Effects of habitat and landscape fragmentation on humans and biodiversity in densely populated landscapes

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Abstract

Landscape fragmentation has often been seen as an only ecological problem. However, fragmentation also has a societal perspective, namely, in how humans perceive landscape fragmentation and in how landscape fragmentation potentially influences human well-being. These latter aspects have rarely been addressed so far. The inter-relationship of ecological and human dimensions of landscape fragmentation becomes especially evident when looking at the landscape where most people in industrial countries live, namely in suburban and urban areas. In these areas, landscape planners and environmental managers are confronted with the problem that landscapes should fulfill various functions, often with conflicting goals, e.g. nature reserves to enhance species richness vs. recreational areas for city-dwellers. We reviewed the ecological and sociological literature relevant for fragmentation in suburban and urban landscapes. In an interdisciplinary approach, we evaluated whether there are similarities and dissimilarities between the ecological and the human aspects of landscape fragmentation. We found important similarities. An example is that for both, humans and biodiversity, the loss of semi-natural areas has more drastic effects than the fragmentation of these areas per se. However, there are also relevant differences. We concluded that in densely populated landscapes a shift from responsive planning to an intentional design of environments is therefore needed.

1. Introduction

During the last 40 years, the human population of Europe living in urban areas has increased twice as much as the population in rural areas. Today almost 80% of Europeans live in cities and their fringes. The spatial extent of urban areas is increasing even faster than urban population growth. While the urban population increased by 6% during the period of 1980–2000, urban areas expanded by 20% (EEA, 2002). In most cities of Central Europe, residential areas have particularly expanded during the last 50 years, indicating both a drop in residential density and a decentralisation of urban land-use (EEA, 2006; Kasanko et al., 2006). Urban environments have been poorly studied despite the fact that urban land-use is expanding and already covers substantial areas of Europe (Pickett et al., 1997; Niemelä, 1999a). Densely populated areas (Fig. 1) are both ecological and social entities. Hence, a more detailed understanding of densely populated landscapes requires integration of natural and social sciences (McIntyre et al., 2000; Kinzig et al., 2005).

On a coarse spatial scale, human presence is positively related to biodiversity, suggesting that people contribute to biodiversity by species introductions and habitat diversification. People also preferentially settled in areas of high biodiversity (Kühn et al., 2004; Luck et al., 2004; Pautasso, 2007). The latter process poses a threat to global biodiversity and stresses the importance of human demographic and socioeconomic dynamics in biodiversity conservation (Cincotta et al., 2000; Liu et al., 2003). On a smaller spatial scale, however, urbanisation destroys, alters and dissects natural and semi-natural habitats, and at the same time, also creates new habitats (Blair, 1999). Patch size of semi-natural areas decreases with increasing urbanisation, and densely populated areas are characterised by small patches isolated by roads, settlements or intensively managed agricultural land. Remaining patches of semi-natural areas often harbour few specialist but many ubiquitous and generalist species. Hence, species richness is generally reduced in small patches (Honnay et al., 1999; Niemelä, 1999a; Godfray and Koedam, 2003). However, some studies indicated that also small patches of semi-natural areas offer habitat for specialist species, depending on local factors such as vegetation type and structure.
Schwenninger and Wolf-Schwenninger, 1998; Niemelä et al., 2002; Helden and Leather, 2004; Kadlec et al., 2008).

In densely populated landscapes, small semi-natural areas like forests as well as natural elements such as single trees enhance human landscape preference and contribute to the well-being of local residents (Kaplan, 2001; Korpela et al., 2001). Matsuoka and Kaplan (2008) delineated three categories of peoples’ needs that are directly linked with natural and semi-natural elements in their environment: aesthetic preference, contact with nature and recreation or play. In these three categories, the existence, quality and accessibility of natural areas are important landscape values (Tzoulas et al., 2007; Matsuoka and Kaplan, 2008). The experience of nature in everyday life and the contact with native plants and animals in the close neighbourhood are especially important for children, as it may counteract the environmental generation amnesia. This phenomenon was delineated by Kahn (2002: 106): “People take the natural environment they encounter during childhood as the norm against which they measure environmental degradation later in their lives. With each ensuing generation, the amount of environmental degradation increases, but each generation in its youth takes that degraded condition as the non-degraded condition – as the normal experience.” Hence, landscape fragmentation also has a societal or human dimension, namely of how human populations perceive the fragmentation and degradation of semi-natural areas and of how this influences human well-being, for instance by reducing the accessibility to green areas. The effects of fragmentation on human populations have rarely been addressed so far (Di Giulio et al., 2008).

