Biodiversity conservation at business sites

Options and opportunities

Robbert Snep

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ALTERRA SCIENTIFIC CONTRIBUTIONS 28

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Abstract

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Key words: biodiversity conservation, business sites, port areas, business park, peri-urban, ecological network, urban ecology, urban bird, natterjack toad, metapopulation, dispersal, urban-rural gradient, butterfly conservation, MCA, ecosystem services.

Business sites are currently not designed and managed to provide added values in terms of sustainability to their (urban) surroundings. This thesis explores the options and opportunities for biodiversity conservation at business sites, with 'biodiversity' thereby being an ecosystem service that may enable business sites to increase their significance for overall sustainability.

Concerning biodiversity levels at current business sites, in a comparison with residential areas and urban greenspace Dutch business sites appeared to have – on average - lower densities and diversity of breeding birds. However especially birds of early-successional vegetation (including some Red List species) preferred business sites above other urban land use types, making the business site birds a distinctive urban bird community. Next, to deal with (protected) species in business site environments, a planning and design strategy (the 'habitat backbone') was designed. This strategy combines opportunities for temporary habitat at business site parcels with permanent habitat structures (the 'backbone') at the public space within the business site. The strategy was successfully applied in the case of the natterjack toad (*Bufo calamita*) in the Port of Antwerp (Belgium). In another study, the impact of creating habitat at peri-urban business sites on the occurrence of species (i.e. butterflies) in inner-city residential areas was explored. Results show that creating extra habitat at the business site may have a positive impact on inner-city butterfly densities if the size and management of the business site habitat was optimal for a large source population, and green structures well connect peri-urban source populations and inner-city habitat. In addition, business sites seems also to have a potential in enhancing rural populations of endangered butterflies. In 93 Dutch business site cases, located near vulnerable butterfly populations, these sites have the capacity and character to incorporate additional butterfly habitats and contribute substantially to butterfly conservation. Finally, in a MCA-study different options for biodiversity conservation at business sites were compared, providing the insight that predominantly business sites with large amounts of urban green were preferred by all stakeholders.

This thesis illustrates that by implementing conservation measures at business sites (e.g. at vacant lots and on top of the flat roofs of business sites buildings) business sites are able to contribute to more sustainability in their (urban) surroundings.

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General Introduction

1 General Introduction

The business site phenomenon

During the Industrial Revolution the first factories were established in the Netherlands, often in the core of cities in those early years. Later, from the 1920s, new town planning concepts spatially divided living and working environments and located industrial complexes more towards the city edge (for the health of citizens). There, local authorities designated special areas for companies, called ‘industrial sites’. When, in the 1970s, distribution and trade of goods became more dominant, the term ‘industrial site’ was replaced by the more general term ‘business site’. Like the industrial sites, business sites were meant only for economic purposes. According to Louw et al. (2004), this choice for strictly mono-functional business site planning is nowadays a typical Dutch phenomenon.

In this thesis, I define ‘business site’ as a (Dutch) planning term for ‘an area designated by local, regional and in some cases national authorities to accommodate multiple companies that produce, transfer or store goods’ (based on Louw et al. 2004). These areas can according to their functional qualities, economic requirements, spatial-visual qualities and flexibility be further divided into high-quality business sites, mixed business sites, distribution centres, heavy industrial areas and seaport areas (Van der Gaag 2004; IBIS 2007). Classifications used in other countries refer to (some of) these sites as ‘business districts’, ‘business parks’, ‘industrial sites’, ‘industrial districts’ or ‘industrial estates’ (e.g. Nahm 2000; Frej et al. 2001). Business sites are distinguished from commercial areas (like shopping malls), where companies sell (instead of producing or transferring) products or services to visiting consumers. Business sites are also different from ‘office sites’ where work is focused on (administrative processing of) information and not on producing, transferring or storing goods (Louw et al. 2004; IBIS 2007).

For decades the planning and design of Dutch business sites has mostly been a local or regional process, with the exception of the large industrial ports (e.g. Port of Rotterdam) and large distribution centres (e.g. the Moerdijk area). Mechanisms in the interaction between local authorities and private corporations have typically led to a dense distribution of relatively small business sites, where little attention has been paid to appearance and life span of the business site environment (see inset). These mechanisms start from a difference in perspective between municipalities and corporations. Municipalities aim to attract firms to business sites within their jurisdiction so as to improve local revenue and employment. For their part, firms tend to focus on a preferred region, and then choose -- within that region and amongst the range of suitable sites -- the municipality which offers the best conditions. This has led to a situation in which neighbouring municipalities compete to provide the best business site conditions, with low land prices being a main sales argument. In this process, municipalities have not insisted on high standards concerning the esthetical appearance and management of business site parcels (so as not to bother firms) (De Graaf 2008). This has resulted in a situation in which little attention is paid to the life span of business sites. As a result most business sites age relatively quickly, prompting companies to quickly vacate older sites for more recently developed areas. Municipalities have responded to the increasing excess capacity at older sites by developing new sites in peri-urban locations, instead of improving the quality of the existing sites (e.g. Louw and Olden 2004).

Business sites in the Netherlands

There are approximately 3,600 business sites in the Netherlands, with a total gross size of almost 97,000 ha (Arcadis and Stec Group 2007). With 443 Dutch municipalities, this amounts to eight business sites per municipality on average. According to the Taskforce (Her)ontwikkeling Bedrijventerreinen (2008) about 30% of business sites are outdated from an economic viewpoint. The Netherlands' 3,600 business sites can be classified into traditional business site types (see table below), though there is a trend towards a mixing of business site types and a mixing of business areas with other functions (e.g. residential and commercial).

Business site type	**# sites**	**Portion**	**Total area (ha)**	**Average size ± SD (ha)**
Distribution centres	50	1.3%	3,298	66.0 ± 63.5
Heavy industrial area	121	3.3%	8419	69.6 ± 106.6
High-quality business parks	119	3.3%	4,176	35.1 ± 79.4
Industrial seaports	48	1.3%	10,784	224.7 ± 405.0
Mixed business sites	2,780	76.7%	53,207	19.1 ± 33.7
Miscellaneous	505	13.9%	16,657	33.0 ± 95.7
TOTAL	3623	100%	96,542	26.6 ± 74.6

Outside of the Netherlands as well, the planning of economic areas is often mono-functionally interpreted. Many countries have areas where governments accommodate firms and where similar problems are being experienced (Thomas 2008). Aging of sites has also emerged as a problem in business districts meant for small- and medium-sized enterprises (SMEs) in the United States. Although revitalization of these districts has a long history (Samli and Prell 1966; Strickland and Judd 1982), these days -- just as in the Netherlands -- 'sub-optimal quality' (of architecture, appearance, life span) is still in evidence in many business districts in the United States and elsewhere (Feehan and Feit 2006).

Business sites in a changing society

Although the concept of the Dutch mono-functional business site has changed little over time, the world has evolved. Various economic, social and environmental trends together have increased the complexity in which business site planning, development and management nowadays take place. Among them is the growing attention for sustainable development.

Sustainable development became a major issue at the start of the 21st century. Although the first call for more sustainable use of land, commodities and energy was made by the Club of Rome as early as the 1970s (Meadows et al. 1972), it is only in recent years that the urge for sustainability has become obvious to the broad public and policymakers (Baldock 2002; Combes 2005). The Brundtland Report of the World Commission on Environment and Development (WCED 1987) defined sustainable development as ‘development that meets the needs of the present without compromising the ability of future generations to meet their own needs’. As such, sustainability is a broad term, related to every economic, social and environmental fact of life.

With respect to urban and economic development, business site development has often been considered unsustainable, as for instance land is wasted in spaciously planned business parks (Johnson 2001). Negative impacts (e.g. habitat destruction) on public goods, like the environment, are called ‘externalities’. Johnson (2005) defines ‘externalities’ as follows:

> a situation in which the private costs or benefits to the producers or purchasers of a good or service differs from the total social costs or benefits entailed in its production and consumption. An externality exists whenever one individual's actions affect the well-being of another individual -- whether for the better or for the worse -- in ways that need not be paid for according to the existing definition of property rights in the society.

In the case of business sites, environmental and social externalities occur when -- during the planning, development, management and use of the site -- (negative) impacts on environmental and social interests are not taken into account by business site stakeholders (e.g. Govindarajalu 2003).

Directions in sustainable business site development

Sustainable economic development strategies promote mutually beneficial environmental, social and economic progress (Robert 2004). Such strategies address many environmental and social aspects that traditionally are not included in business site development and management. Current strategies act at different levels (regional, business site and company level) and relate to various aspects of the business site (planning, development, design, management, corporate use).

