Resilience assessment of Maastricht as a social-ecological system

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Abstract
The aim of this report is to assess the resilience of Maastricht as a multi-level, dynamic, social-ecological system by following the 'Workbook for Practitioners' by the Resilience Alliance (2010). A description of the system outlines historical events that had impacts on the landscape, such as urban expansion and the mining of limestone. The evaluation concludes that Maastricht finds itself at a point in a dynamic adaptive cycle of events where citizens' awareness of nature and global environmental issues led to reconsiderations of ecological values and the reorganisation of the city according to these values. The assessment applauds the adaptive governance approach of the city and the current implementation of various 'greening projects'. However, issues regarding possible lack of system resilience are criticised. Among others, recommendations are given related to increasing species diversity within and surrounding the urban area of Maastricht.

This report aims to assess the resilience of the urban area of Maastricht as a social-ecological system. The resilience is defined as the capacity of a system to maintain or return to its identity, including its function, feedbacks, and structure, after a major disturbance (Walker & Salt, 2012). Maastricht's general resilience to disturbances will be looked at, as well as some elaboration on its resilience towards biodiversity threats. Maastricht's social-ecological system involves multiple scales, which interact with each other and the focal scale, resulting in changes in the landscape. This report adopts a 'resilience thinking' approach. Additional attention will be drawn to the St. Pietersberg area within the urban landscape and assess the impacts of changes within this area on the whole system's resilience. It will further identify and describe the system's dynamics, interactions between different scales, assess the governance, and finally suggest actions to improve the resilience of Maastricht's urban landscape.

I. Methods

This resilience assessment closely follows the 'Workbook for Practitioners' by the Resilience Alliance (2010). It observes Maastricht as a dynamic, self-organising system with emergent behaviour and affected by cross-scale interactions. Its general resilience to cope with various future social and ecological change and disturbances, such as temperature change, floods, or urban expansion, depends on its diversity, social capital, and openness (Walker & Salt, 2012). Identified interactions between different scales, thresholds, and adaptive governance will be used to evaluate social and ecological resilience.

II. Area

Maastricht is the capital city of the province of Limburg in The Netherlands. As the focal scale, it covers a total area of 6007 ha (Gemeente in Cijfers, 2014). The city itself is home to about 122 000 inhabitants (Gemeente in Cijfers, 2014). Even though the city experienced some significant urban expansions within the last 200 years, it is only increasing at a slight rate (Gemeente in Cijfers, 2014). Important features of the landscape include the river Maas, which runs directly through Maastricht, the side-river Jeker, which connects the Maas to the Albert Canal, the proximity of the Belgian border, and the excess of agricultural area around the city. The municipality of Maastricht is currently implementing a number of projects with the intention of drawing green spaces into the city and thereby increasing the connectivity between these areas. They realised that, because the land around Maastricht is mostly devoted to agriculture, the city and its trees are becoming a refuge for certain species. Due to the scope of this report, some focus shall go to the St. Pietersberg area and will later be related to the 'Groene Loper'. These two areas are part of two major greening projects within the city that are currently in motion.

III. The St. Pietersberg Area

The St. Pietersberg area comprises a total area of 350 ha in the south of Maastricht between the Maas and the Jeker, including a limestone quarry of 125 ha (Gemeente Maastricht, 2014). The St. Pieters 'mountain' itself has been protected since 1974 and has been established as a Natura-2000 area (Gemeente Maastricht, 2014). Natura-2000 is a policy set up by the European Union to protect significant areas to Europe's biodiversity (European Commission, 2014). Due to the limestone formation, unique limestone grassland species occur in this area that are normally found in Southern Europe (Gemeente Maastricht, 2012; Stichting Ontwikkelings-maatschappij ENCI-Gebied, 2014, a).

Miners started using the limestone in the 12th Century to build houses, creating an intricate tunnel system that is now a touristic attraction (Peters & van Winden, 2002). The ENCI ("Eerste Nederlandse Cement Industrie" – First Dutch Cement Industry) got permission to extract limestone for cement production since 1926 (Groen Maastricht, 2014, a). They are now part of the 'Transformation Plan', established in 2009, in which the decision was made to convert the quarry into a nature reserve for biodiversity and recreational purposes (Groen Maastricht, 2014, a). Natuurmonumenten, a Dutch nature conservation organization, will manage the area from 2018 onwards (Peters & van Winden, 2002). The 'Oehoevallei', which is the area of the quarry furthest away from the factory and closest to the city, is already dedicated to Natuurmonumenten (Stichting Ontwikkelingsmaatschappij ENCI-gebied, 2014, b).