In densely populated regions an integration of nature and urban environments has the potential to foster native species and to improve human well-being. For this purpose, conservation scientists have to participate in partnerships with planners, land managers, policy-makers and the general public (Miller, 2005). They need to define land-management strategies that reduce the negative environmental impacts of human land-use and result in social and economic benefits at the same time. Such strategies should thus combine ecological values like local biodiversity with social values like restoration for city-dwellers (Miller and Hobbs, 2002; Foley et al., 2005; Forman, 2008). Knowledge whether the needs of biodiversity and humans are compatible and how they can be reconciled, would support such management strategies (Fitzsimons and Wescott, 2007). Although the inter-relationships of ecological and human dimensions of fragmentation are most relevant in densely populated regions, corresponding ecological studies and sociological studies are scarce.

The objectives of this study were (i) to identify the needs of biodiversity and humans that specifically arise in densely populated landscapes; (ii) to assess the possibilities to reconcile ecological and societal needs; and (iii) to give recommendations for integrated planning and future research. We therefore first review

Fig. 1. The city of Zurich with the northern part of Lake Zurich as an example of a densely populated landscape. In the year 2000, the agglomeration of Zurich had more than a million inhabitants. On the aerial photograph neither the individual municipalities nor the borderline between settlements and the countryside can be distinguished. (Aerial photograph of swisstopo, 8.6. 2000, Fotothek Wabern, route 2000245001, picture nr. 4744, reproduced with the authorisation of swisstopo JA082265).
and evaluate the ecological literature relevant for fragmentation in densely populated landscapes. Second, we do the same for the sociological literature. Because of the scarcity of respective studies, we also refer to general theories on how humans perceive their everyday landscape. Third, we briefly show how planning tries to incorporate both the ecological and human dimensions of fragmentation in densely populated landscapes. Finally, we evaluate whether there are similarities or dissimilarities between the ecological and human dimensions of landscape fragmentation and identify potential topics of future research.

2. Methods

We searched the ISI Web of Science for literature on habitat fragmentation and landscape preferences (years 2000–2007) and added citations of earlier articles and books. We selected studies from densely populated and urbanised regions and excluded studies from tropical rainforests and large national parks. Since densely populated regions differ ecologically and sociologically among continents, we mainly referred to studies from Europe. However, as the corresponding literature is not vast, we also considered relevant studies from other continents, although a direct transfer of their results to European landscapes is problematic.

Densely populated areas enclose both urban centres and their fringes. The transition between urbanised areas and the proper countryside is diffuse (Fig. 1), resulting in suburban landscapes characterised by a variety of land-uses and consisting of a mosaic of land cover types such as settlements, transportation infrastructure and agricultural areas (Antrop, 2004). Furthermore, ecological studies often treat urban areas as homogenous entities and do not clearly define study areas as urban or suburban (Godefroid and Koedam, 2007). In contrast, sociological studies use standardised definitions of urban areas. This discrepancy makes the comparison between sociological and ecological studies difficult (Niemelä, 1999b; McIntyre et al., 2000). In consequence, we considered studies from urban, suburban and other densely populated regions.

In our article we use the terms “landscape” and “habitat” according to Lindemayer and Fischer (2006). Landscape is defined from a human perspective and covers hundreds of hectares. We adopted this definition because we are especially interested in the relationship between humans and their environment. Habitat is a species-specific entity and defines the environment suitable for a particular species (Hall et al., 1997). We therefore use the term “habitat fragmentation” when we refer to the ecological effects of fragmentation, because they are species-specific, and we use the term “landscape fragmentation” when we specifically refer to the sociological aspects of fragmentation.

3. Ecological effects of habitat fragmentation

We first refer to the general effects of fragmentation on biodiversity, in particular the effects of edges and small patch size. Then, we treat the questions of whether urban land-use and the high road density in densely populated areas lead to effective isolation of animal and plant populations. Subsequently, we provide appropriate management strategies.