At the regional level '*sustainable land use planning*' as applied to business sites focuses on the choice of location for economic activities, with the aim to minimize negative impacts on the environment (Naess 2001). Planning tools, like for instance environmental impact assessments (EIAs), have been developed to compare options in the planning and design of economic activities and to indicate the best (environmentally friendly) location for new developments (Botequilha Leitao and Ahern 2002).

Another strategy to deal with the different functions and interests that need to be incorporated within the same region or location is called '*multifunctional land use planning*'. Work and business are among the functions (next to residential housing, infrastructure, amenities, and recreation and culture) that are considered relevant for multifunctional land use in urban areas (Rodenburg and Nijkamp 2002). Rietveld and Rodenburg (2003) define a land use pattern as becoming more multifunctional when,

> in the area considered, the number of functions, the degree of interweaving, or the spatial heterogeneity increases. An increased degree of multifunctionality may therefore result from the addition of functions to that area (multifunctionality by diversity), from an increase in dispersion from the number of functions over the area (multifunctionality by inter-weaving), or from an increase of the number of other functions touching a territory (multifunctionality by spatial heterogeneity).

Applying the multifunctional land use concept to business sites can be seen as a way to make more effective use of the space available in a region and thus to impact the environment less.

Other sustainability strategies take as their starting point the economic focus of the business site. '*Industrial ecology*' considers the industrial system as a certain kind of ecosystem. Thereby the industrial system, like natural ecosystems, can be described as a particular distribution of materials, energy and information flows (Erkman 1997). This strategy emerged in the 1980s and focuses mainly on sustainability in production processes (Frosch and Gallopoulos 1989; Jelinski et al. 1992).

A more recent sustainability strategy, '*careful industrial land use*', emphasises not so much flows but rather business site design. Careful industrial land use is the utilization of land and floor space in such a way that space use per unit of economic activity is minimized to give way to other activities of the same or other kinds. At the same time the architectural qualities of the business site is to be safeguarded and the economic functioning of firms is not to be obstructed (BCI in Pellenbarg 2004). Sustainable and careful industrial land use has become a key target of 'park management', the new organizational model for the development of business sites (Pellenbarg, 2004).

Business sites and ecosystem services

In conclusion, current strategies reflect attempts to create more sustainable business sites. These strategies focus on diminishing the negative environmental impacts of the business site (e.g. water pollution, excessive energy consumption and habitat destruction). However, sustainable development is also about creating added value, and not only preventing damage to the environment. It may include land management to improve provision of ecosystem services to humans (Constanza and Daly 1992). Indeed, urban ecosystems contribute to the quality of life of citizens by providing ‘services’ such as air filtering, micro-climate regulation, noise reduction and enhanced biodiversity (Bolund and Hunhammar 1999; Takano et al. 2002; Anderson 2006). Bolund and Hunhammar list several urban land use types that may be part of urban ecosystems, such as parks, street trees, lawns, cultivated land and streams. The fact that business sites are lacking on this list indicates that these economic areas are not yet considered to accommodate ecosystems and thus provide ecosystem services (Fig. 1a). In this thesis I explore options and opportunities in planning, design and management of business sites to accommodate ecosystems as a source of ecosystem services to their surroundings (Fig. 1b).

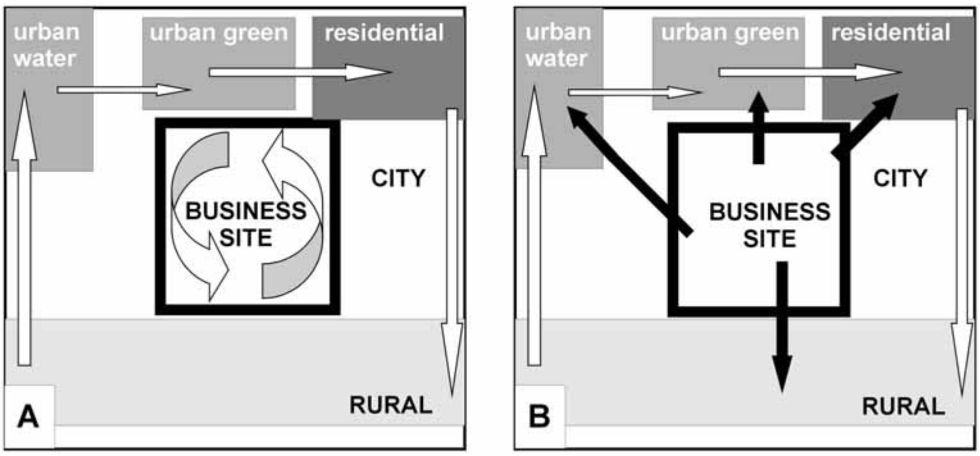

Figure 1. *a) A business site not considered part of the urban ecosystem network, not providing ecosystem services to its urban and rural surroundings. b) A business site considered part of the urban ecosystem network, including ecosystems that provide services (like supporting biodiversity) to surrounding land use types. In this thesis I explore opportunities to evolve from (a) to (b).*

Opportunities for business sites to provide ecosystem services are now gradually being recognized. For example, recent studies have focused on how flat roofs, a typical feature of business site buildings, can be used (designed as green roofs) to reduce urban air pollution (Yang et al. 2008) or road traffic noise (VanRenterghem and

Botteldooren 2008). In this thesis, I focus on the ability of business sites ‘to support biodiversity’, an important ecosystem service related to the quality of human life (Ehrlich and Wilson 1991).

Since the 1992 Convention on Biological Diversity was adopted in Rio de Janeiro, it has become obvious that many plant and animal species are in danger of extinction (CBD 1992). According to Ehrlich and Wilson (1991), there are various (e.g. ethical, economic) reasons why humans should care about the ongoing loss of biodiversity, most of them touching upon the quality of human life. By now, governments, companies and non-governmental organizations (NGOs) have come to realize the urgent need to conserve biodiversity. Even in urban areas, the places where people live and work, opportunities to enhance biodiversity are receiving attention (ICLEI 2008; Countdown 2010). From this perspective, it is of interest to governments and companies to consider how business sites may contribute to biodiversity conservation. This is because:

i) There are practices and examples that show that business sites may accommodate high levels of biodiversity (although empirical data is as yet limited).

ii) These examples illustrate the potential to implement conservation measures at business sites for biodiversity conservation, providing companies a means to demonstrate their corporate environmental responsibility.

iii) Biodiversity is an appealing indicator of the quality of life.

iv) Conservation measures for biodiversity (e.g. development of habitats) may support other ecosystem services and diminish negative impacts of the business site environment.

The following section briefly elaborates on these arguments and discusses what this implies for scientific research.

Business sites and biodiversity conservation

Regarding biodiversity conservation at business sites some initiatives are already under way in current practice. The US Wildlife Habitat Council encourages corporations to voluntarily manage lands for wildlife and biodiversity protection, and certifies companies that substantially contribute to biodiversity conservation on their corporate lands (WHC 2008). Cardkadden and Lober (1998) studied the benefits to corporations of participating in the WHC programme in terms of its influence on relationships with key corporate stakeholders including employees, host communities, environmental groups and regulators. They report that at 164 sites, 95% of respondents indicated that wildlife habitat programmes had led to improved employee morale; 72% indicated improved relationships with environmental groups; 60% noted a positive effect on community relations; and 49% of respondents reported improved relations with regulators. These benefits were in addition to the annual cost savings reported by 50% of the programmes. Besides, relationships with the community, government and environmental groups led to better wildlife programmes due to increased expertise. Furthermore, 24% of the wildlife monitoring was done by outside groups.

In another example, the UK British Trust for Ornithology (BTO) awards companies that take specific measures to conserve bird diversity on their lands (BTO 2008). The Business Bird Challenge began in 1994 and is a partnership between businesses, the BTO and local communities which encourages biodiversity on business and industrial sites. Sites range from working quarries, power stations and oil refineries to research establishments, company headquarters and restored nature reserves. The aim is to maximize the potential of business sites for birds and other wildlife whatever the business site size.

In the Netherlands, Dutch Landscape Management promotes the integration of landscape elements and species conservation measures into business site development (LBN 2006). It aims to raise awareness among municipalities and the business community, but also amongst project developers and designers, regarding opportunities and advantages that 'green' business sites offer. They thereby focus on fitting business sites into their surrounding landscape, enhancing the ecological significance of business sites and increasing the accessibility of the sites for recreation purposes.

The initiatives in the United States and United Kingdom deal mainly with individual corporations (conservation on corporate lands), which makes it difficult to derive general strategy from these experiences to apply to biodiversity conservation at most business sites, which house multiple corporations at the same site. Though the Dutch experience offers a useful reference point for the country's typical business site environment, it nonetheless lacks sufficient cases and data to generalize practices into a comprehensive strategy. Thus, currently insufficient insight can be derived from practice on how business sites may contribute to biodiversity conservation.