IV. Results

Ecosystem Services

The entire focal scale provides the citizens of Maastricht with the following ecosystem services, table 1.

Throughout history, this landscape has had to cope with urbanisation, the conversion of forested land to agricultural areas, and limestone mining practices. The ecosystem services have contributed a lot to the development of the city, but the biodiversity has been compensated to the extent where conservation policies need to be strictly implemented to avoid extinction. For example, the Buba Buba owl, which is the largest owl in Europe and has its habitat in limestone grasslands, is nearing extinction in this area. By increasing its habitat by enhancing green areas and hunting grounds, their numbers might grow. The costs include the termination of the ENCI in the quarry and costs involved in executing greening projects, such as the 'Groene Loper', of which the contract budget amounts up to €515 million (Projectbureau A2 Maastricht, 2009, b).

Description of the System

Maastricht's urban history goes back to the time before the Roman occupation around Christ. Due to its strategic location, Maastricht became an important city for cultural, political, and economic purposes (Panhuysen, 1996). In 1867, Maastricht was no longer a fortressed city, meaning that from then on property was allowed to be build outside the city walls (Stedentrip, 2010). This opened the doors to urban expansion. The population dramatically increased after World War II, resulting in an increase in construction activities as there was a lack of housing (Stouthart, Jenniskens, & Baeten, 1985). The University of Maastricht was set up in the 1970s as a compensation for the economic loss to the province due to the closing of the coalmines (Stouthart, Jenniskens, & Baeten, 1985). This attracted an international population and more urban development. Maastricht's history as sa fortressed city is the reason for its relatively compact urban state today.

Maastricht's landscape was formed through the influence of multiple systems over time at larger and smaller scales than the focal scale (figure 1). Cross-scale interactions and anthropogenic activities in the past have led to some threats to the resilience of the social-economic system. The main threat was the gradual decline in biodiversity. The increase in limestone extracting operations by the ENCI had a significant impact at this scale. In contrast to the centuries-long underground mining operations in the past (which created habitats for at least twelve bat species (Stichting Ontwikkelingsmaatschappij ENCI-Gebied, 2014, a)), the ENCI dug away half of the tunnel system at the St. Pietersberg, thereby disturbing grassland habitats and removing forests. In the 1950s, some parts to the western side of the quarry were reforested (Peters & van Winden, 2002). Diseases and pests will be a continual threat that affects the diversity of the whole system, also within the city itself. In 2012, 384 of the 1397 Horse Chestnut trees had to be cut due to the rapidly spreading, fatal bleeding canker disease that was spreading throughout The Netherlands at the time (Dichtbij, 2012).

Despite the threat to biodiversity within the quarry, some species found recovery when the ENCI stopped digging in the northern part of the quarry (the 'Oehoevallei'). The area was covered with soil, allowing for loam soil formation, which retained water and attracted various dragonfly species and toads, specifically the Natterjack toad and Midwife toad (Peters & van Winden, 2002). This area has also become the preferred breeding ground for the Buba Buba. Additionally, as limestone extraction occurred below the water table, this lead to the formation of natural pools and seepages, which have formed valuable habitats to different species (Peters & van Winden, 2002). The variety in the quarry's landscape and the old city walls around Maastricht have a similar effect in that they form species habitats (Gemeente Maastricht, 2012). The old city walls, for example, have many cracks between which plants can grow. The walls have become a refuge where species can rest, feed, and nest.

One of the future threats to the whole system is climate change, which causes temperature increases that can be exacerbated by the urban heat island effect. A study done on surface temperatures in Maastricht shows lower temperatures for more green spaces than for more urbanised spaces, such as the city centre (Duyzer, Verhagen, & Klok, 2012). Increasing heat can be detrimental to the health of the citizens, especially people who are physically more sensitive, such as the elderly. As Maastricht has a relatively high percentage of elderly people (Duyzer, Verhagen, & Klok, 2012), maintaining valuable ecosystem services is vital. Climate change also promises more precipitation in the winter, which can lead to an increase in flooding frequencies of the Maas (Gemeente Maastricht, 2012).

Another future threat is the tendency of agriculture to increase in scale, posing not only another threat to biodiversity by monoculture, but also to the local economy, cultural landscape, and burgundian image of the city (Gemeente Maastricht, 2012).

