in the proposed regional plan (RUF 2010). Today Stockholm is a relatively green and spacious metropolitan region with a small compact city core. We found correlations between compactness (product of floor area and nature recreation area) and highly mixed parcels ($R^2=0.729$, $p<0.001$), between compactness and overweight ($R^2=0.47$, $p<0.001$), and between accessibility to nature recreation and reduced psychological well-being ($R^2=0.40$, $p<0.001$). It seems that new housing developments and income levels are driven by compactness in the city centre and spaciousness (quotient of nature recreation area and floor area) in the suburban periphery. The scenario FÖRDELAD is more spread out and spacious in the periphery and the scenario TÄT is more compacted in the city centre; however, they both decrease in compactness and spaciousness in the inner suburbs. We claim that the decline in spaciousness in inner suburbia would be accepted if compactness were also increased, a situation that is not the case in either scenario. The apparent risk of this development is that suburbia will lose its attractiveness to a level that it will fuel peripheral sprawl even more. With support from the correlation studies and other sprawl research, we claim that this planned development could have severe negative consequences for the sustainability and attractiveness that are claimed to be the core goals in the proposed regional plan.

Introduction

This paper reports findings on; analyses of landscape morphology by density and green space distribution of the Stockholm county region; correlations between morphology and socio-economic data and; assessments of two regional development scenarios for 2030 modelled in the proposed regional plan (RUF 2010). In the paper alternative ways to analyze landscape and density morphology by the distribution of regional densities and green space are examined. We introduce new measures and concepts that in a concrete way show how green in general and nature recreation areas in particular can be studied as an interwoven part of the urban landscape morphology and regional development scenarios. Practically speaking, this has been a central task for regional planning from the 19th century, including today's studies of growing metropolitan regions.

“The story of cities and nature is both a love story and a battle and in both, green structure may be a useful concept. Structuring the scattered archipelago of green areas means joining forces in a battle to defend vulnerable green spaces against increased pressure from busy traffic, construction works and other dynamic urban activities. But green structure may also describe a policy to create conditions for the love story between urban citizens and their parks and playgrounds. Both the rich and poor benefit from the presence of a green network, a green structure that links small gardens and neighbourhood greens to the green fingers and green belts of the urban landscape”. (COST 2005)

This quotation represents a summary of 40 experts in green structure and urban planning from fifteen countries in Europe gathered in the EU-financed project COST Action C11 (COST 2005). Green areas are as much part of cities now as they were in the beginning of modern urban planning in the 19th century. Green areas were and are used for sustaining and promoting as well as limiting and controlling urban growth. From a regional perspective, the most concrete green land pattern and planning paradigm is the *green belt*. The idea was born parallel to modernist planning in the 19th century and pioneered in the UK. The first documentation on green belts was in John Claudius Loudon's 1829 plan for London (Turner 2008), but the most influential diagram (fig. 1) was presented by Howard in the book “Garden cities of to-morrow” (Howard [1898] 1945), a strategy implemented in a comprehensive green belt policy for fourteen cities in the UK, such as Abercrombie's Greater London Regional Plan from 1944 (fig. 2). In this plan, the concepts are developed into a “park system” to provide open spaces from garden to park, from park to *parkway*, from parkway to *green wedge*, and from green wedge to *green belt*. The park system's prior aim was to limit urban sprawl by using small urban parks that ensure quality of life close to people and a large green belt to define the city periphery.

Fig 1-2. Howard's diagram on the Garden City and its green belts (Howard [1898] 1945) and Abercrombie's open space plan for Greater London for green belts and green wedges (Abercrombie 1944).

Abercrombie's concepts are still used today in regional green structure planning in cities all over the developed world. For example, green belt policies have been applied in Adelaide, Melbourne, Ottawa, Ontario, Vancouver, Toronto, Seoul, Beijing, Hong Kong, Portland, Minneapolis, Virginia Beach, Lexington (http://en.wikipedia.org/wiki/Green_belt), and more than 20 cities in the San Francisco Bay Area (<http://greenbelt.org/>). In these examples, the green belt is a protected land aimed to reduce sprawl and to compact the city core, an approach that is often supported by an "Urban Growth Boundary" (UGB).