From a scientific perspective the relation between biodiversity and the business site environment -- and the extent to which this suggests ways to contribute to biodiversity conservation -- is an important aspect to discuss. After all, it is necessary to find out whether and under what conditions business sites can provide ecosystem services, in particular support to biodiversity. What biodiversity can be expected at business sites and why? Answering this obvious question first requires a theory about what business sites – as a type of urban land use -- are all about. Based on such a theory the availability of specific biotopes in the business site environment can be determined, which then would enable ecologists to predict the significance of business sites for biodiversity. However, the scientific literature as yet offers no coherent theory about the land use at business sites, and its dynamics in space and time. This may be explained by the fact that the planning and development of the sites is mostly a local event, not following strict architecture or urban planning guidelines (Frej et al. 2001).

Nevertheless, some studies have analysed biodiversity in case studies which include business sites. Additionally, they provide a list of land use characteristics that may explain species richness and abundance at business sites. Blair (1996, 1997, 2001) studied breeding bird and butterfly abundance and species richness along the urban-rural gradient in three geographical regions in the United States. Business districts (business sites for mixed companies) were one of the land use types examined in those urban-rural gradient studies. Results from bird and butterfly monitoring plots in these landscapes were used to conduct cluster analysis and indicate where species diversity and abundance were highest. Business districts appeared to be the land use types with the lowest abundance of breeding birds and butterflies. In the Seattle region (Washington, USA) several studies were conducted recently to learn whether reserve size, landscape surrounding the reserve and their interaction affect forest-dwelling songbirds in this metropolitan area (Alberti and Marzluff 2001; Donnelly and Marzluff 2004). Their monitoring plots included those located in industrial development sites and business districts. These studies focused on percentage of urban cover and other aspects related to urbanization intensity within a range of exurban, suburban and urban plots, rather than taking the business site as a specific study area. The results from these studies therefore cannot be directly related to biodiversity levels observed at business sites. Schadek (2007) studied the driving factors of site conditions and of plant functional group occurrence in urban brownfields, including some parcels that were located on industrial lands. These ecological studies focus on species-habitat interactions in urban environments in general, rather than specifically addressing the role of the business site (i.e. business district, industrial development site) -- being a separate land use type -- in biodiversity conservation.

Other studies have addressed biodiversity conservation at business sites, industrial ports in particular, from a different perspective. Legal obligations originating from the EU Habitat and Bird Directives force port authorities to create compensatory habitat for protected species which occur in the ports and are threatened by economic developments (Morris and Gibson 2007). This obligation includes the creation of inter-tidal and sub-tidal habitats (e.g. mudflats and sandbanks) in estuarine environments and species-specific measures like the creation of the human-made ‘Tern Island’ in the Port of Zeebrugge (Stienen et al. 2005). So far, Tern Island appears to be a success, as the Little Tern (*Sterna albifrons*), the Common Tern (*Sterna hirundo*), the Sandwich Tern (*Sterna sandvicensis*) and the Black-headed Gull (*Larus ridibundus*) are now observed there in large numbers. This may be the result of a keen choice of location and design of the island, based on long-term monitoring of the seabird populations in this industrial port environment.

Problem statement, objective and research questions

In the Netherlands, but presumably also in other countries, there is a societal demand to better incorporate landscape and ecological qualities into business site planning, development and management (e.g. Vreeze 2006; Taksforce Herontwikkeling Bedrijventerreinen 2008). As such, business sites should be able to better provide ecosystem services to their surroundings. Yet with respect to biodiversity conservation, business sites have hardly been a topic of scientific research. This means that their current and future significance for biodiversity conservation is unknown, besides the dearth of planning and design strategies to utilize the opportunities that business site environments may offer for biodiversity. Few examples exist showing how to deal with protected species occurring in business site environments. Planners, developers, firms and business site managers therefore lack adequate information to incorporate biodiversity conservation in their business site activities.

The main objective of this thesis is to explore the range of options and opportunities for incorporating biodiversity conservation goals in business site design and management. This is done by exploring (primarily from an ecological viewpoint) the current and potential contributions that business sites could make to biodiversity conservation, both at the site level and on a landscape scale. It subsequently ranks (from a multifunctional point of view) the best options for conservation as preferred by stakeholders.

A series of five research questions was defined -- linked to gaps in existing scientific literature – to fulfil this aim:

1 *How can the biodiversity at current business sites be characterized compared to other urban land use types and in relation to local, regional and landscape factors?*
This question focuses on the current state of affairs concerning the biodiversity occurring at business sites: what species can be found, in what quantities, and to what extent does this make business sites a different urban biotope than other urban land use types such as residential areas or urban green space?

2 *How can endangered species currently occurring at business sites be conserved despite the dynamic and economically oriented land use of these sites?*
In some cases protected plant and animal species are found at business sites. How in these highly dynamic urban environments can the legal obligation to protect those species be met, without obstructing ongoing economic activities?

3 *Could peri-urban business sites strengthen inner-city nature and thus support the quality of life of citizens?*

Most business sites are located at the edge of cities. Here, due to their size and land use, business sites may contain relatively large biotopes with pioneer and brushwood vegetation, which is scarce elsewhere in urban landscapes. This question addresses the potential of business sites to act as a home of source populations for plants and animals species further towards the central parts of cities. What proportion of individuals from peri/sub-urban business site sources could colonize the inner city, thereby increasing the probability of human-wildlife interactions in the city? Furthermore, how do landscape structures support this colonizing behaviour?

4 *To what extent may business sites (because of their location, size and use) potentially be capable of supporting the biodiversity occurring in the surrounding landscape?*

Many business sites offer opportunities to develop early-successional vegetation on vacant lots, within the sites' main green structure and on the flat roofs of the business site buildings. Apart from the significance of such opportunities for biodiversity at the sites themselves (local scale), could such habitat also contribute to the persistence of population networks of (endangered) species that occur in the direct neighbourhood of business sites (landscape scale)? If so, under what conditions?

5 *What are the design and management options for biodiversity conservation at business sites, and which of these options are preferred by business site stakeholders?*

Biodiversity conservation at business sites can be shaped in different ways, each with its own (socio)economic and environmental characteristics. What are the main options for biodiversity conservation in terms of the business site design and management? How do stakeholders rank these options, given their preferences for the various characteristics? Does this ranking provide clues for the implementation of biodiversity conservation at business sites?

Research approach

A research topic such as that addressed here, is closely related with current issues in society. The interaction between theoretical and practical methods therefore not only strengthens the results of this study, but also increases the application value for planners, developers and nature conservationists. This is why the research questions in this thesis combine theoretical conceptualization (what is the potential of the business site for biodiversity conservation and how would a biodiversity-friendly design look?) with knowledge derived from learning by doing (case studies).

Thereby, this thesis centres on the options and opportunities for biodiversity conservation at the business sites themselves. Other perspectives, like the search for the best location (business sites or other terrains) to fulfil biodiversity conservation goals in a specific region, are – though quite challenging -- outside the focus of this research.

Apart from its relevance to current social issues, the idea itself, the incorporation of biodiversity conservation at business sites as an example of how business sites may provide ecosystem services to their surroundings, is rather new and almost unexplored from a scientific viewpoint. Therefore, I have chosen for a broad, explorative approach, rather than a focus on specific points (Fig. 2).