Furthermore, the population expansion in Maastricht right after WWII and the fact that people generally live longer are leading to a significant increase in the number of people aged 65 and older (de Jong & van Duin, 2009). Limburg is one of the provinces that will have to cope most with an aging population, as younger (more international) generations tend to move out of the area (de Jong & van Duin, 2009). The government might be forced to economise, which poses a threat to future investment in green infrastructure.

Additionally, as Maastricht is already a compact city, management decisions lean towards species that are most resistant to compaction, such as Linden trees. This creates a monoculture, decreasing the system's resistance to pests and other disturbances, thereby decreasing the general resilience. For example, the 'Groene Loper' (i.e. 'green belt') involves planting 2000 Linden trees for reasons such as their tolerance for compaction, ability to grow rapidly and healthily in shallow soils, and high resistance to most pests and diseases (Arbor Day Foundation, 2014). However, Linden trees lack resistance against road salt (Arbor Day Foundation, 2014). This characteristic questions the resilience of the system in the face of climate change effects, which includes more precipitation and colder temperatures in winter.

The termination of mining practices allows for opportunities in the future to maintain and enhance the variety in the landscape of the St. Pietersberg area that it has created, such as bare limestone cliffs, rough slopes, shallow waters, grasslands, recovering patches of vegetation, seepage waters, and swamps (Peters & van Winden, 2002). This allows for a diverse species community. For example, birds like the Buba Buba owl or the Kestrel can nest in the rough slopes, unique butterflies and salamanders benefit from the grasslands, toads and dragonflies can live around the lakes and swamps, and orchids and other species dependent on soil rich in limestone can thrive in the open areas (Peters & van Winden, 2002).

A benefit of using native tree species within the city is that they can become very old, allowing for tree hollows to form and providing more habitats.

System Dynamics

The adaptive cycle illustrates the dynamic nature of a system characterized by a rapid growth followed by a conservation phase, which is disrupted by an event, which leads to a release within the system that results in the reorganization phase (Gunderson & Holling, 2002). Based on the research of this report, the adaptive cycle, as illustrated in figure 2, is applied to Maastricht as a social-ecological system.

After WWII, Maastricht experienced a rapid population increase coupled with urban expansion (rapid growth phase). In the 1970s, the citizens of Maastricht started to appreciate the cultural values of the century old tunnel systems that were being destroyed by the ENCI and realized what kind of impacts the factory and urbanization had on the environment (conservation). Population growth was simultaneously gradually decreasing, relieving urban expansion pressures (de Jong & van Duin, 2009). The system gradually entered the release phase, as citizens' concern for the environment began to reflect in the municipality's decisions, which included a number of greening initiatives, such as the 'Groene Loper', to increase the wellbeing of the citizens and mitigate climate change effects (reorganization).

Maastricht's current state includes a combination of forests, agriculture, grasslands, and urban area (figure 3). Individual areas within the focal scale have been converted to different states over the years according to the influence of cross-scale interactions. The main social threshold is population growth or strong decline, which affects the local economy and demand for agricultural or urban area. The conversion to urban area is a sudden, often irreversible threshold, due to a complete alteration of the landscape's identity. Agriculture involves the use of fertilizers, pesticides, and the disruption to soil horizons, decreasing its reversibility to native vegetation. The system, however, has quite a high resilience in the sense that, if left untouched, the system will gradually return to its 'forest state' (Peters & van Winden, 2002). For example, the 'Oehoevallei' within the quarry naturally regenerated to a native 'grassland state'. As the aim is to enhance the biodiversity of species dependent on limestone grasslands, sheep have been put on grazing patches to naturally avoid the regrowth of the forest (Peters & van Winden, 2002). Presently, management is efficient at avoiding overgrazing. The area directly around the quarry was agricultural area that has been re-forested in the 1950s. The rest of the quarry is going to be subject to natural regeneration; some areas will be allowed to reforest, others will be managed to stay in the 'grassland' state (Peters & van Winden, 2002).

Interactions Between Scales

Whether Maastricht will re-enter the same adaptive cycle depends on the change in other scales (figure 4). The St. Pietersberg area has gone through the following cycle:

- Rapid growth: after WWI, the ENCI got concession to extract limestone at the quarry site and was able to extend its exploitation throughout the 20th century. This had negative impacts on the biodiversity in the area
- Conservation/accumulation: ENCI experienced challenges extending mining operations due to increasing community appreciation of biodiversity and conservation.
- Release: Increase in friction until 2004, when, instead of ending ENCI's concession in 2010, the province of Limburg and the municipality of Maastricht decided to extend their concession until

2020, because resource demand had increased as well as its price (Soete, 2008). This lead to protests by Maastricht's citizens, for example, by the 'ENCI-Stop' foundation (Smeets, n.d.).