The outcomes of green belts and UGBs have been heavily debated, and research shows that these land use policies could compact city cores preserving prime farm and forest lands from urban encroachment (Nelson & Moore 1993, Nelson 1999), leading to benefits from the amenity value of living near the greenbelt, recreational resources, bequest and heritage values, and biodiversity (Bengston & Youn 2006). On the other hand, green belts mean that fast growing cities leap-frog over the boundary and actually develop low density sprawl (Nelson 1994, Kelly 1993). This will actually enhance negative consequences of sprawl, such as automobile dependency and low levels of public transport for those living outside the UGB. Also differences in housing prices increase creating patterns of social segregation (Bengston & Youn 2006). Research also shows that where state control and planning authority is diminishing and market forces take over, previously protected green belts, such as those in post-Soviet Russia, are developed by "elite suburban housing" (Boentje & Blinnikov 2007). Similar development is ongoing in Beijing (Yang & Jinxing 2007), Hong Kong (Tanga et al. 2007) and Seoul (Bengston & Youn 2006). However, when looking at the city cores in heavily sprawled cities such as Detroit, Atlanta, and Dallas, there seems to be a relation. This "donut effect" is often boosted by inner city cores that lack useful public open space.

In Nordic countries, UGBs have not been systematically used and the discourse on green belts has not had any real effect in planning politics. What has been heavily debated, especially in Copenhagen and Stockholm, is the concept of green wedges. In Stockholm, the General Plan from 1952 suburban development is set out along subway lines. In Copenhagen, the Finger Plan from 1947 created a similar urban morphology. Abercrombie's Greater London Regional Plan inspired both plans, but both plans emphasized star shaped urban development with green wedges rather than a compact city with a green belt. Since then, Stockholm and Copenhagen have doubled in size – from one

to about two million people – with extensive urbanization and sprawl. The importance of green areas in this urbanization process has been especially highlighted in Swedish national planning policies (Boverket 2007a,b).

When looking at the regional development plan for Stockholm from 2001 (RTK 2001), the green wedges are still the central theme for the regional green structure (RTK 1990, RTK 1992) and currently planning authorities are introducing conservation areas such as nature and culture reserves to preserve this green structure (LSTY 2003). Compared to UGBs and green belts, wedges are probably a much more efficient way of treating the preservation of regional green because they do not limit urban growth in the same absolute way. Wedges, a continuous green area connected to the rural countryside, can be integrated into the central city core irrespective of the size of the city. The city can keep on growing and preserving the ‘wedginess’. The determining factor instead becomes the width of the wedges when the city grows.

Currently, the regional planning authority is formulating a new regional development plan to be implemented in 2010 (RTK 2008). In this work, urbanization is expected to continue with an estimated population growth of about 200 000 people every ten years within Stockholm County. Different development scenarios have been modelled and evaluated, and what has been concluded is that sprawl is slowing down and that urban growth is also pointing inwards. What the region faces is mass densification. This has finally been modelled in two scenarios: “FÖRDELAD” (fig. 3) for decentralization into regional cores and “TÄT” (fig. 4) for centralization.

Fig 3-4. The two scenarios; “FÖRDELAD” (left) and “TÄT” (right) proposed for the regional development plan 2010 (RTK 2008).

The emphasis on densification and green wedges is not necessarily the same discourse as the debates on green belts. Belts have a fixed radius and ‘ringiness’, but wedges can be transformed and translated into greenways or even green networks interwoven in the urban fabric without losing its function and identity. Given the current patterns of urban growth, it focuses on suburbia. What we are facing is “After sprawl” (Xaveer De Geyter Architects

2002): the challenge of compacting the suburban landscape that was built in the 20th century. This puts particular pressure on the large stretches of undeveloped land in suburban settings where ‘green wedges’ (fig. 5) face a future transformation from nature to park, from single use to multi use, from impediment to landscaping (Erixon et al. 2008). Due to the nature of contemporary urban growth, many large suburban greens have started to be developed as landscape parks promoting urban growth, rather than limiting it, like the Downsview park project in Toronto (fig 6) and the Orange county park in California (Czerniak & Hargreaves 2007). A field of “landscape urbanism” design and research practice is starting to evolve from this development (Waldheim 2006).

Fig 5-6. Part of the “green wedge” Järvakilen in suburban Stockholm (Goggle Maps 2008) and the plan for Downsview park in suburban Toronto (<http://www.brucemaudeesign.com/>).

It is evident that a regional green plays an important role in distributing quality of life and health amenities that have a substantial impact on real estate values (Tyrväinen 1998, 2000, 2001). In Stockholm, suburban housing is sold with nature (see developer websites: <http://www.jm.se>, <http://www.jarvastaden.se/>). This means that how we preserve and develop a certain type of green (nature) structure is crucial for the developer and the building industry. The correlates between urban (regional) green and real estate value, health, income, and population structures are thus surprisingly unexamined. There is very limited research given the large surface area they consume in cities, especially in Nordic countries. What is it good for? Who does it benefit? And above all – in which environments are dense settlements combined with high green space accessibility, creating a compactness that benefits all citizens, both residents and businesses?