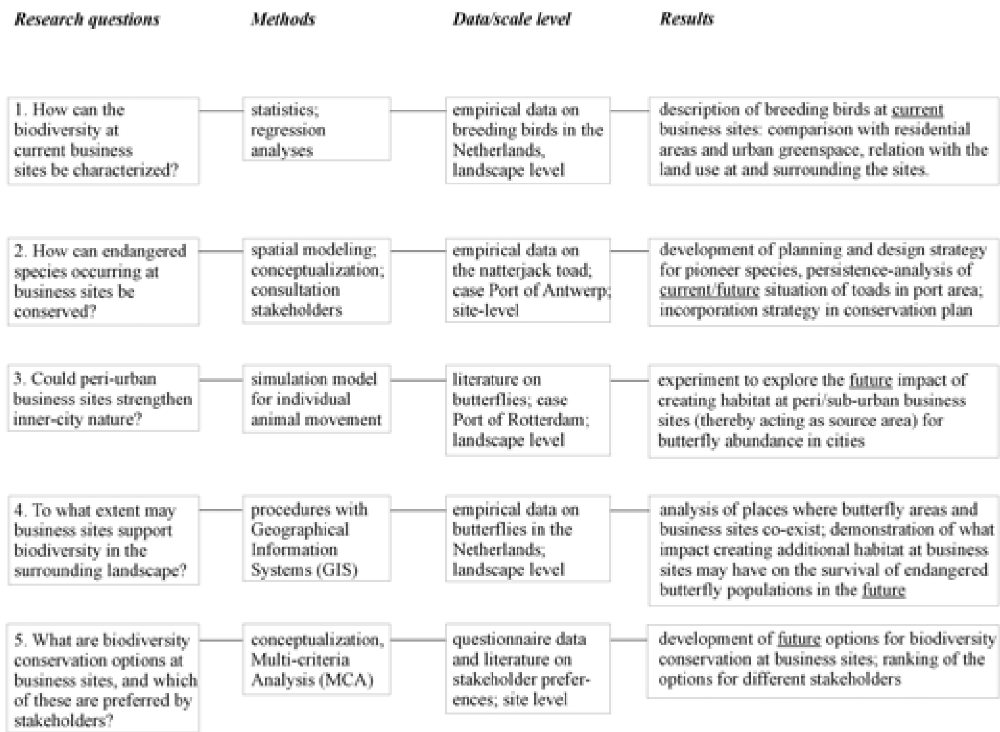

Figure 2. *Overview of the approach per research question.*

Research question 1

To characterize the biodiversity occurring at business sites, I used breeding birds, as these were the only species for which sufficient data was available. Based on several business site features, I expected business sites to be preferred by certain birds and less preferred by other bird species. To explore these expectations, I formulated six hypotheses related to the preference of specific bird guilds for business sites. In a statistical analysis, census data (1999-2004) from business sites, residential areas and urban green spaces was compared, providing insights into the differences between the breeding bird populations occurring at these various urban land use types. With these results, I could test the hypotheses, and thereby better characterize the significance of business sites for breeding birds in urban environments.

Research question 2

Endangered species that occur at business sites are often attracted by the supply of pioneer situations, created by the land use dynamics at these sites. For this question I choose to focus on ground-dwelling animal species, as no strategies have yet been developed to conserve these species at business sites. Based on the typical layout of business sites, I distinguished (from a conservation viewpoint) the (semi)public land that makes up the main contours of the business sites and the (private) business site parcels where companies are situated. The (semi)public land provides opportunities for a small but constantly available amount of habitat, whereas the (private) parcels may offer large quantities of habitat (on vacant lots) that are more temporary in nature. I therefore developed a spatially explicit planning and design strategy in which the (semi)public land acts as a permanent '*habitat backbone*', to accommodate persistent populations. From this backbone habitat structure animals should be able to colonize the early-successional vegetation that may develop for some years on the adjacent (private) parcels. To demonstrate the working of this planning and design strategy the actual case of the natterjack toad (*Bufo calamita*) in the Port of Antwerp (Belgium) was chosen. Here, conventional landscape ecological techniques were employed to gather insights into opportunities and bottlenecks that the current and future (planned) situation offer for natterjack toads. Empirical data on the natterjack toad's (meta)population in the port area was used as the input for a persistence analysis assessing the two situations. The output of this analysis was then discussed with stakeholders and resulted in a conservation goal to accommodate a large population of this toad species in the port area. Finally, based on the habitat backbone strategy, a plan was developed to provide a sustainable habitat network for the natterjack toad without obstructing planned economic activities.

Research question 3

To explore the extent to which plant and animal populations on the city edges (e.g. at business sites) may be able to support the abundance of species in the inner city, I choose an experiment with a landscape ecological model, using various future scenarios which cannot be explored in reality. I selected butterfly species and a practical case (the settlement of Hoogvliet, adjacent to the Port of Rotterdam) where there was demand for more inner-city nature quality (citizens would like to experience urban wildlife). Butterflies were chosen for this experiment, as their habitat preferences and mobility are believed to fit well with the spatial scale applied in the experiment. To learn whether butterflies originating from a peri-urban location (e.g. the port area) could colonize the locales in the inner city, I used a spatially explicit simulation model for individual butterfly movements. The model simulated -- for two model butterfly species differing in dispersal ability -- the movements of individual butterflies through the Hoogvliet landscape, based on various movement parameters and life span data. In addition, scenarios varied the location and size of the peri-urban butterfly population (the source population). Thus, the output of the model runs provided insight into the impact of these landscape factors on the abundance of butterflies in the settlement. The model runs also showed the range of the colonization area in the city for butterfly species with different dispersal abilities.

Research question 4

To illustrate the potential added value of the development of habitats at business sites on the abundance and persistence of plant and animal species occurring in the surrounding landscape, once again butterflies were selected as the study species. This time, however, instead of a single case-study approach, efforts were made to generate a national overview of locations where business sites may contribute to butterfly conservation goals. In so doing, the potential impact on biodiversity in the Netherlands of incorporating biodiversity conservation measures at business sites became more obvious, as well as where conservation measures would be most effective (from an ecological viewpoint). Eight ‘Red List’ butterfly species were selected, all preferring nutrient-poor early-successional vegetation (habitats that can be developed at business sites). With butterfly distribution data (2000-08) and current data on the locations and sizes of Dutch business sites, the butterfly data was analysed to identify where the butterfly networks (continuous areas where the species was observed) were located and what were the population size of these networks. This led to the identification of the butterfly networks most relevant for conservation. Business site data was divided in sub-selections, based on their size and their associated capacity to accommodate (a series of) local populations of butterflies. Matching the butterfly networks that were in need of additional habitat to support their vulnerable populations with the business site locations that could offer this additional habitat led to a list of business sites at which developing butterfly habitat could effectively conserve endangered species.

Research question 5

The earlier chapters of this thesis provided insights into opportunities for biodiversity conservation at business sites. These insights were used to derive a series of business site scenarios, each elaborating a different option regarding the incorporation of biodiversity conservation into business site design and management. In addition, one scenario was included representing the ‘conventional’ business site where there is no attention for biodiversity. Using literature and expert judgements, these scenarios were then assessed according to a range of (socio)economic and environmental criteria. These criteria were linked with the specific measures to conserve biodiversity at business sites, and specifically selected to differentiate among the scenarios. The assessment resulted in an 'effects table'. Next, I conducted questionnaires and reviewed the literature to learn the preferences of business site stakeholders concerning the criteria: What aspects of the biodiversity conservation measures were important to them? Using these preferences as weights, the scenarios were subsequently ranked for each stakeholder. This was done using multi-criteria analysis (MCA), a method chosen because most of the effects could not be expressed in monetary units. Though MCA techniques are commonly used to compare planning or design options, their application was new in this case (biodiversity conservation at business sites). In addition, an uncertainty analysis was conducted to explore the impact of possible uncertainties in the effects table and the weights. Finally, the outcome of the ranking led to a recommendation about which biodiversity conservation options seem most likely to be implemented based on the stakeholders' preferences.

Organization of the thesis

This thesis is comprised primarily of a series of five journal articles (chapters 2-6), at different stages of review (chapters 2 and 5) and acceptance (chapters 3, 4 and 6). Each accepted paper has been peer reviewed by experts in urban ecology, landscape ecology, landscape architecture or spatial planning. The individual papers were submitted and published, to be included as chapters of this thesis. Table 1 illustrates how the papers are linked with the research questions. Overall findings and conclusions are discussed in Chapter 7.

Table 1. *Overview of how the research questions are addressed in the different papers of this thesis*

Chapter	Research question	Paper
2	How can the biodiversity at current business sites be characterized in comparison to other urban land use types?	Snep RPH, Kwak RGM, Foppen RB, Goedhart PW, Opdam P. (subm.). Business sites as breeding bird habitat: using census data to compare business sites with residential areas and urban green spaces.
3	How can endangered species currently occurring at business sites be conserved despite the dynamic and economically-oriented land use of these sites?	Snep RPH and Ottburg FGWA 2008. The 'habitat backbone' as a nature conservation strategy for industrial areas: Lessons from the natterjack toad (*Bufo calamita*) in the Port of Antwerp (Belgium). Landscape Ecology 23: 1277-1289.
4	Could peri-urban business sites strengthen inner-city nature and thus support the quality of life of citizens?	Snep RPH, Opdam P, Baveco JM, WallisDeVries MF, Timmermans W, Kwak RGM and Kuypers V 2006. How peri-urban areas can strengthen animal populations within cities: A modelling approach. Biological Conservation 127 (3): 345–355.
5	To what extent may business sites (because of their location, size and use) potentially be capable of supporting the biodiversity occurring in the surrounding landscape?	Snep RPH, WallisDeVries MF and Opdam P. Conservation where people work: can business parks and industrial estates make a difference for endangered butterflies?
6	What are the design and management options for biodiversity conservation at business sites, and which of these options are preferred by the business site stakeholders?	Snep RPH, Van Ierland EC, Opdam P 2009. Enhancing biodiversity at business sites: What are the options, and which of these do stakeholders prefer? Landscape and Urban Planning: doi: 10.1016/j.landurbplan.2008.11.007