3.1. Effects on biodiversity

The effects of habitat fragmentation on biodiversity have been studied for several decades, resulting in a vast literature on this topic. However, findings often remained contradictory and did not lead to a generally accepted concept of the underlying effects of habitat fragmentation. As a consequence, fragmentation effects are difficult to translate into management strategies and into general rules to mitigate the negative effects of fragmentation on biodiversity (Haila, 2002; Ewers and Didham, 2006; Lindemayer and Fischer, 2007). Two main reasons account for this discrepancy. First, the concept of habitat fragmentation is ambiguous. A major problem is that, in the process of habitat fragmentation, changes in the spatial configuration of habitat and resources are inevitably confounded with a reduction in total habitat area. Most fragmentation studies did not distinguish between the reduction of habitat area and fragmentation per se, i.e. the breaking apart of a habitat and the spatial separation of habitat fragments (Harrison and Bruna, 1999; Debinski and Holt, 2000; McGarigal and Cushman, 2002; Fahrig, 2003). Second, there is a mismatch between theoretical and empirical studies. Theoretical studies emphasise the importance of dispersal (Kareiva and Wennergren, 1995; Rosenberg et al., 1997; but see Bowman et al., 2002; Tischendorf et al., 2005), while empirical studies indicate that fragmentation is rather a matter of habitat degradation and edge effects than of decreased migration among populations (Harrison and Bruna, 1999; Melbourne et al., 2004).

During the last few years, several authors critically reviewed the existing literature of habitat fragmentation (Harrison and Bruna, 1999; Debinski and Holt, 2000; McGarigal and Cushman, 2002; Fahrig, 2003; Ewers and Didham, 2006; Lindemayer and Fischer, 2006). We are, however, not aware of any reviews that specifically looked at densely populated areas.

Densely populated, especially urban areas may exert strong, hard and abrupt edge effects. There are both physical and biological edge effects. Physical edge effects are mainly due to microenvironmental changes, while biological edge effects result from changes in species interactions, e.g. increased predation. Often physical and biological edge effects interact. Fragmented habitats harbour a larger amount of edges and a smaller amount of core areas, only the latter being unaffected by changes in surrounding land–use (Saunders et al., 1991). For densely populated areas, several studies showed that agricultural lands and settlements result in negative edge effects that change species composition and jeopardise habitat specialists (Jokimäki and Huhta, 2000; Niemelä, 2001; Chalfoun et al., 2002; Lienert, 2004). Disturbances from leisure activities change the bird species composition of edges in urban forests. At the edges, the breeding density of bird species foraging on the ground and of species nesting in tree cavities is reduced. Disturbance by pedestrians and traffic noise impede some bird species from breeding near streets and footpaths. However, other bird species have higher breeding densities at the edges of urban forests. They probably exploit anthropogenic resources such as garbage and are not disturbed by human activities (Fernandez-Juricic, 2001).

Fragmentation also increases the number of habitat patches and decreases patch size. At some point, each habitat patch will be too small to sustain a local population. Species that are unable to cross the matrix will then be restricted to too small patches, reducing population sizes and the probability of persistence (Fahrig, 2003). Studies indicated that in densely populated regions of Europe many types of semi-natural areas have become too small to permanently maintain viable populations of habitat specialists (Vos and Charbon, 1998). Semi-natural vegetation like extensively used calcareous grasslands and fens were abundant in the former, extensively managed agricultural landscape. These habitat types strongly declined during the last century due to land-use changes (Baur et al., 2004). Studies indicated that the population size of plants, especially those of habitat specialists, is reduced in the remaining patches (Fischer and Stöcklín, 1997; Stöcklín et al., 2000; Lienert et al., 2002).
3.2. Fragmentation effects of urban land-use

Land-use between habitat patches affects the communities within patches as well as the effective isolation of animal and plant populations (Vandermeer and Carvajal, 2001; Jules and Shahani, 2003). For instance high road and traffic density augments migration mortality of animal species and enhances the isolation of populations (Ricketts, 2001; Forman et al., 2003). We are, however, only aware of three studies explicitly examining the isolating effect of urban land-use on plant and animal populations (for transport infrastructure see below). Hitchings and Beebee (1997, 1998) showed that populations of common toad (Bufo bufo) and common frog (Rana temporaria) in urban regions were smaller than populations in rural areas and that the urban matrix isolated local populations genetically, leading to inbreeding. Thus, urban land-use acts as a barrier to gene flow in animal populations, even in relatively abundant and widespread species. In contrast, species richness and total abundance of leaf-mining moths on oaks (Quercus agrifolia) were not affected by urban land-use. These small insects can maintain large populations in relatively small patches of one to several oak trees (Rickman and Connor, 2003). In summary, urban land-use seems to effectively separate populations of vagile animals, but may not necessarily affect small and sedentary animals.

3.3. Fragmentation effects of roads and traffic

Transport infrastructure is a prominent component of urban land-use, and road and traffic densities are generally high in human-dominated landscapes (Oggier et al., 2001; EEA, 2002). Several reviews summarised the effects of roads and traffic on biodiversity (Trombulak and Frissell, 2000; Spellerberg, 2002; Forman et al., 2003).