Theory and methodology

This study within the field of urban landscape morphology (Moudon 1997, Batty 2008, Frenkel & Ashkenazi 2008, Jenks & Jones 2010) is supported and partly financed by The Office of Regional Planning and Urban Transportation in Stockholm (RTK) and the Swedish Research Council FORMAS. The research project's aim was to study regional green in terms of the distribution of nature recreation areas and to study how these areas were affected by the two proposed scenarios for 2030 in the proposed Regional development plan (RTK 2008). The study was conducted in close dialogue with the regional planners.

Mapping potential nature recreation

In an earlier study for the Stockholm County Administrative Board, a method for mapping potential regional nature recreation amenities was investigated (Spacescape 2007). The method developed started from an existing map of the “social amenities” in the green wedges (RTK 2004:1-10) based on a qualitative survey of people's evaluations and expectations on nature outdoor recreation and various municipal mappings of nature amenities (RTK 2003, 2004). This approach is similar to the sociotope mapping model developed at the Stockholm Urban Planning Administration (Ståhle 2006). In the existing map from RTK, seven main social amenities were identified: “forest”, “wilderness”, “openness”, “diversity”, “cultural landscape”, “service”, and “physical activities”. In our study, the first four were selected to represent nature recreation in an urban context representing quite exclusive amenities for an urbanite that also proved to be significant to contemporary (Nordic) urban life quality (Grahm & Stigsdotter 2003).

The previous study correlated the existing mapping of the four nature recreation amenities by RTK (2004:1-10) with GIS-analyses of landscape patterns. A GIS-measure was developed for every nature recreation amenity (Table 1).

Nature recreation amenity	Description from RTK (2004)	Our GIS-measure
Forest	Continuous forest area older than 60 years. Low noise. 250 meters from major roads.	More than 75% forest biotope within 100 meters from every parcel and at least 250 meters from major roads (motorway or highway). Areas must be at least 4 hectares.
Wilderness	Older forest and untouched nature. Low noise. 250 meters from major roads and settlements.	More than 75% coniferous forest, wet forest, and wetland biotopes within 100 meters from every parcel, and at least 100 meters from built up settlements, 100 meters from all roads and 250 meters from a major road (motorway or highway). Areas must be at least 4 hectares.
Openness	Water areas and open landscapes. Low noise. Panoramic views.	Water areas and more than 75% open crop land biotopes within 100 meters from every parcel, and at least 100 meters from major roads (motorway or highway). Areas must be at least 4 hectares.

Diversity	Areas with biodiversity, edges of woods, shores lines, and wetlands.	25 meter buffer around the edge between forest and open land, and between land and water areas. Also included are wet forest, wetlands, and noble broadleaved forest. Areas must be at least 4 hectares.
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Table 1. RTK's description of the four nature recreation amenities and our GIS-measure translating landscape patterns to nature recreation amenities.

Landscape patterns were described using regional maps of over built-up areas, road systems, and biotopes (biological types of natural green space). Built-up areas consisted of parcels with a total Floor Area Ratio above 0.05 at a parcel-level of 100X100 meter. Built-up parcels also contain data on the amount of residential and non-residential floor area. The road system was separated into classes of roads from local roads and streets to national motorways. (RTK 2007) The biotope maps came from a national satellite survey of nature types "Kontinuerlig naturtypskartering" (Naturvårdsverket 2004) at a parcel level of 25X25 meters. The main aim of this mapping was to identify areas for nature conservation from a rural landscape ecological point of view. When applying this model to urban settings from an anthropocentric point of view, this is of course a limitation resulting in some bias in the results. On a comprehensive regional scale, this distortion, however, is not particularly significant; in fact, the GIS-measures for "forest" and "openness" highly correlated to the mapping of urban nature recreation amenity map from RTK. For "wilderness" and "diversity", the results were not as strongly correlated due to the diversity of local mapping methods in the RTK material. (Spacescape 2007) Given the broad definition of these amenities, our analysis represents a fair amount of valuable land and does not seem to affect the major result patterns.

In the GIS-analysis the four nature recreation amenities were fused into one nature recreation map layer, where every area is indexed by the number of amenities. When calculating the amount of nature recreation area, the number of amenities is multiplied by the surface area, i.e. areas with several recreation amenities imply a larger useable space. This method has been verified in previous green space studies (Ståhle 2005).

Analyzing landscape morphology

The (parcel) raster GIS-data on nature recreation areas and the built-up volume (residential and non-residential floor area) can produce many morphological analyses that can be executed that are useful for regional planning. In this study, we have performed a variety of analyses from simple density measurements to more combined morphological indices (table 2).