Business sites as breeding bird habitat: Comparison of business sites with residential areas and urban green spaces using bird census data

2 Business sites as breeding bird habitat: Comparison of business sites with residential areas and urban green spaces using bird census data

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Abstract

There is a growing interest and need for biodiversity conservation in cities. Little is known, however, about the significance of business sites (business districts, industrial areas, ports) for biodiversity. This explorative study characterizes the current role of business sites in providing nesting sites for breeding birds, in terms of abundance and species composition. We formulated several hypotheses related with the preference of specific bird guilds for business sites. Dutch bird census data for business sites was then compared with data from residential areas and urban green spaces. Generally, abundance and species richness of breeding birds were lower at business sites. However, the bird guild level presented a more nuanced picture. Business sites seemed especially preferred by birds that can be linked with early successional vegetation and open landscapes. Especially for coastal species and the Common Linnet, *Cardualis cannabina*, a Red List species, business sites appear to be favorite urban habitats.

Introduction

Most people live in cities today, and the urbanization process is still continuing. This has led to a growing interest and need for biodiversity conservation in places where people live and work (Miller and Hobbs 2002; Müller et al. 2008). ‘Business sites’, a collective term for areas where municipal authorities accommodate clusters of commercial firms (e.g. mixed industrial sites for small and medium-sized enterprises, distribution centres and industrial ports), have become important working environments (IBIS 2007; Frej et al. 2001). Every city contains such economic areas, and business sites can now be said to constitute an ubiquitous part of our urban landscapes. So far business sites seem to be outside the focus of planners, decision-makers and others working to strengthen biodiversity values in metropolitan regions. However, this may change in the near future, as among local and regional actors there is an increasing interest in urban biodiversity conservation (ICLEI 2008). Especially if the aim is to counteract the ongoing biodiversity loss (e.g. Countdown 2010), cities-among other areas – may consider biodiversity conservation at business sites as a serious option. This is because business sites may provide – due to their location, different development stages, architecture and use – several unique habitats that remain uncommon in cities and thus enlarge city biodiversity (e.g. Snep and Ottburg 2009). In addition, implementing conservation measures at business sites may not only increase the local biodiversity at these sites, but it could also strengthen adjacent inner-city nature (Snep et al. 2006). Finally, a reason for implementing biodiversity conservation at business sites may come from enterprises that want to express their concern for worldwide biodiversity loss by creating wildlife habitat on their own corporate lands (Cardskadden and Lober 1998).

Regarding their significance for biodiversity, business sites contain several features that – in theory – should determine the level of biodiversity they accommodate. Although these features are quite different in nature, they can all be linked to habitat conditions present both at the site (local scale) and within its surroundings (regional scale). We distinguish four such features: business sites' peri-urban location; the variety of habitats offered at different stages of site development; the characteristic architecture of the buildings; and the level of human and other activities at business sites.

A. *Business sites' peri-urban location*. Apart from some older inner-city industrial areas, most business sites are located in suburban or peri-urban locations, which are easily accessible for both urban and rural species (e.g. Dickman and Doncaster 1989).

B. *Immaturity in habitats available at different stages in business site development*. Business site development takes place in stages (Frej et al. 2001), each with its own characteristic land and vegetation types (e.g. Schadek 2007). As a result, each development stage offers opportunities for species linked with different habitats (fig. 1). In addition, business sites are known for their relatively high rate of aging, requiring restructuring after some decades (CPB 2001). Business site vegetation therefore seldom reaches full maturity.

C. *Architecture of business site buildings*. Unlike residential buildings, most business site buildings have flat roofs, which may favor pioneer species (if covered with gravel or sedum) (Raven and Coulson 1997; Grant et al. 2003; Kubetzki and Garthe 2007; Soldatini et al. 2008). Besides, business site buildings are often modern, functional edifices, lacking opportunities for cave and hole-nesting bird species.

D. *Human and other activities at business sites*. A nine-to-five culture is typical for most business sites, meaning that human activity is low from evening until the early morning. This favors nocturnal animals. Moreover, the extent to which economic activity causes disturbance varies widely across business sites, because some activities are noiseless and quiet while others include busy human activity throughout the day. Disturbance may therefore range from low to high. Furthermore, we assume that there are few pets at business sites and little attention is paid to wildlife (Sims et al. 2008). This implies a low density of domestic predators, but also few nesting boxes and little (winter) feeding of birds

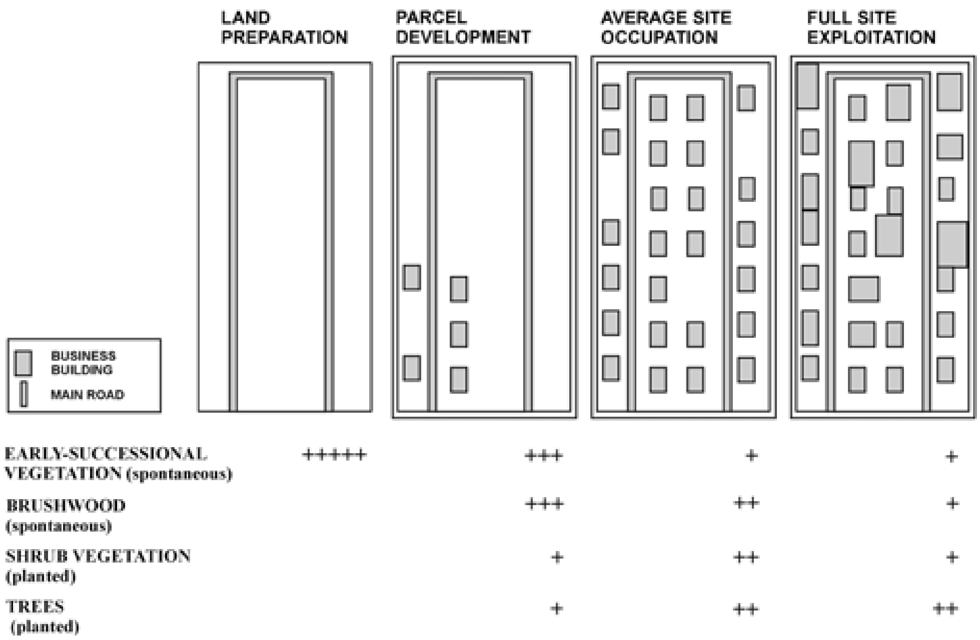

Figure 1. *Abundance of various vegetation types (estimated based on multiple field trips) during successive stages in business site development.*

Based on these features, we may expect a specific range of biodiversity at business sites. Although biodiversity in cities has been examined extensively for various urban land-use types (e.g. Clergeau et al. 1998, Savard et al. 2000), only few studies have investigated biodiversity (i.e. of birds) at business sites (Blair 1996; Alberti and Marzluff 2004). Moreover, these studies addressed habitat conditions at only a small number of sites (less then 4), as in most studies the business sites were part of a much larger research area. Also, the business sites in these studies were in full use, and thus did not represent all the development stages found at such sites (fig.1). Finally, both of these studies were conducted in the United States, providing a selective view on the biodiversity potential of business sites worldwide.

Altogether, this means that the current and potential suitability of business sites as habitat for plant and animals species has not yet been fully characterized. This could – among other reasons – explain why opportunities to conserve and develop biodiversity at business sites have gone unrecognized in urban nature conservation policy (e.g. Adams 2005; Breuste 2004), and in urban planning (Niemelä 1999a) and business site management (Pellenbarg 2004).

To learn more about biodiversity at business sites, we used census based breeding bird data to conduct a comparative study. Birds are frequently listed in conservation schemes (e.g. Butchart et al. 2004), they are popular among the general public (McCaffrey 2005), and their visibility is appreciated in the context of image-building of the companies housed at the business sites (BTO 2008). Breeding birds are strongly site-bound and bird-habitat relationships are well known, both at the local and regional level.

Because little is known about birds (and other species) at business sites, it is first necessary to learn whether these sites display different avifauna than other land-use types within the urban landscape. For this, a comparison is needed of the birds breeding at business sites and those present at other land-use types that are abundant in cities and where breeding birds have been extensively studied (e.g. Crooks et al. 2004; Sandström et al. 2006a). Secondly, assuming there are differences, we must ask why the bird population at business sites differs from that at other urban land-use types. As different birds have specific requirements related to breeding habitat, a comparison at the bird guild level could explain more about any differences found.