- The area is now starting its reorganisation phase: The decision was made to terminate the concession by 2018 and let the area regenerate for biodiversity conservation and recreation purposes.

Subsystems, like the St. Pietersberg area and other 'greening' projects in the city, influence the stability of Maastricht's resilience to biodiversity threats. Enhancing biodiversity within the St. Pietersberg area will enhance that of the entire focal system, because it will attract species that can more easily increase their habitat area through the connectivity between green spaces (Manning, Gibbons, & Lindenmayer, 2009).

At a larger scale, the population composition of Limburg has gone through the following cycle:

- Rapid growth: after WWII, The Netherlands experienced a 'babyboom'.
- Conservation/accumulation: the population increased and a shift is occurring towards a larger proportion of elderly citizens born in the 'babyboom', while younger generations tend to leave the province. This is putting strains on governmental economic decisions.
- The release phase has not occurred yet, but it might entail reaching a certain proportion of elderly people that significantly affects the economy and thus decisions related towards maintaining a 'green' city. Moreover, a strained economy is unattractive for companies and people seeking employment.

This is a system that might destabilise the resilience of Maastricht. However, climate change is also in its accumulation phase, which might shift future priorities more towards green technology and green spaces to mitigate its effects. Likewise, people's values, which are influenced by education, are slowly changing towards conservation and more sustainable options. This is often reflected in policies, such as Natura-2000 of the EU and development plans of Limburg that protect ecological values of certain areas (Gemeente Maastricht, 2012).

Besides climate change, population growth, and values, another slow variable is the aging of trees. Trees planted in one period will die in approximately the same time-frame. It is therefore important that there is a diversity of age among the trees to avoid high maintenance costs in the future.

A fast variable to take into consideration is the economy. For example, in 2004 the demand and price for cement suddenly increased, initiating a cascade of change that changed the quarry's future. A threshold among the community had been reached, causing protests that lead to a change in decisions of land use (Soete, 2008). More exposure to nature influences education and further contributes to conservation.

V. Governance

Decision-making processes and formal power lie mainly with the province of Limburg and the municipality of Maastricht at the scale of the province and city, respectively. These are influenced by other stakeholders, such as the community and the EU. Maastricht's community has the largest informal power through votes, norms, and local initiatives. The EU provides a flexible policy framework within which the municipality can make further decisions. For example, Natura-2000 areas do not exclude human interaction with the specified environment, allowing for more flexibility when issues arise (European Commission, 2014).

Through its implementation of 'greening' projects throughout the city, the municipality adopts an adaptive governance approach. It includes citizens in enhancing recreational, cultural, economic, and ecological opportunities, thereby involving various scales and organizational levels, such as corporations. This allows for flexible approaches to solve future issues. By increasing the green space in the city, the municipality is preparing for the uncertainty of effects that climate change might have on the city. Even though the municipality has a fixed aim to unify urban areas with nature, it learns from past impacts of policies and implements new understandings into new policies.

Natuurmonumenten has an increasingly important role at the sub-system scale, as it will be managing the whole St. Pietersberg area by 2018. This allows for more flexibility and diversity among the system it can manage. It will ensure recreational opportunities within the area, as well as provide a diverse ecological system. This allows for experimentation of effective implementations to enhance the system's resilience towards disturbances, including those by humans.

The ENCI restrained flexibility; no matter how well they complied with environmental policies regarding emissions and operations, extracting the limestone still required digging away at ecological systems. When the protests against the extraction operations began, they had no way of creating cooperation amongst the stakeholders involved. It is, however, flexible in its own survival, as it will only process imported limestone from Belgium after 2019 instead of extracting it at the site (Peters & van Winden, 2002).

Even though Maastricht is a tight network in itself, stakeholders are linked in a centralized network where the municipality is the main stakeholder holding the network together. This allows the municipality to unite various stakeholders in the goal to conserve and enhance nature within the city. Maastricht has the advantage that it is small in scale and decisions are therefore more likely to impact the whole network, instead of isolated stakeholders.

Its centrality allowed the municipality to resolve the conflict between the interests of the community and the ENCI. However, the resilience of the central system might be affected in the future by differing interests and lobbying activities. For example, for community and ecological purposes, the municipality decided to let some urban spaces temporarily be used for community initiatives, such as urban gardening, until the space can be included in a permanent plan (Gemeente Maastricht, 2012). Yet, to apply innovation and receive long-term benefits, the community demands a long-term solution, which the municipality cannot give due to economic obligations.