Measure	Formula	Description	Area	Location
Total Nature Recreation Area (TNRA)	Nature Recreation Area X Number of Amenities	This measure describes the amount of qualitative nature recreation area.	X	X
Total Floor Area (TFA)	Residential Floor Area + Non-Residential Floor Area	This measure describes the amount of floor space, residential and non-residential.	X	X
Land Use Mix (LUM)	Residential Floor Area / Total Floor Area	This measure describes the share of residential space in	X	

		the built-up areas. This is a rough measure not including the diversity of land uses.		
Floor Area Ratio (FAR)	Total Floor Area / Area of Analysis [3,14 Mn sqm in location analysis]	This measure describes the relation between total floor area and the ground area.	X	similar Loc TFA
Spaciousness Ratio (Open Space Ratio: OSR)	Total Nature Recreation Area / Total Floor Area	This measure describes the relation between nature recreation area and floor area – value is high if RA is high or FA is low.	X	X
Compactness Index (Spatial Compactness Index: SCI)	(Total Nature Recreation Area X Total Floor Area) / (Area of Analysis) ²	This measure describes the product of nature recreation area and floor area - value is high when both aspects are high.	X	X

Table 2. Measures on landscape morphology used in the study.

Two types of analysis were made – *area analysis* and *location analysis*. Area analysis simply means calculating the spaces within a sub-region. Location analysis means calculating accessible space within a certain radius. In raster-GIS, this is done using neighbourhood statistics. In transportation research, it is called attraction-accessibility (Miller 2007), and it is commonly used in walkability studies (Lee & Moudon 2006). The radius was set to 1000 meters based on previous studies that report this to be the distance that people are generally willing to walk (Ewing, 1995; Hottenstein et al., 1997) and also particularly to nature recreational areas in Sweden (Hörnsten & Fredman 2000). It has to be noted that accessibility is here not measured in a network but as straight-line buffer distance due to lack of network data, limiting and reducing perceived pedestrian space (Stähle 2005). Even so, there are studies that have found straight-line distance to correlate with walking behaviour (Lee & Moudon 2006). Location analysis results were summed up as averages within every sub-region.

As shown in Table 2, location analysis is calculated for density indices such as FAR, which in Stockholm roughly describes accessible population (Rådberg 1988, Stähle 2008) and Spaciousness ratio (commonly known as Open Space Ratio), which roughly estimates the potential crowdedness in open space, in this case nature recreation areas. Private green space is not included in this measure. Introduced in this study is the Spatial Compactness Index (SCI), which indicates when there is significant accessible floor area and nature recreation area. This measure consequently increases when built urban areas integrate spaces for nature recreation, a strategy that affects high-density cores. This Compactness Index is consequently a new type of indicator of sprawl-like development patterns directly connected to open space since open space determines where urban development (densification) is possible and since it can control the limits of urban growth (e.g., Green belts) and also since under certain circumstances it can promote urban growth (e.g., Central Park).

Results were also sorted by landscape type within sub-regions: *whole landscape* (all parcels), which is divided into *water* and *land*, and where the latter is divided into *built-up areas* for *nature recreation areas* and for *other areas* that do not fit into these last two categories (table 3). So-called “other areas” could theoretically be considered as impediments, but in practise these spaces contain many very low-density surfaces such as extensive industrial areas, derelict open spaces, and even some urban park areas without the selected nature

recreation amenities. This last observation is important since it limits the scope of this study, a limitation that allows the integration of quite exclusive nature recreation spaces in the urban structure, not public green space in general. Nevertheless, this is especially intriguing since nature is often regarded as something opposed to urbanism, a view that this study shows is actually incorrect.

Whole landscape (H)			
Water (W)	Land (L)		
	Built-up (B)	Nature recreation (N)	Other (O)

Table 3. Landscape type for presenting analysis results.

Analysis results were agglomerated by 43 sub-regions, which are the municipalities within the Stockholm County and city districts within Stockholm City (large central municipality).

Searching for health and socioeconomic correlates

How can we explain the large amounts of green space in cities? A major challenge for green structure research is to find evidence on its social and economical importance. Can nature recreation areas or compactness explain *health status*? In this study, a questionnaire on perceived health in the Stockholm County (SLL 2007) is used for correlating health status with the landscape analysis. The questionnaire was sent out to 57000 people (61% response rate). In addition, *demographic data* (SCB 2006) is used to look for relations between ages and urban morphology: Is it true that families with children move from high density areas? Does compactness have any effect on demography? Lastly, data on *income* (SCB 2006) was correlated with the landscape analysis. It is of vital importance for urban growth and “spatial justice” (Soja 2000) to investigate whether there is a relation between wealth and nature recreation accessibility or compactness in the sense measured in our study.