The aim of this explorative study is to characterize the current significance of business sites for breeding birds as a first step towards exploring the potential of business sites for increasing biodiversity. Do business sites, in terms of numbers and species composition of breeding birds, differ from residential areas and urban green spaces, and, if so, in what bird guilds?

Material and Methods

Our explorative study was conducted in the Netherlands, which is a highly metropolitan landscape. We used breeding bird data from urban areas including business sites. These business sites varied in location, business site type and actual land use. For example, the proportion of non built-up land (officially planted urban green, vacant land and water) ranged from 1-92%, with on average 31% (±26) (unpublished data). This average was relatively high, as two plots were included where so far only land preparation for business site building had taken place (first stage in development, fig.1). Without these plots the average would have been much lower

(22% ±13). Although a land use analysis was no part of this study, this implies that i) the business site plots represented different stages in development and ii) these figures may provide an explanation for the results of this study.

We formulated and tested a series of hypotheses to compare bird populations at business sites with those in residential areas and urban green spaces. Most hypotheses were defined at the bird guild level and based on the general features of business sites as delineated earlier in this paper. The hypotheses were tested by comparing breeding bird abundance and species richness.

Hypotheses

Bird species may respond differently to urban biotopes. To compare the business site avifauna with that in residential areas and urban green spaces we selected a number of bird guilds for which we expected to see the largest differences. For this, the breeding birds observed at Dutch business sites and in residential areas and urban green spaces were classified into bird guilds based on their nesting habitat in natural situations, as for most bird species urban habitats resemble their natural habitats (Tomialojc 1998) (Appendix A). In addition, we indicated which bird species are primarily ground-nesting and which are exclusively tree-hole breeders.

Our hypotheses (tab.1) are based on expected differences in habitat conditions between business sites, residential areas and urban green spaces. For business sites, we focus on the features listed earlier (see A–D in the introduction).

- *Hypothesis 1* (H1) states that business sites are preferred by ground-nesting birds as compared to residential areas and urban green spaces, as the sites are expected to offer ample pioneer vegetation at the early stages of business site development (B) and low levels of human disturbance and predation (D).
- *Hypothesis 2* (H2) states that business sites are especially preferred by pioneer birds as compared to residential areas and urban green spaces. This is expected for the same reasons as H1 and in addition because other (rural) pioneer habitats may be present in the peri-urban vicinity of the business sites (A).
- *Hypothesis 3* (H3) states that business sites are generally less preferred by woodland (edge) birds than compared to residential areas and urban green spaces, because business sites may offer only a small amount of higher vegetation (B).
- *Hypothesis 4* (H4) states that business sites are especially less preferred by strict tree-hole nesting species than compared to residential areas and urban green spaces, as these sites are expected to contain few old trees due to the dynamic nature of their land use and development (B). This

limits the sites' carrying capacity for strict hole-nesting species (Newton 1994).

- *Hypothesis 5* (H5) relates to birds that nest in nooks and crannies in buildings (and were originally associated with rocky environments) than compared to residential areas. This hypothesis states that business sites are less preferred by birds that typically nest in buildings, because buildings at business sites offer fewer nesting opportunities than in residential areas (C).
- *Hypothesis 6* (H6) states that business sites are less preferred by birds in general, due to the low overall quantity of bird habitat for nesting and foraging (B & C). As such, H6 recapitulated the overall view of business sites as breeding bird habitat.

Table 1. *Hypotheses regarding abundance and species richness of breeding birds at business sites compared with birds in residential areas and urban green spaces.*

Hypotheses	Business sites	Residential areas	Urban green spaces
H1	1) Business sites are preferred by species that are ground-nesting.	Are less preferred	Are equally preferred
H2	2) Business sites are preferred by pioneer species.	Are less preferred	Are equally preferred
H3	3) Business sites are little preferred by woodland (edge) and shrub birds.	Are more preferred	Are more preferred
H4	4) Business sites are little preferred by strict tree-hole nesting birds.	Are more preferred	Are more preferred
H5	5) Business sites are little preferred by building-nesting birds.	Are more preferred	Are equally preferred
H6	6) Business sites are little preferred by birds in general.	Are more preferred	Are more preferred

To test the six hypotheses we analyzed data on breeding birds from 119 breeding bird census plots (tab. 2). These plots were located at business sites (15), in residential areas (55) and in urban green spaces (49). There was a moderate variety among the land use types in terms of the total number and size of the plots.

***Table 2**. Number and size of breeding bird monitoring plots per urban land use type*

	Business site	Residential area	Urban green space
# plots	15	55	49
total area (ha)	580	1920	1033
plot size (ha)	38.66 (±29.50)	34.91 (±25.07)	21.08 (±15.41)

Breeding bird data

We analyzed breeding bird data (census years 1999–2004) from plots located at business sites, in residential areas and in urban green spaces throughout the Netherlands. Data were collected using a standardized territory mapping method that estimates the number of breeding pairs of each observed species (Hustings et al. 1985; Marchant et al. 1990; Bibby et al. 1992; Van Dijk 2004). During the breeding season (March–July) volunteers made 5–10 field visits to their plot, examining the entire plot area. The visits were in the early morning and at an interval of at least 10 days. Usually one night visit was dedicated to owls and other nocturnal species. Observations of birds showing territorial behaviour were collected on a field map. At the end of the season the cumulative results of all visits were used to extrapolate breeding territories, using excluding observations to distinguish territories. Plot borders were chosen based on natural habitat borders and structures (roads, woodland edges, urban areas). The observers classified their plot habitat from a list of habitat types. Using the plots from built-up areas (one habitat type), business sites were later distinguished from residential areas using national data on business site locations.

Apart from the land-use classification, we divided the data on breeding birds into two subsets based on geographical region. This further classification at the regional level is a standard procedure in Dutch breeding bird studies, as in many studies this regional level was an explaining factor for bird abundance (e.g. Van Turnhout et al. 2007). It also appeared relevant for this study, as for most bird guilds there was a significant difference observed between the number of territories of each species per region. The two geographical regions are (i) Eastern Netherlands, the inland Pleistocene region with sandy soils and half-open landscapes and woodlands and (ii) Western Netherlands, the coastal Holocene region with clay or peat soils and open meadow landscapes. Both regions contain high densities of urban areas.

Statistical analysis
To compare business site breeding bird fauna with that in residential areas and urban green spaces we first focused on differences on the species level. We constructed an overview of all the species observed in the 119 plots. For each species Fisher Exact test was employed to test whether the proportion of business sites where that species was present equals the proportion of residential areas where the species was present, and likewise to compare business sites with urban green spaces. We then defined response variables for each bird guild in the data:

- *abundance* – the total number of territories of a specific bird guild per plot;
- *species richness* – the number of species of a specific bird guild present in a plot as proportion of the total number of species of that guild as observed in all plots (%);

The abundance variable was chosen as it illustrates the number of individuals of a specific guild that can be observed at the different urban land use types, the species richness variable because it illustrates how ‘diverse’ an urban area is in terms of species belonging to a specific guild. For hypothesis 6 (i.e. birds in general) we focused on the overall abundance and species richness of the breeding birds, instead of that on the bird guild level.

We analyzed the response variables separately. Where a single plot was censused for more than one year, we used averages over the years for which data were available. Abundance was analyzed using a log-linear regression model employing the Poisson distribution. Species richness, expressed as a proportion, was analyzed using logistic regression, which employs the binomial distribution. Overdispersion with respect to the Poisson or binomial variance was accounted for by inflating the Poisson variance by an overdispersion parameter (McCullagh and Nelder 1989). Since we expected a larger response for larger sites, the logarithm of the plot size was first added to each regression model. We tested whether there were differences in averages according to the land use of the plot (i.e. whether it was a business site, a residential area or urban green space) and according to region (i.e. Eastern or Western Netherlands). We also tested for the interaction between land use of the plot and region. The interaction was almost never significant (2 out of 32 interactions), and we therefore present only results for the model without the interaction. Predicted values were calculated for 100 ha plots. For strict tree-hole nesting birds we also compared figures on abundance with those for woodland (edge) birds. As species diversity here is less relevant, we only calculated absolute and proportional abundance and not species richness. By doing so, we could examine whether strict tree-hole nesting species appeared to be relatively scarce at business sites (because of a lack of old trees) despite the occurrence of other woodland (edge) birds – and therefore woodland habitat - at the business site (H4).