Studies conducted in Europe indicated a general fragmentation effect of roads and traffic on populations of animal species based on three main effects: (1) inaccessibility of resources, (2) increased road mortality due to collisions with vehicles and (3) subdivision of populations by roads (Jaeger et al., 2005).

(1) As roads can act as barriers to animal movement, resources like food and breeding sites may not be accessible for individuals that cannot cross roads. Reduced access to resources can lead to lower reproductive and survival rates, which, in turn, may reduce population persistence. This separating effect of roads especially affects species avoiding roads (Mader et al., 1990; Wirth et al., 1999), species requiring multiple habitats (Richarz, 2000) and species migrating over long distances to access different resources at different stages of their life-cycle (Pfister et al., 1998; Holzgang et al., 2001; Georgii et al., 2002).

(2) Every year, enormous numbers of animals are killed on roads due to collisions with vehicles (Van der Zande et al., 1980; Seiler and Helldin, 2006). However, the number of road kills is not necessarily a meaningful indicator for population decline, because low numbers may indicate reduced population densities near roads or road avoidance (Fahrig et al., 1995; Forman et al., 2003; Jaeger et al., 2005). Nevertheless, there are several species suffering population declines due to traffic mortality. For badgers (Meles meles) traffic mortality is a major threat. In Holland, yearly traffic mortality of badgers is estimated to sum up to 25% of this species’ total population size and is responsible for the decline of the species during the last decades. Similarly, road traffic is the largest single cause of deaths in badgers in Great Britain and other European countries (Van der Zee et al., 1992; Aaris-Sorensen, 1995; Clarke et al., 1998; Van Langevelde et al., 2009). Many amphibian populations are compromised due to traffic mortality (Fahrig et al., 1995; Hels and Buchwald, 2001), as their seasonal migration between aquatic breeding sites and terrestrial habitats makes them particularly vulnerable to roads and traffic. The species most imperilled by roads are vagile species and species using multiple habitats separated by roads (Fahrig et al., 1995; Gibbs, 1998; Carr and Fahrig, 2001; Pellet et al., 2004).

(3) Population subdivision occurs when populations become separated into smaller, isolated subpopulations. Populations living in habitats surrounded by roads are less likely to receive immigrants from other habitats and thus suffer a lack of gene flow potentially leading to inbreeding (Hanski and Gilpin, 1991; Keller and Waller, 2002). Several studies proved the isolating effect of roads on animal populations: Highways disrupt gene flow among populations of bank voles (Clethrionomys glareolus), common frogs (R. temporaria) and a Carabid beetle (Carabus violaceus), both reducing the genetic diversity of subpopulations and enhancing their genetic differentiation (Reh and Setz, 1990; Gerlach and Musolf, 2000; Keller and Largiadé, 2003; Keller et al., 2005).

3.4. Discussion and management strategies

The present results indicate that the effects of a reduction of habitat area on species richness and species composition are better established and seem to be stronger than the effects of fragmentation per se. Hence, the amount of available habitat and its quality is judged to be more important for the persistence of animal and plant populations than the spatial configuration of habitat patches. Environmental management and planning should therefore pursue strategies to enhance habitat quantity and quality above all. However, when restoring new habitat, the spatial configuration of habitat patches is important so that plants and animals can recolonise new patches rapidly. In densely populated landscapes, patches of semi-natural areas are often isolated by urban land-uses, especially by traffic infrastructure. The latter strongly enhance the effective isolation of animal and plant populations by impeding individual and gene exchange among populations. Due to high road and traffic densities in densely populated regions, it is assumed that the isolating effect of roads on populations is especially strong here. In addition to a strong focus on habitats, planning should therefore comprise measures that can reduce the separating effects of traffic infrastructure. When planning mitigation measures an integrated strategy considering regional networks of major and minor roads is needed (Van Langevelde et al., 2009). An example for such a regional planning approach is the “long-term defragmentation programme” in The Netherlands. This programme includes different modes of human transport such as roads and railroads and aims to enhance habitat connectivity and population persistence for various species jeopardised by transport infrastructure. The regional planning approach is especially appropriate for highly fragmented landscapes because it coordinates defragmentation measures, such as overpasses, at neighbouring infrastructure barriers (Van der Grift, 2003; Van der Grift and Pouwels, 2006).

4. Effects of landscape fragmentation on humans

Are humans affected by the fragmentation of their environment? What factors make humans perceive their environment as fragmented? Does landscape fragmentation isolate human populations? Recent studies indicated that people’s needs are similar in different cultures and political systems (Matsunaka and Kaplan, 2008). However, our search for relevant articles in electronic
databases yielded a disillusioning result: very few specific studies, especially from Europe, are available, which contrasts sharply with the vast amount of ecological and landscape ecological studies on habitat fragmentation. Therefore, we first summarise the general literature on the relationship between humans and landscapes and then refer to studies evaluating whether land-use types such as roads have a barrier effect on people.