Evaluating scenarios

This study evaluates the two development scenarios for the year 2030 modelled by The Office of Regional Planning and Urban Transportation for the proposed regional development plan (RTK 2008). The two scenarios were created by a set of spatial development rules that defined attractions and restrictions. Attractions were mainly generated by accessibilities created by the infrastructure such as roads and public transport. Restrictions were mainly areas where it is not possible or preferable to build, such as water and nature reserves. Hence, green structure served as a restriction (limiting growth) or a passive background where new developments were set. The “FÖRDELAD” (allocated) scenario follows the old regional plan strategy from 2001 to decentralize the central city core to a couple of external regional cores in outer suburbia. The “TÄT” (dense) scenario focuses on developing the existing central city core to, among other things, counter sprawl. The measures examined in the existing situation were applied to evaluate the scenarios.

Results

The results from the GIS-analyses are presented as maps over the central areas of the Stockholm county region: the city core, inner suburbs, and outer suburbs. Rural areas are basically not shown in the maps but are of course represented in the statistics. First, the contemporary landscape morphology is described and then the investigations of correlates are presented. Lastly, the evaluation of the two regional planning scenarios is described.

Contemporary landscape morphology

The images below show the analysis results in the city core, inner and outer suburbs of Stockholm, and the central part of Stockholm County. Exurbia and rural areas are of course also represented in the statistics.

Fig 7-8. "Wilderness" and "Forest"

Fig 9-10. "Openness" and "Diversity"

Fig 11. Total nature recreation of the Stockholm metropolitan area.

The Stockholm county region is for the most part rural, dominated by forest and agricultural land that are potential nature recreation areas (fig 7-11). The more interesting areas for investigating, areas where urban growth is ongoing are in the suburban landscape of the metropolitan area of Stockholm. It is here that the concepts 'green structure' and 'wedges' become relevant. As shown in the maps, the wedges of nature recreation areas are cut off at several locations, creating something more similar to green chains or 'strings of pearls'. These are also interconnected by stretches of water going into to the very core of

the inner city. This is in large parts an integrated blue-green structure that explains much of the results below.

Fig 12-13. Total Floor Area and Land Use Mix (black = 25-75% residential, i.e. highly mixed parcels)

Higher densities are and mixed land uses are mostly found in the city core with a few exceptions in new towns and external towns (fig. 12-13).

Fig 14-15. Location Floor Area (L) and Location Nature Recreation Area (L). Darker = higher value.

Fig 16-17. *Location Compactness Index (L) and Location Spaciousness Ratio (L). Darker = higher value in the former and reversely in the latter.*

Fig 18-19. *The relation between Location TFA and Location TNRA (B). The relation between Location SCI and Location OSR (B).*

The results show interesting patterns that is rather self-evident for anyone working with regional or urban planning in Stockholm (fig. 14-17). Perhaps the high compactness in the inner city is surprising, but as Stockholm is well known for its central water and nature areas like Riddarfjärden, Djurgården and Långholmen, this is not really unexpected. Looking at the relation between Location TFA and Location TNRA (fig. 18), it reveals limits to compactness. It is not possible to build too dense and at the same time have nature. This is further emphasized by looking at the relation between Location SCI and Location OSR (fig. 19). The diagram shows an L-shape, a configuration that explains urban form in a concrete way. Compact settings are in general also less spacious since compactness can be increased by building height, i.e., overlaying floor area.

Health and socioeconomic correlates

Regression analysis was used to evaluate the dependency between variables and the correlation coefficient was used to test independence between variables (Montgomery

1991). In addition, descriptive statistics and graphical methods were used to characterize the data. All analyses were carried out using the MINITAB system, and the 5, 1, and 0.1% levels of significance were considered. In the case of a statistically significant result, the probability value (p-value) has been given.

We investigated correlates by sub-regions in Stockholm County municipalities and the city districts within Stockholm City municipality. Because the sub-regions have an internal heterogeneous morphology and suffer from the “Modified Area Unit Problem” (Openshaw 1984), results are in some cases quite arbitrary. Location measures from built-up areas are one way to deal with this bias. In the search for correlates between the landscape morphological analysis and health and socioeconomic variables, some significant relations have been found that indicate the long-term impact of landscape morphology and spatial density on urban society.

Land use mix

Land use mix, measured as the share of residential floor area, is significantly related to location FAR (B) ($R^2=0.649$, $p<0.001$). By adding Location TNRA (B) in a forward stepwise regression, the correlation increases significantly ($R^2=0.77$, $p<0.001$). It clearly looks like high density is related to land use mix, but that regional green structure can play a part in the mix. This result is emphasized when looking at the share of highly mixed parcels with 25-75% residential space within the built-up areas and its correlation to location SCI (L), which is considerably high ($R^2=0.729$, $p<0.001$). These measures, however, do not say anything about park planning, walkability, and traffic regulation at the neighbourhood scale. This remains to be investigated although we know from previous studies (Stähle 2005) that Stockholm inner city districts have both high nature recreation and park accessibility. Hence these results would probably be roughly applicable in a more detailed scale. Development rates in the central parts of Stockholm somewhat confirm the attractiveness in the land use mix created by high compactness.