VI. Actions

Transformation to a greener city is already taking place. The question is whether this increase in nature also makes the system resilient. Ecologically, the system shows remarkable resilience. Seed banks and dispersion of native vegetation guarantee natural regeneration of nature if left unmaintained (Peters & van Winden, 2002). For example, after 100 years of mining, grazing sheep need to suppress the growth of forest in the quarry. Old buildings and nature even unify, which makes the city, its inhabitants, and species more adaptable to effects of climate change (Manning, Gibbons, & Lindenmayer, 2009).

The landscape's diversity promotes a range of ecological, cultural, and recreational opportunities that enhance interaction of people with nature and absorbance of different shocks. Especially the increasing connectivity between green areas facilitates movement. Increasing biodiversity of target areas, such as the quarry, will have biodiversity "spillover" effects, even to non-targeted areas (Brudvig, Damschen, Tewksbury, Haddad, & Levey, 2009). Studies have even shown that the Buba Buba owl has started hunting within the city (figure 5) (Houben, 2011).

Using diversity for lower maintenance costs and resilience is a strategy that is not sufficiently used in the approach for the 'Groene Loper', which will consist out of 2000 Linden trees to connect other existing green spaces (A2 Maastricht, 2013; Groen Maastricht, 2014, b). Even though the Linden tree is resistant to compaction and pests, the monoculture and similar age of trees can become a problem in the future if too much road salt is used, a new disease emerges, or the trees need to be replaced at once.

The political support and 'learning by doing' approach of the municipality make institutions and the community quite resilient. The municipality continually seeks ways to facilitate communication and public participation, such as setting up an information platform (www.groen-maastricht.nl). Maastricht is a small and tight system that enhances social cohesion, communication, and interactions among different stakeholders. Recreational opportunities and increasing exposure to nature enhances social ties (Tzoulas, et al., 2007).

To pursue a more resilient socio-economic system, new projects should implement greater diversity with regards to species, structure, and tree age. The contribution to the system's resilience by the 'Groene Loper', for example, would augment if it had greater diversity, allowing greater shock absorbance and more dynamic habitats. It should also be understood that focusing on resilience against a specific disturbance, such as compact soils, might affect the general resilience, such as susceptibility to diseases due to monoculture.

In case of economic collapse, the system would be more resilient if there was a trust fund for the maintenance of green spaces. Additionally, keeping the economy diversified enhances social resilience. Diverse agricultural land would therefore create social cohesion and keep the community in touch with their natural surroundings.

To build a stronger bridge between science, education, and policy, research and experiments in greening projects for students should be promoted to enhance collaborative learning and innovation. Advancement in quantifying and understanding ecological values can improve resilient decision-making and cost-benefit analyses.

Institutions need to be transparent to gain mutual and community trust. Continuous assessment of social and ecological resilience is important for decision-makers to maintain alignment in interests among stakeholders, maintain sufficient amounts of flexibility within the system, and anticipate threshold-crossings across different scales.

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Appendix

Provisional service		Regulating service		Supporting service		Cultural service	
Service	**Natural capital**	**Service**	**Natural capital**	**Service**	**Natural capital**	**Service**	**Natural capital**
Agriculture (crops)	Soil, nutrients	Flood regulation	Soils, vegetation	Forest regeneration	Seed bank, roots, soil, vegetation	Recreation (walking, cycling)	Paths, hills, river Maas
Cement	Limestone (quarry)	Shade	Trees	Soil structure regeneration	Soil, water	Sense of place	Trees, understory species
		Temperature (mitigating urban heat island effect)	Trees, other vegetation within the city	Biodiversity	Wildlife (e.g. the 'Oehoe', vegetation (esp. understory species), river Maas	Education, awareness	Green spaces, trees, bushes, river Maas
		Dust uptake (e.g. from factory)	Trees	Nutrient cycling	Vegetation, soils, water, slopes	Psychological well being	Green spaces, vegetation
		Water filtration	(Limestone) soils, vegetation	Pollination	Wildlife, insects, wind, vegetation	Tourism	Tunnel system, landscapes (incl. agricultural)

Table 1: Identification of the ecosystem services provided by the green spaces within and around Maastricht.