4.1. Which kinds of landscape do people prefer?

An important current research topic is landscape aesthetics, which examines the perception and assessment of landscapes by humans (Bourassa, 1991). Following Bourassa (1991), there is a biological and a cultural dimension to landscape aesthetics. The biological dimension of landscape experience is based on two different hypotheses, which explain why humans prefer certain landscape types. The first hypothesis is based on the assumption that certain environments enhanced survival during human evolution. Therefore, a preference for these landscape types evolved during human history (Kaplan and Kaplan, 1989; Kaplan, 1995). The second hypothesis is based on findings showing that natural landscapes have a restorative effect on humans. Restorative landscapes often contain natural elements like trees or possess distinct topographies (Kaplan and Kaplan, 1989; Hartig et al., 1997; Purcell et al., 2001). Water is a key factor evoking interest, calm and positive feelings and therefore has a high aesthetic preference (Zube, 1973; Ulrich, 1983). Most humans prefer landscapes that appear natural, with a mixture of open areas and forested land. In contrast, dense forests and landscapes without structuring elements are less preferred (Bourassa, 1991; Hunziker and Kienast, 1999; Hunziker, 2006).

Theories describing the biological dimension of landscape aesthetics neglect the cultural dimension of human environments (Bourassa, 1991). Landscapes and certain landscape elements obtain social significance and become cultural symbols. Examples are historical buildings like churches and castles as well as natural elements like prominent trees. These elements establish cultural identity and continuity in local human populations. Their change or loss is objected by local people because this results in a disruption between the past and the future (Sell and Zube, 1986; Felber Rufer, 2006). Landscapes thus serve as a kind of external memory, reminding people of their experiences, values and social affiliation.

A positive interaction between human population and environment results in place identity (Proshansky et al., 1983; Twigger-Ross and Uzzell, 1996). Place identity affects place attachment, the latter being important for experiencing restoration (Korpela et al., 2001). Favourite places have a restorative effect on people and cause feelings such as calm, happiness, being away from everyday life, forgetting worries and contemplation (Korpela and Hartig, 1996; Korpela et al., 2001). However, for local human populations, the function of a landscape such as agricultural use may be more important than just its visual characteristics. Landscape values strongly depend on personal experiences as well as personal utility functions (Coeterier, 1996).

4.2. Contact with nature and recreation

Several studies showed that contact with nature is a human need and contributes to an improved quality of life (Kaplan and Kaplan, 1989; Matsuoka and Kaplan, 2008). In urban and densely populated areas, the desire for contact with nature is an important motivation for visiting green spaces, for instance to enjoy changing seasons or to observe wild animals (Harrison et al., 1987; Burgess et al., 1988). Contact with nature and native wildlife can reduce the gap between humans and the natural world. This gap is held responsible for the lacking public support for biodiversity conservation (Miller, 2005). Further motives for visiting green spaces are recreation, calm, contemplation, physical activities and social interactions (Baur et al., 2003; Seeland and Ballesteros, 2004; Gidlöf-Gunnarsson and Öhrström, 2007).

Local residents visit green spaces for daily recreation, and these open spaces are hence an important part of their everyday life and their everyday landscape (Kaplan, 2001; Tzoulas et al., 2007). Accessibility to such areas is important: public green spaces are more appreciated than private gardens (Wild-Eck, 2003; Gobster and Westphal, 2004). In addition, a short spatial distance between green spaces and home is crucial as most residents visit them by foot. Green spaces should be reachable within 15 min walking distance, otherwise they will not be visited for daily recreation (Grahn and Stigsdotter, 2003; Töyvänen et al., 2005). Green spaces near residential houses are also relevant for children, because they allow children to play outside and to socialise, supporting their physical and psychical development and social behaviour (Degen-Zimmermann, 1995; Schenkel et al., 2005; Tzoulas et al., 2007).

In densely populated landscapes, residential areas spread and settlements become more compact. These trends result in a decrease of green spaces. How does this trend affect local human populations? First, local residents regret the loss of green spaces both within settlements and in the surroundings, because these areas are seen as important elements of the everyday environment (Felber Rufer, 2006; Töyvänen et al., 2007). Second, the loss of green spaces seems to have negative effects on people’s health. Most people visit green spaces to recover from stress: the more and longer they visit green spaces the better they recover and the less they suffer from illness caused by stress (Grahn and Stigsdotter, 2003; Töyvänen et al., 2005; Tzoulas et al., 2007). As green spaces enhance physical activities they generally enhance human health. In neighbourhoods with a high density of green spaces people are healthier (De Vries et al., 2003; Pikora et al., 2003) and live longer (Takano et al., 2002) than in neighbourhoods with fewer green spaces.