Development rates

No strong correlations were found between landscape morphology and the number of new apartments built between 2000 and 2006. There is a weak tendency ($R^2=0.169$, $p<0.006$) that more have been built in already dense districts close to the inner city districts rather than in suburbia, which supports the claim that the city has in recent years also been built inwards. There are however some inner city districts – e.g., Norrmalm and Östermalm – that have been developed very little. When looking at the volume of new development in relation to the density where it is built (New apartments/Location FAR (B)), another pattern emerges where we find fast growing and sprawling suburbs such as Värmdö, Nacka, and Österåker east of Stockholm, close to the attractive archipelago. These areas have a high degree of nature recreation area accessibility ($R^2=0.370$, $p<0.001$). Although the correlations are not very strong, it shows tendencies, well known to urban planners, that central density (or compactness) and peripheral nature (or spaciousness) simultaneously attracts urban densification and sprawl development, respectively. This becomes more evident when looking at income correlates.

Income groups

No correlations were found between income and any morphological measure for all sub-regions. However, interesting relationships were found when sorting out sub-regions of different land density in terms of Area FAR (L). In the group of higher area densities (FAR=0.19-0.6), some, though not highly significant, correlations were found between income levels and Area SCI ($R^2=0.474$, $p=0.019$). This would mean that the higher compactness the higher income in Stockholm inner city and inner suburbs, which also means that lower incomes are located in less compact settings. Incomes in this urban group range from the lowest (110 000 SEK/year) to one of the highest (302 000 SEK/year) in the County. When looking at the outer suburbs, or rather exurban and rural settings, with very low Area FAR (L) (<0.02), the relation is in fact reversed. Here higher incomes means lower Location SCI ($R^2=-0.552$, $p=0.002$), but higher Location OSR ($R^2=0.373$, $p=0.020$). This indicates that higher incomes seem to correlate with spacious areas in rural settings, seeking the 'splendid isolation' that, for example, can be found in the Stockholm archipelago. There are, of course, many other variables that affect the location of different income groups. The correlation analyses below show that some of the morphological measures relate to perceived health and children demographics.

Health

Perceived general health status correlates quite significantly with income (SLL 2007). Since there are some relations between income and landscape morphology, it is possible that income is part of the health correlates found; however, no strong correlations were found between perceived general health status or specific health issues such as depression, trust, and loneliness and any morphological measure. However, a more compact landscape in terms of Location SCI (L) correlated to less *overweight* ($R^2=0.47$, $p<0.001$). The correlation included all sub-regions. This finding relates to other research such as Frank et al. (2004), a study that emphasized that denser settings encourage walking and discourages car use, which can decrease overweight and obesity. Low Location TNRA (B) was related to *reduced psychological well-being* ($R^2=0.40$, $p<0.001$). This result confirms Grahn and Stigsdotter's results (2003), which show that closeness to nature can benefit psychological health and reduce stress.

Children density

There is a slight tendency that high accessible floor area means a lower percentage of children (0-6 years) in the population. This is often emphasized in regional planning – families with children move out of dense areas. However, when looking at the number of children per square meter, there is a relation to accessible floor area and compactness from built-up areas ($R^2=0.54$, $p<0.001$). This might say something about the micro environmental qualities in Stockholm inner city, i.e., park planning, walkability, and traffic regulation. Families with children in Stockholm have probably not moved to the suburbs to the same extent as, for example, in North American donut-cities. Surprisingly, there is very little correlation between nature recreation area accessibility and children density.

Performance of scenarios

The GIS-analyses of the two scenarios FÖRDELAD (allocated) and TÄT (dense) for the Stockholm County region 2030 show some differences in outcome for regional nature recreation areas, density, compactness, and spaciousness.

Fig 20. Average change in percent in the Stockholm County region for the scenarios FÖRDELAD (light grey) and TÄT (dark grey). TNRA, TFA, Land Use Mix, and 25-72% Mix are area measures. The rest are location measures that show accessibility within 1000 meters for nature recreation land (N) and the built-up land (B).

The average change for the whole county region is not as interesting as the differences in change within the region (fig. 20). There are also some interesting differences between scenarios. FÖRDELAD, for example, is more spread out in the periphery; however, they both have morphological deficiencies in inner suburbia in terms of the relation between compactness and spaciousness.