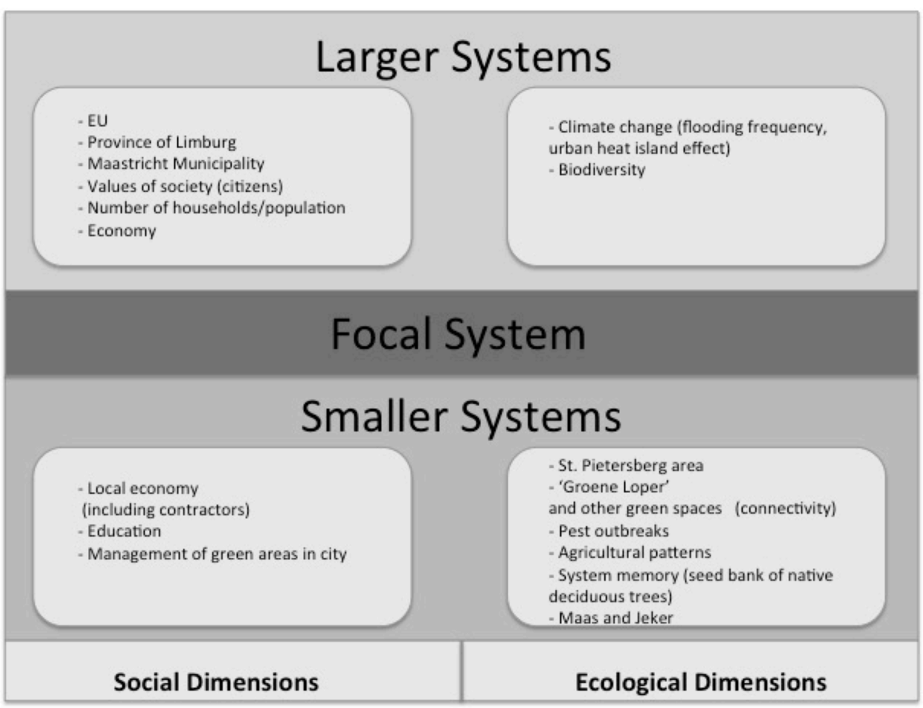

Figure 1: Social and ecological dimensions of larger and smaller systems that influence Maastricht's social-ecological system.

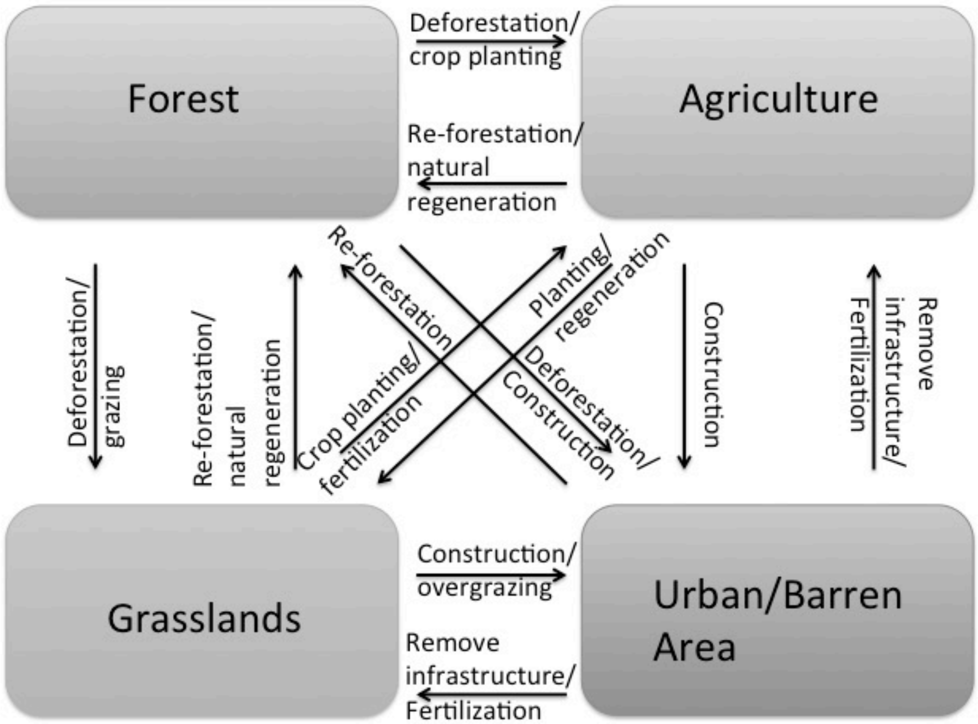

Figure 3: Different ecological states of the focal scale and actions or processes that influence state transitions.