4.3. Barrier effects on humans

Roads with high traffic frequencies might present barriers to humans, especially pedestrians. This barrier effect has been recognised for a long time and is a pervasive social problem in urbanised areas. Even so, the effects on pedestrian movement are usually not measured and have regularly been ignored in transportation planning and traffic engineering practice (Russell and Hine, 1996; Guo and Black, 2000; Egan et al., 2003). Not referring to the literature on the well known medical effects of noise and pollution on humans, the studies presented below are selected from traffic engineering, health and social sciences and show various aspects of road effects on humans.

Busy roads and high traffic densities reduce the restorative effect of everyday landscapes. People often take a walk in their neighbourhood for daily recreation (see Section 4.2.). In neighbourhoods with heavy traffic, people tend to stay at home and fail to walk outside and get exercise. Hence they cannot recover and suffer from stress related illness (Grahn and Stigsdotter, 2003; Lee and Moudon, 2004; James et al., 2005). Abraham et al. (2007) stated that pedestrian friendly environments foster physical activities and human health. Calmness is an important motive for visiting recreational areas and represents a basic quality of green spaces (Frick et al., 2007; Gidlöf-Gunnarsson and Öhrström, 2007). Therefore, green areas that are large enough to shelter visitors from traffic noise are particularly relevant (Töyvänen et al., 2007).

Wide and busy roads like highways also divide human communities into parts that hardly interact with each other, thus
causing community severance (Guo and Black, 2000). Community severance has two components: road infrastructure as a static barrier to the local community and traffic as a dynamic barrier to pedestrians. The direct effects of severance are trip diversion and suppression, poor accessibility and restricted personal mobility in affected neighbourhoods. The indirect effects may be psychological, cultural and social. For example, people reduce their involvement with quarters on the opposite side of busy roads. Therefore, social activity across such roads is reduced (Lee and Tagg, 1976; Guo and Black, 2000; James et al., 2005). Community severance does not affect all social groups equally. The most vulnerable groups are people with restricted mobility (e.g. elderly people), school children and people without access to a personal car (Hine and Russell, 1996; James et al., 2005).

4.4. Discussion and management strategies

Landscape preferences are important in densely populated landscapes, because they can establish cultural identity. Environmental management and planning should therefore preserve landscape elements that are cultural symbols and that can establish cultural identity and continuity in human populations. The primary goal should not be to conserve static landscape scenarios but to foster a dynamic development of landscapes. Furthermore, in densely populated landscapes, the existence, quality and accessibility of recreational areas are important landscape values. These recreational areas should enable children and adults to experience nature and to encounter native plants and animals so that they prevent environmental generation amnesia (Kahn, 2002; Miller, 2005). Green spaces for daily recreation are important for the well-being of local residents and are mainly visited by foot. Barrier effects of roads on pedestrians may reduce accessibility of recreational areas and lower the physical activity of people. Environmental management and planning should therefore account for barrier effects of roads and take measures to mitigate them. In the town of Zurich (Switzerland), for example, a motorway was covered over a length of 550 m to reduce noise exposure of the local population and to re-connect the quarter Zurich-Wollishofen with the nearby recreation area Enzelm. During 40 years the motorway passed through the quarter and led to a strong barrier in the landscape, isolating the local human population from their recreation area. On the new motorway cover, landscape elements such as meadows and ponds were created that also enhanced the ecological quality of the landscape (Di Giulio et al., 2008).

5. Quantifying fragmentation in ecology and landscape aesthetics

Environmental managers depend on tools to integrate biodiversity issues and people’s needs in landscape planning and environmental assessment. Indicators are common tools to define planning goals and to evaluate the measures taken (Opdam et al., 2002; Mörtberg et al., 2007; Quine and Watts, 2009). Relevant indicators should be applicable at various spatial scales and describe varying landscape functions (Girvetz et al., 2008; Quine and Watts, 2009). In densely populated landscapes, indicators for integrating biodiversity and aesthetic issues are needed, but not yet developed (Dramstad et al., 1998; Antrop, 2004; Schupp, 2005).