Built-up density

The amount of total floor area added is principally the same for both scenarios, increasing approximately 28%. There are some significant differences within the region. TÄT means a bigger increase in floor area in the inner city and the outer suburbs. FÖRDELAD results in a considerably higher increase in exurban rural areas (fig. 21).

Fig 21. Average change of floor area in percent in the Stockholm County sub-regions for the scenarios FÖRDELAD (light grey) and TÄT (dark grey). Sub-regions are sorted by area density (Floor Area Ratio) from left to right.

The results for location TFA (accessible floor area) from built-up areas shows a rather different picture because it is a measure that captures the structural morphology. With this measure, the average accessible floor area is increased by 12% in FÖRDELAD and 26% in TÄT. Within the region, there are some major differences. The largest addition is made in the outer suburbs and in the inner city. There is generally a slight stronger densification in TÄT except in the rural areas where FÖRDELAD has a larger increase (fig. 22).

Fig 22. Average change of accessible floor area from built-up areas in percent in the Stockholm County sub-regions for the scenarios FÖRDELAD (light grey) and TÄT (dark grey). Sub-regions are sorted by area density (Floor Area Ratio) from left to right.

Nature recreation areas

The amount of nature recreation area decreases with approximately 1% in both scenarios. Looking at the differences within the region there is a different picture. There is actually a quite large decrease, -10 to -30%, in the inner suburbs. The decrease subsides towards the urban periphery (fig. 23).

Fig 23. Average change of nature recreation area in percent in the Stockholm County sub-regions for the scenarios FÖRDELAD (light grey) and TÄT (dark grey). Sub-regions are sorted by area density (Floor Area Ratio) from left to right.

The connectivity of nature recreation area (measured as accessible nature recreation area within 1000 m from nature recreation parcels) decreased on average by only 1%. This fragmentation is slightly higher in inner suburbia. Looking at the potential visit frequency to nature recreation areas (measured as accessible floor area from nature recreation parcels), it increases by 26% in FÖRDELAD and 12% in TÄT. The reason for this is the great increase in rural areas in FÖRDELAD, although TÄT puts a slight higher pressure on central nature areas because of centralized densification (fig. 24).

Fig 24. Average change of Location TFA in nature recreation areas in percent in the Stockholm County sub-regions for the scenarios FÖRDELAD (light grey) and TÄT (dark grey). Sub-regions are sorted by area density (Floor Area Ratio) from left to right.

Concerning the accessibility to nature recreation from built-up areas, there are significant differences between scenarios. FÖRDELAD has average increase by 8% and TÄT has an average decrease by 5%. This difference is mainly created by the large increase in rural areas in FÖRDELAD. Otherwise, the alternatives are quite similar. Both decrease, especially in inner suburbia and inner city (fig. 25).

Fig 25. Average change of accessible nature recreation area from built-up areas in percent in the Stockholm County sub-regions for the scenarios FÖRDELAD (light grey) and TÄT (dark grey). Sub-regions are sorted by area density (Floor Area Ratio) from left to right.

Compactness

Location compactness, measured as the product (combination) of location TNRA and location TFA, increases by 7% in FÖRDELAD and 13% in TÄT. There are large differences within the region. In FÖRDELAD, compactness increases in rural areas, outer suburbs, and the inner city. In TÄT, compactness increases in outer suburbs and the inner city slightly higher than in FÖRDELAD. Both scenarios have unchanged or slightly decreased compactness in the inner suburbs (fig. 26).

Fig 26. Average change of location compactness from built-up areas in percent in the Stockholm County sub-regions for the scenarios FÖRDELAD (light grey) and TÄT (dark grey). Sub-regions are sorted by area density (Floor Area Ratio) from left to right.

Spaciousness

Location spaciousness, measured as the quotient of location TNRA and location TFA (roughly ‘nature recreation area per person’), increases on average by 63% in FÖRDELAD and decreases by 11% in TÄT. The distribution in the region is evident and given by the spread out settlements in FÖRDELAD that create a radical increase in spaciousness in rural and exurban areas. Spaciousness decreases in suburbia and even more in the inner city in both scenarios. This is a result of the green wedges and current centralized density structure. When the periphery has low-density settlements in nature, it increases spaciousness. When the inner city is densified, it decreases it (fig. 26).

Fig 27. Average change of location spaciousness from built-up areas in percent in the Stockholm County sub-regions for the scenarios FÖRDELAD (light grey) and TÄT (dark grey). Sub-regions are sorted by area density (Floor Area Ratio) from left to right.