Results

Comparison of business sites, residential areas and urban green spaces

First, we analyzed our data at the species level (Appendix A). In total, 122 bird species were observed breeding at our urban plots, fewer at business sites (66) than in residential areas (104) and in urban green spaces (105). This is probably because the total size of the business site plots was much smaller than that of the residential areas or urban green spaces (tab.2). Of the 66 bird species found at the business sites, some passerines (e.g. Black Redstart, *Phoenicurus ochruros* and Common Linnet, *Cardualis cannabina*) and a few non-passerines (mostly pioneer birds) seemed to be more frequently present at business sites than in residential areas and urban green spaces (Appendix A). In addition, of the 29 Red List species that were observed in these urban plots, 13 (including the Common Linnet) were found at business sites.

Furthermore, this comparison on the species level confirmed the general idea that in cities' green space has a distinctive meaning for species of old trees (e.g. Great Spotted Woodpecker, Short-toed Tree creeper, European Green Woodpecker), whereas residential areas are of interest for species of mosaic habitats with coniferous trees and rosaceous shrubs (like European Greenfinch).

Our analyses showed that for H2-H6 the differences in data were what we expected, with most relations significantly proven. However, ground-nesting birds (H1) were significantly more common at residential areas and urban green space than at business sites, opposite to our hypothesis.

Additionally, we plotted the abundance of pioneer and woodland edge birds found at the business sites, in residential areas and in urban green spaces using a scatter diagram (fig. 2). This diagram positions business sites as breeding bird habitats with a relative high number of pioneer birds and a low number of woodland edge species in relation to residential areas and urban greenspace.

***Table 3**. Results of testing the hypotheses using each response variable. Abundance was expressed in number of territories per 100 ha. Significant differences in breeding birds between business site and urban green spaces, and business sites and residential areas are indicated with p-values: * <0.05; ** < 0.001*

	Hypotheses	Business site	Urban green space	Resi-dential
H1	*Business sites are preferred by species that are ground-nesting*			
	Ground-nesting birds			
	Abundance	37.68	185.32**	82.88**
	proportional species richness – bird guild (%)	14.29	24.20**	16.88
H2	*Business sites are preferred by species of early-successional vegetation.*			
	Pioneer birds			
	Abundance	26.28	24.13	9.49**
	proportional species richness – bird guild (%)	19.37	15.76	7.55**
H3	*Business sites are less preferred by shrub and woodland (edge) birds*			
	Shrub birds			
	Abundance	38.3	222.6**	169.8**
	proportional species richness – bird guild (%)	27.82	52.12**	44.54**
	Woodland-edge birds			
	Abundance	17.52	105.89**	79.43**
	proportional species richness – bird guild (%)	21.37	44.46**	39.85**
	Woodland birds			
	Abundance	8.36	106.15**	78.75**
	proportional species richness – bird guild (%)	6.40	34.03**	24.01**
H4	*Business sites are less preferred by tree-hole nesting birds*			
	Strict tree-hole nesting birds			
	Abundance	0.43	19.32**	6.95*
	proportional species richness – bird guild (%)	2.29	38.73**	19.98**
	Strict tree-hole nesting birds compared to woodland (edge) birds			
	proportional abundance – woodland (edge) birds (%)	1.76	10.02*	4.46
	proportional species richness – woodland (edge) birds (%)	4.94	27.09**	17.24*
H5	*Business sites are less preferred by birds that nest in buildings compared to residential areas*			
	Building-nesting birds			
	Abundance	25.8	39.7	177.3**
	proportional species richness – bird guild (%)	28.10	37.18	49.40**
H6	*Business sites are less preferred by birds in general, in terms of abundance and species richness.*			
	All birds			
	Abundance	116.8	619.8**	578.8**
	proportional species richness – overall (%)	15.49	33.61**	27.36**

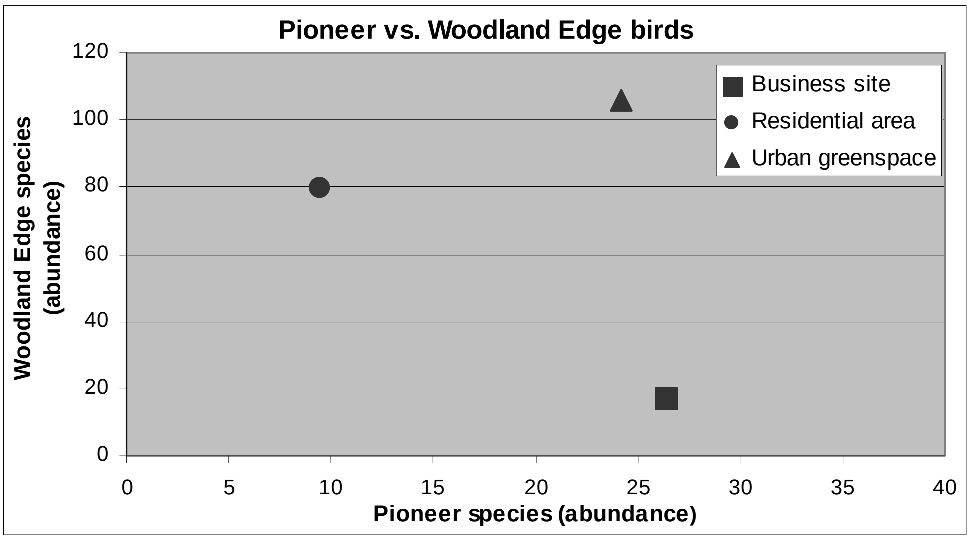

Figure 2. *Business sites, residential areas and urban green spaces compared for the abundance (# territories per 100 ha) of pioneer and woodland-edge birds, illustrating the different habitat characteristics of these urban land use types.*

Discussion

How representative is the study?

Our number of business site plots with breeding bird data was relatively large compared with those in the existing literature (Blair 1996, 2001; Albert and Marzluff 2004). Also, our plots represented different stages in business site development (fig.1). Such a selection of different business site plots was not addressed in earlier studies. Nonetheless, we consider our analysis exploratory as the 15 business site plots are still too low to represent the total variety of business site environments. For residential areas and urban green space we are more convinced of their representativeness, as here there were much more plots that were also better distributed over the country.

In this study bird guild classification was based on nesting site preference. Other aspects in the bird’s life (e.g. availability of food) also determine whether a species may occur in an area. For some breeding bird species for which the nesting site and the foraging area distinctively differ in land use (e.g. Barn Swallow or Common tern), the availability of the former may not have been sufficient to explain the presence or absence of the species.

Conclusions

Breeding birds at business sites differed distinctively from those in residential areas and urban green spaces. In general, a significantly lower abundance and species richness of breeding birds was found at these economic sites, as observed at survey plots in the Netherlands. However, the bird guild level presented a more differentiated picture regarding the role of business sites as habitats for breeding birds. The business sites in our sample appeared to be especially preferred by birds linked with early successional (e.g. sparse or low) vegetation. In contrast, birds that prefer climax vegetation (e.g. old forests) were almost absent, reflecting the trees at these sites not being old enough for tree-hole nesting. The resulting bird assemblage differentiates business sites from other urban land-use types, both built-up and not built. Business sites especially contribute to the city's bird diversity by providing habitats for breeding birds that prefer dynamic habitats with low, early successional vegetation.

Our study contributes to the existing literature by providing insights into the suitability of existing business sites as places for biodiversity conservation, in particular, for breeding birds, as illustrated by the Dutch situation. It quantified the extent to which breeding bird communities at business sites differed from those found in residential areas and urban green spaces, specified up to the bird guild level. As such, it provided an indication of the added value of business site habitat for urban bird communities.

Implications for planning, design, development and management of business sites

Business sites have a low cover of vegetation, compared to other urban land use types (Blair 1996). Preliminary results from a land use analysis on the plots as used in this study confirmed this finding. The lack of habitat therefore seems the primary reason for a low abundance and diversity of breeding birds at business sites. As bird-habitat analyses in different urban bird studies suggest, a way to increase breeding bird numbers would be to increase the proportion of shrub and tree cover at the business sites (Tilghman 1987; Leston and Rodewald 2006; Lee et al. 2007). However, not only would this be hard to achieve at actual business sites, it also would go by the idea that business sites have their own character and may provide unique opportunities to enrich the city's bird diversity with species linked with early-successional and brushwood vegetations.

Besides, when biodiversity conservation at business sites is being considered, the regional and landscape factors present in the wider surroundings of the sites must also be taken into account (De Graaf and Wentworth 1986; Mörtberg 2001; Hodgkison et al. 2007). Each location has its own potential for biodiversity conservation, apart from the nature and size of the business site. For example, for the Dutch situation, this implicates that along the coastal zone a good way to enhance biodiversity levels may be to use derelict lands and the many flat roofs available at business sites to provide nesting opportunities for species such as gulls, the Common Tern (*Sterna hirundo*) and Eurasian Oystercatcher (*Haematopus ostralegus*). This can be done by temporarily designating and managing for pioneer species specific areas within the business site that are ready for development but have yet not been built up. Also, a proportion of the – usually quite abundant – flat roofs at business sites could be transformed into gravel or sedum roofs (resembling early successional vegetation). Especially in the vicinity of open water, such measures could support local populations of waders and terns, not only at coastal sites but also inland.