In landscape ecology, numerous indices have been developed to assess and quantify the structure and heterogeneity of landscapes. Landscape indices describe the composition of landscapes (e.g. the proportion of forests) and the spatial arrangement of landscape elements (e.g. the spatial position of trees in a landscape). There are also indices that assess the temporal change of landscapes (Turner et al., 2001; Bolliger et al., 2007). In contrast, landscape indices for human landscape preferences should assess the essential characteristics of landscapes and establish a relationship to their aesthetic qualities. Landscape indices, either ecological or aesthetic, that fulfil these prerequisites could contribute to the development of standardised methods to assess and quantify landscapes (Piorr, 2003; Dramstad et al., 2006; Ode et al., 2009). In the following sections, we discuss the application of landscape indices as indicators for the ecological effects of habitat fragmentation and as indicators for visual aspects of landscapes.

5.1. Landscape indices as indicators of habitat fragmentation in ecology

Several authors critically reviewed studies using landscape indices in landscape ecology (Gustafson, 1998; Li and Wu, 2004). A main problem is that most landscape indices focus on the description and quantification of spatial patterns, but neglect how these patterns affect or are affected by ecological processes (Gustafson, 1998; Li and Wu, 2004). Landscape indices may link ecological processes to landscape structure, but their ecological relevance is often not empirically established. In the absence of such evidence, landscape indices are mathematical constructs of unproven ecological meaning (Holderegger et al., 2007). Landscape indices must reflect a clear relationship between spatial patterns and ecological processes, otherwise they are practically insignificant (Schumaker, 1996; Li and Wu, 2004; Niemi and McDonald, 2004).

The mentioned flaws also apply to landscape indices reflecting habitat fragmentation. Rutledge and Miller (2006) reviewed 566 studies and concluded that the majority contributed little to the understanding of the relationship between pattern and process. Furthermore, few of these indices are specifically geared to habitat fragmentation (Jaeger, 2000). Lastly, most fragmentation indices are strongly interrelated and insensitive to variation in the spatial arrangement of habitat patches. They are thus not appropriate to quantify patch configuration, but mainly measure the amount of habitat area in a landscape (Hargis et al., 1998; Bender et al., 2003). During the last years, specific fragmentation indices have been developed. For example, effective mesh size (Jaeger, 2000) is a measure used as an indicator for landscape fragmentation in various countries, e.g. Switzerland, Germany and California (Jaeger et al., 2006, 2008; Girvetz et al., 2008). Its ecological relevance has been verified in recent studies (Roedenbeck and Köhler, 2006; Roedenbeck, 2007), showing that effective mesh size is a suitable indicator for generalist species with large home ranges such as roe deer (Capreolus capreolus). However, for more specialised species, effective mesh size is only an adequate indicator, if specific habitat requirements are incorporated into analysis. Roedenbeck and Köhler (2006) suggested that effective mesh size should be applied together with quantitative measures for quality and occurrence of habitat when monitoring habitat fragmentation.

5.2. Landscape indices as indicators for landscape preferences

There are only few sociological studies that used landscape indices to quantify the landscape preferences of humans. These studies nevertheless indicated that measures quantifying the number and diversity of land-use types as well as the heterogeneity of landscapes correlate well with human landscape preferences for diverse and heterogeneous landscapes (Hunziker and Kenan, 1999; Palmer, 2004; Dramstad et al., 2006; Lee et al., 2008). Since humans prefer landscapes that are perceived as “natural”, landscape indices associated with naturalness are positively correlated with landscape preference (Ode et al., 2009). Moreover, landscape indices are suited to assess the perceived aesthetic quality of
landscapes in the long term. Palmer (2004) showed that for the human population of Dennis (Massachusetts, USA), values given to landscape elements such as forests and naturalness were stable over 20 years, while, in fact, the landscape itself strongly changed during this period.

Despite the above results, the application of landscape indices in sociological studies must be questioned in densely populated landscapes, because place identity and place attachment are formed in relation to the local environment (Hunziker, 2006; Hunziker et al., 2007). Place identity and attachment are both only indirectly affected by the spatial landscape characteristics. For example, Dramstad et al. (2006) found that the landscape preference of students and local people differs in Norway. Students of a nearby university, which had no personal relation to the study region, preferred diversified and heterogeneous landscapes. For local people, however, diversity and heterogeneity were not important environmental values. In densely populated areas, landscape indices may thus not be suitable to quantify the landscape preferences of local human population.