Summary

TÄT is more densified centrally than FÖRDELAD. The biggest addition in floor area is in the outer suburbs in both scenarios. The development in rural areas in FÖRDELAD means considerably higher accessibility to nature recreation in the periphery. Both scenarios decrease in nature accessibility in the central parts of the metropolitan region. Taken together, this means an average increase in spaciousness in FÖRDELAD, but a decrease in TÄT. Compactness is raised in the inner city and in the outer suburbs in both scenarios but most in TÄT. Consequently, FÖRDELAD manages to raise both compactness and spaciousness. Yet both scenarios suffer from loss in both compactness and spaciousness in the inner suburbs due to the little increase in density and great loss in nature recreation area. This kind of densification of inner suburbia could then be considered sprawl, lowering compactness and perhaps supporting further sprawl in the city's outer peripheries (fig. 28).

Fig 28. Principal section on the change of Location TFA, Location TNRA, Compactness and Spaciousness in the scenarios FÖRDELAD (left dotted arrows) and TÄT (right arrows) for the Stockholm county region 2030, based on the proposed regional plan RUF 2030.

Conclusions and discussion

This study examines Stockholm County density and landscape morphology. Stockholm is a relatively green and spacious metropolitan region with a small compact core compared to other big cities in the developed world. An important aim was to seek the relation of landscape morphology to a number of dependent variables such as land use mix, development rates, income groups, health, and children demography. Some interesting correlations were found, especially with new measures such as spatial Compactness Index (Location SCI). Higher density and compactness relates to potential land-use mix. This is important since land use mix often is a major aim in contemporary urban planning when it comes to creating urban quality and walkability (Kerr et al. 2007); land use mix have also been claimed to stifle the distribution of nature recreation areas (Lee & Moudon 2006).

Urban growth from 2000 through 2005 developed both in the centre and in outer suburbia. There is a slight tendency that new city core developments seek higher densities and suburban and exurban developments seek closeness to nature recreation areas on the coastline. This is confirmed by the income correlates. Higher income groups seem to seek the benefits of compactness in highly urbanized areas, but the benefits of spaciousness in exurban settings that are more automobile dependent. Suburbs are most likely a mix of these two polarities. They can be relatively compact with a high level of public transport service or spacious with a high automobile dependency. Higher income groups probably seek to maximize the two.

Correlations were found between morphology and some particular health issues. Low compactness related to overweight and low nature recreation accessibility related to reduced psychological well-being. These findings are not surprising given earlier research on walkability and travel behaviour (Grahn & Stigsdotter 2003, Frank et al 2004, Lee & Moudon 2006, Kerr et al 2007, Litman 2007). This study also found a high density of children in the Stockholm inner city. This can be explained by the relatively high compactness creating work places and residential qualities simultaneously. The correlations imply that cities actually generate useful nature, and urban and landscape planning is partly responsible for allocating prosperity by including green structures. At least this is a challenge facing contemporary planners and urban designers.

How then is this challenge taken up by the regional planners in Stockholm 2008? The analyses of the two scenarios for the Stockholm County region 2030, FÖRDELAD (Allocated) and TÄT (Dense), indicate a limited consideration of the potential in inner suburbia. Consequently, there is an acceptance that the Stockholm region needs to or will sprawl. Sprawl and its increased spaciousness in (outer) suburbia are demanded by many citizens (especially considering current oil and energy prices). We also know that compactness is demanded in more central locations. Hence a decline in spaciousness in (inner) suburbia would be accepted if compactness also was raised, which is not the case in the scenarios studied here. The apparent risk of this kind of development is that suburbia will lose its attractiveness to a level that will fuel peripheral sprawl even more. This is a development that has obvious consequences for economical, social, and environmental sustainability. Losing both spaciousness and compactness in suburbia cannot possibly benefit competitiveness, social justice and sustainability, which are the prime goals stated in

the proposed regional plan for the Stockholm County region (RUF 2010). Thus, the vision seems far from becoming a reality.

Although the findings in this study are promising, there are several serious limitations in data and models. When analyzing urban landscape morphology (whole landscape including green, built-up areas, roads and streets in cities), borrowing methods from landscape ecology is of course a limitation. Using buffer analysis and not network distances is also a brave reduction of the notion of distance and cognitive accessibility. In fact, at the least, one should use methodologies and data created within the field of urban morphology, space syntax, and accessibility research when working in urban settings (Batty 2008, Ståhle et al 2005, Ståhle 2005). The correlates between urban (regional) green and real estate value, health, income, and population structures are still amazingly unexamined. There is very limited research given the large amounts of land green space in these cities, especially in Nordic countries. What is it good for? Who does it benefit? And above all – in which environments are dense settlements combined with green space, creating a compactness that benefit all citizens, both residents and businesses?

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