Interactions Between Scales

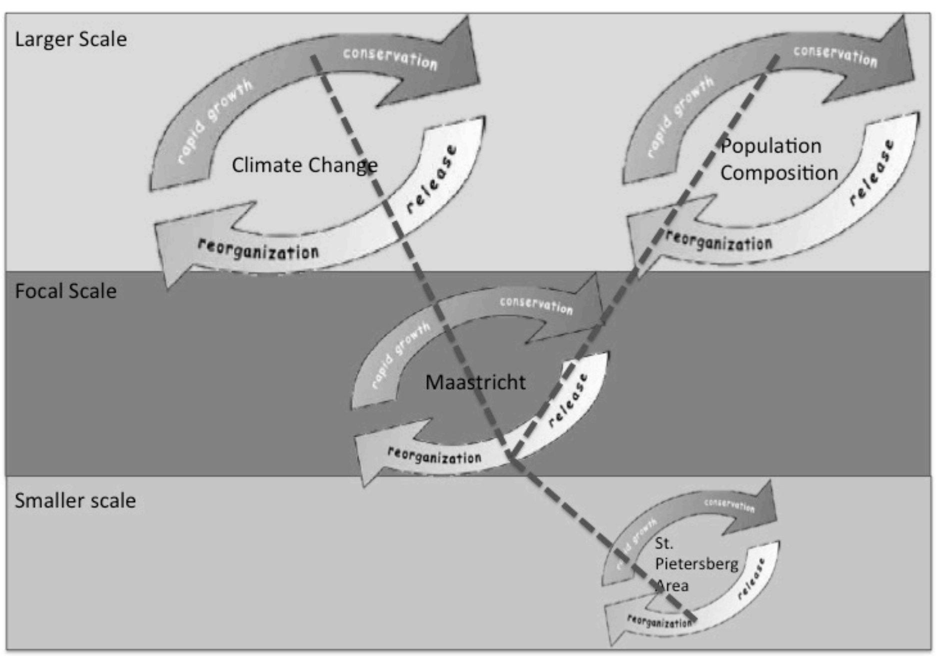

Figure 4: Interaction between different scales (Adaptive cycle figures used from Resilience Alliance, 2010).

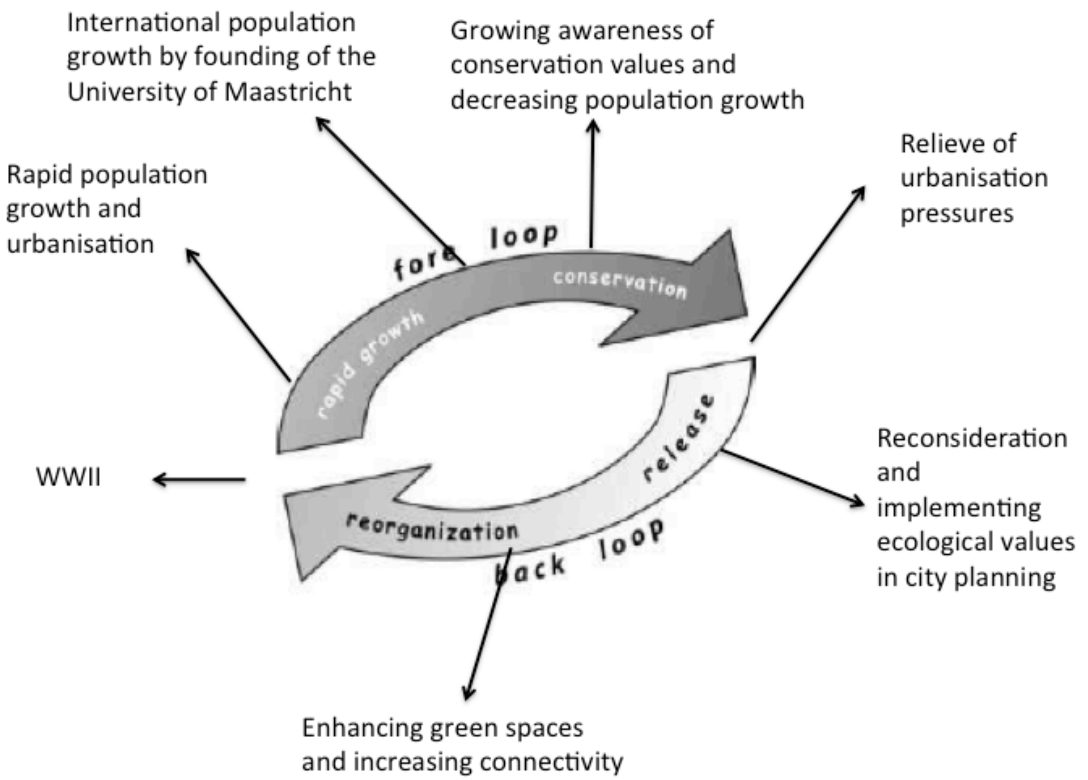

Figure 2: Adaptive cycle of Maastricht (Adaptive cycle figure, adapted from Resilience Alliance, 2010).