Landscape indices including the qualitative aspects of landscapes may be better suited. For example, the proportion and accessibility of green spaces are important values in densely populated areas (De Vries et al., 2003; Tyrvainen et al., 2005). Hence, indices that include quantity, quality and accessibility of green spaces might be suitable measures to assess the landscape preference of human populations. City authorities already use such specific indices in open space planning, e.g. the proportion of public urban green spaces in a given neighbourhood (Tyrvainen et al., 2007). Social values, however, are not yet sufficiently taken into account, because they are affected by personal experiences and are therefore difficult to assess. Tyrvainen et al. (2007) developed a tool to map the social values of green spaces such as naturalness and tranquility. Such maps can be used in planning and management of open green spaces. Generally, visualisations are a good method to incorporate landscape qualities as well as the needs of local people in landscape planning and environmental management. For example, future landscape development (e.g. the infill of existing housing areas) can be visualised by photo simulation and used to assess the effects on visual aspects of landscape change as well as the attitude of local people (Hunziker and Kienast, 1999; Tahvanainen et al., 2002; Ode et al., 2009).

5.3. Discussion and management strategies

Landscape indices potentially link landscape patterns to ecological processes and to visual aspects of landscape preference. If so, they could become important indicators for policy and planning. A prerequisite is that there is a relationship between landscape indices and ecological processes and human landscape preferences. There are currently no indices that integrate both aspects of fragmentation. In recent years, specific fragmentation indices have been developed to assess the ecological effects of habitat fragmentation on animals. Empirical data indicate that these fragmentation indices, in combination with indicators for habitat quality, are suitable for monitoring habitat fragmentation. In contrast, indicators that generally assess the relationship between human populations and their environment are still missing. However, specific indicators assessing qualities of urban environments, e.g. security and accessibility of green areas, are suitable to depict peoples’ need. They may thus constitute applicable indicators for landscape planners and managers. In summary, a set of quantitative and qualitative landscape indices or indicators would be needed that integrate both the societal and ecological aspects of fragmentation for the purposes of management and planning.

6. Conclusions and future directions

Our literature review indicated that the needs of humans and biodiversity in response to fragmentation have some similarities. We depicted the most important ones: the loss of semi-natural areas has stronger effects than the isolation of these areas per se. In densely populated landscapes, landscape planning and management should therefore enhance the amount and the accessibility of semi-natural areas for recreation and as habitats for plants and animals. In intensively used and multifunctional landscapes, however, the total amount of semi-natural areas tends to decrease, and the quality of the remaining areas becomes more important. Interestingly, the ecological quality of remnant patches is important for both humans and biodiversity, because it fosters biodiversity, and biodiversity, in turn, enables people to have a stimulating contact with nature. The latter improves human well-being in densely populated landscapes. So far, only little is known about the ecological and social qualities of semi-natural areas and open green spaces in urban environments. Future research should therefore focus on the factors affecting their qualities: Which are the most important social and ecological qualities of semi-natural areas and green spaces and how can their quality be enhanced? How shall they be designed to meet the demands of people and biodiversity?

Another important similarity between the needs of humans and biodiversity is a positive effect of heterogeneity. Humans seem to prefer natural and heterogeneous landscapes. Heterogeneity also enhances biodiversity at different spatial scales (Benton et al., 2003). However, people’s preference for heterogeneous landscapes, have mainly been explored in rural landscapes and heterogeneity might be less important for local people than other landscape functions, in particular personal uses. An interesting topic for future research is whether heterogeneity is an important aesthetic quality of urban environments and at which scale it enhances landscape preferences. Several studies showed that in urban areas people prefer heterogeneity at the very local scale, but it has not yet been shown, whether people also prefer heterogeneity at the landscape scale. An important premise to analyse similarities in the needs of humans and biodiversity is a common definition of heterogeneity at various spatial scales. Here landscape ecological research can support an interdisciplinary approach by providing common definitions and measures. Corresponding results will help to define guidelines for the design of semi-natural areas and green spaces that are geared to both fulfilling the needs of local human populations and fostering biodiversity.

There are also some important differences in the needs of local human populations and biodiversity. Therefore, there are no general, empirically tested ready-made solutions that are applicable in environmental planning and management to fulfil both, the needs of humans and biodiversity, simultaneously. In densely populated landscapes a shift from responsive planning to intentional design of environments is needed. Such intentional planning requires well-founded problem definitions and objective settings. Lindenmayer et al. (2008) stress the importance to derive clear objectives from a broad vision of what people expect from their landscapes in the future. Priorities must then be set, because not all goals are equal and cannot be reached by the same measures. For semi-natural landscapes, several authors (e.g. Lindenmayer et al., 2008) recommended management approaches and strategies for planners and environmental managers. However, for densely populated regions, these management approaches are not sufficient, because conflicting goals are prominent, e.g. reserves to enhance species richness vs. access and recreation for city-dwellers. Future research should complement the management approaches suggested for semi-natural landscapes and generate
urgently needed empirical results contributing to effective management strategies for densely populated areas.

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