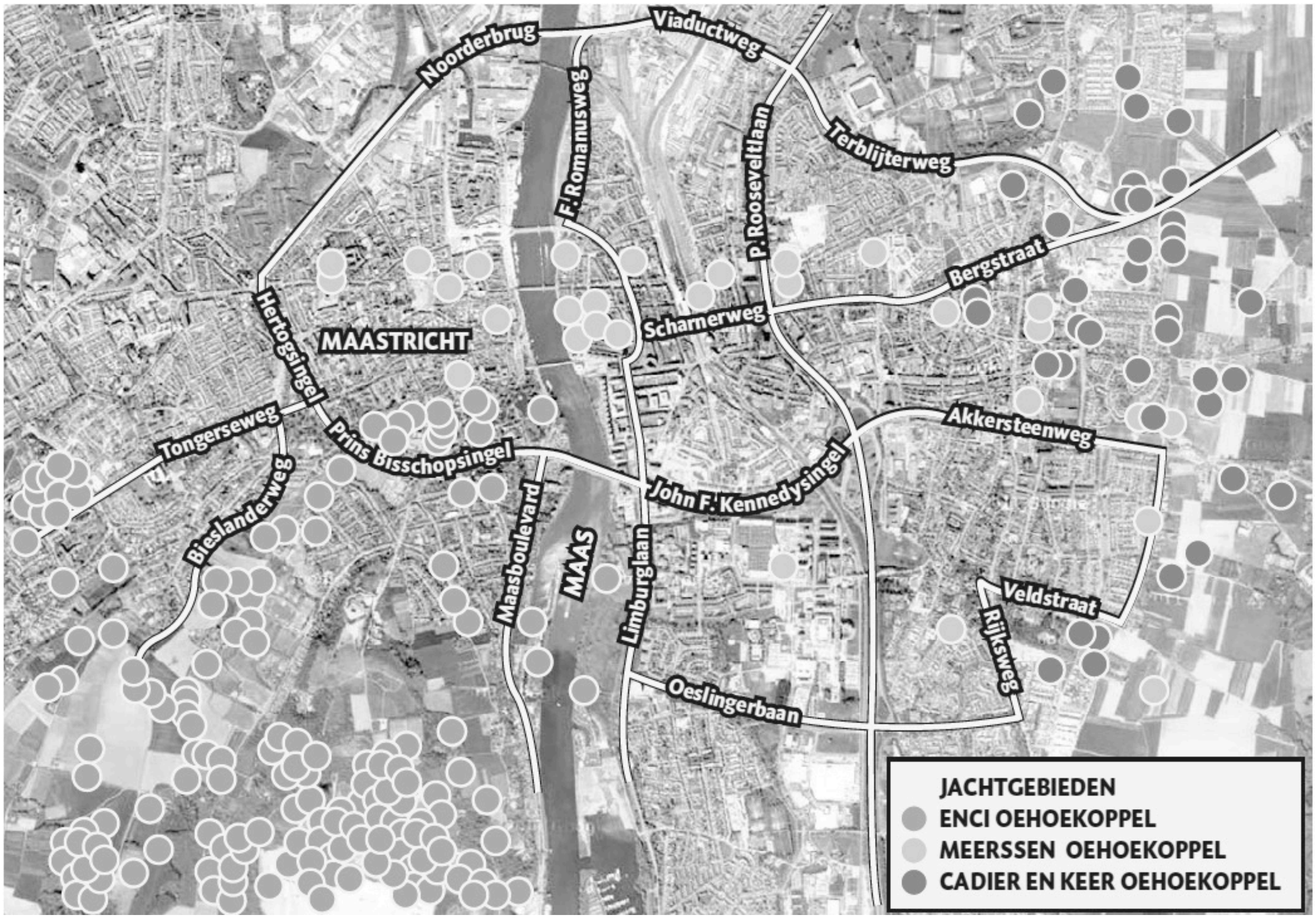

Figure 5: Hunting areas of the Buba Buba owl (Houben, 2011). The three colours indicate three owl couples that have been tracked. Results show that the owls are starting to hunt within the city at night, mainly in greener areas.