In other landscapes, such as those where small-scale agricultural parcels surround a city, we suggest that herbaceous vegetation could be developed at business sites to support rural species like the Grey Partridge (*Perdix perdix*) (Sálek et al. 2004) and small passerines including the Common Linnet (Timmermans and Snep 2001). Business sites that are already nearly fully occupied probably offer opportunities for integrating a more ecological design and management of the urban green at the site, thereby favouring especially shrub birds. An associated advantage is the value employees place on such measures, as the presence of urban green and varied biodiversity in the working environment tends to be highly appreciated (Kaplan 2007).

Finally, at business sites that have little possibilities to increase their cover of vegetation, extra attention could be paid to the business site buildings to create nesting opportunities for species that prefer these highly paved environments (see e.g. Black Redstart Action Plan 2008).

Further research

In addition to the described work, we explored the possibility to conduct a regression analysis on the relationships between the business site land use and the abundance of breeding bird territories of different bird guilds. However, we were not able to obtain results that were robust enough to define significant and profound relationships. Limited availability of breeding bird data of business sites restricted our opportunities to accomplish additional analyses and thereby the extent to which we could clarify what land use factors determine breeding bird abundance.

For future research we recommend not only to census more business site plots, but also to collect long-term data on both breeding birds as well as the land use at business sites. This would make it possible to link changes in the breeding bird community with changes in land use in and around the plots. Also research to the level of breeding bird disturbance at business sites (like Fernandez-Juricic 2000) may offer better insight to what extent business sites have a (potential) significance for breeding bird conservation. In the light of these recommendations we consider this study as a signal that business sites may provide interesting biodiversity levels, such as an encouragement for further research.

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Appendix A. Average occurrence (%) of breeding bird species (n=122) in different urban land-use types, including significant differences.

Bird group classification is largely according to Tucker and Evans (1997). Bird names highlighted in grey are species that were more frequently present in our plots at business sites than at urban green space and/or residential areas. Red List: CE = critically endangered; EN =endangered, EW = extinct in the wild; VU = vulnerable. P-values: ~ < 0.10; *< 0.05; **< 0.01; ***< 0.001.

English name	Red List	Bird guild	ground-nesting	strict tree-hole nesting	Business site	Urban green space		Residential area	
Black-tailed Godwit	CE	Meadow birds	1		0	2		2	
Common Redshank	CE	Meadow birds	1		0	6		2	
White Stork		Meadow birds			0	8		0	
Common Buzzard		other birds			0	27	*	7	
Common Kestrel		other birds			13	16		16	
Common Cuckoo	VU	other birds			0	27	*	18	
Eurasian Hobby		other birds			0	16		6	
Northern Goshawk		other birds			0	2		0	
Common Black-headed Gull		pioneer birds	1		7	0		0	
Common Pheasant		pioneer birds	1		33	49		16	
Common Quail		pioneer birds	1		0	0		2	
Common Sandpiper	CE	pioneer birds	1		0	0		2	
Common Shelduck		pioneer birds	1		7	10		4	
Common Snipe	EN	pioneer birds	1		0	2		0	
Common Tern	VU	pioneer birds	1		7	0		0	
Corn Crake	VU	pioneer birds	1		0	0		2	
Crested Lark	CE	pioneer birds	1		0	0		4	
Eurasian Oystercatcher		**Pioneer birds**	**1**		**60**	**16**	**	**26**	*
Eurasian Sky Lark	CE	pioneer birds	1		7	2		2	
Grey Partridge	VU	pioneer birds	1		7	4		2	
Herring Gull		**Pioneer birds**	**1**		**20**	**0**	*	**6**	
Lesser Black-backed Gull		pioneer birds	1		7	0		4	
Little Ringed Plover		pioneer birds	1		0	4		0	
Meadow Pipit	CE	pioneer birds	1		13	2		4	
Mew Gull		**Pioneer birds**	**1**		**20**	**0**	*	**2**	~
Northern Lapwing		pioneer birds	1		7	10		6	
Northern Wheatear	EN	pioneer birds	1		7	0		0	
Sand Martin		pioneer birds			0	4		0	

English name	Red List	Bird guild	ground-nesting	strict tree-hole nesting	Business site	Urban green space		Residential area	
Wood Lark		pioneer birds	1		0	2		0	
Black-crowned Night-Heron	EW	reed birds			0	2		0	
Common Reed Bunting		reed birds	1		13	18		6	
Eurasian Reed Warbler		reed birds			20	45		22	
Sedge Warbler		reed birds	1		0	8		2	
Water Rail		reed birds	1		0	4		0	
Barn Swallow	CE	rock birds			7	8		20	
Black Redstart		**rock birds**			**67**	**2**	***	**27**	*
Common Barn Owl	VU	rock birds			0	0		6	
Common House Martin	CE	rock birds			7	0		13	
Common Starling		rock birds			13	59	**	89	***
Common Swift		rock birds			0	0		46	***
Eurasian Collared Dove		rock birds			7	51	**	78	***
Eurasian Tree Sparrow	CE	rock birds			20	12		26	
House Sparrow	CE	rock birds			27	45		93	***
Little Owl	VU	rock birds			0	0		6	
Stock Dove		rock birds			27	69	**	31	
Western Jackdaw		rock birds			27	51		69	**
White Wagtail		**rock birds**	**1**		**60**	**14**	**	**42**	
Bluethroat		shrub birds	1		7	8		2	
Common Grasshopper Warbler		shrub birds	1		7	2		2	
Common Linnet	**CE**	**shrub birds**			**60**	**16**	**	**29**	~
Common Nighthingale	VU	shrub birds	1		7	20		11	
Common Whitethroat		shrub birds			40	29		31	
Common Blackbird		shrub birds			53	100	***	100	***
Dunnock		shrub birds			73	94	~	95	~
Eurasian Blackcap		shrub birds			47	92	***	91	**
Eurasian Turtle Dove	VU	shrub birds			0	2		11	
Eurasian Bullfinch		shrub birds			0	6		11	
European Robin		shrub birds	1		40	88	***	82	**
European Stonechat		shrub birds	1		0	2		0	
Garden Warbler		shrub birds			33	65	~	58	
Icterine Warbler	CE	shrub birds			7	20		31	
Lesser Whitethroat		shrub birds			27	18		58	~
Long-tailed Bushtit		shrub birds			13	84	***	73	***
Marsh Warbler		shrub birds			20	35		22	
Song Thrush		shrub birds			13	96	***	89	***
Willow Tit	CE	shrub birds			0	33	*	13	
Willow Warbler		shrub birds	1		33	65	~	71	*
Winter Wren		shrub birds			40	98	***	98	***
Barnacle Goose		water birds	1		0	2		0	

English name	Red List	Bird guild	ground-nesting	strict tree-hole nesting	Business site	Urban green space		Residential area	
Canada Goose		water birds	1		0	8		6	
Common Kingfisher		water birds			0	4		2	
Common Moorhen		water birds	1		13	78	***	51	*
Common Pochard		water birds	1		7	0		2	
Common Teal	VU	water birds	1		0	2		0	
Egyptian Goose		water birds			7	37	*	7	
Eurasian Coot		water birds	1		13	78	***	62	**
Feral duck		water birds	1		7	51	**	40	*
Gadwall		water birds	1		7	14		4	
Great Crested Grebe		water birds	1		7	31		27	
Grey Wagtail		water birds	1		0	0		2	
Greylag Goose		water birds	1		0	2		2	
Mallard		water birds	1		47	80	*	67	
Mute Swan		water birds	1		7	14		16	
Northern Shoveler	VU	water birds	1		0	8		0	
Tufted Duck		water birds	1		7	16		2	
Black Woodpecker		woodland birds		1	0	0		2	
Coal Tit		woodland birds			0	10		9	
Common Chaffinch		woodland birds			13	90	***	84	***
Common Wood Pigeon		woodland birds			67	98	**	96	**
Eurasian Golden Oriole	VU	woodland birds			0	6		6	
Eurasian Jay		woodland birds			13	90	***	76	***
Eurasian Nuthatch		woodland birds		1	0	31	*	26	*
Eurasian Siskin		woodland birds			0	2		0	
Eurasian Sparrowhawk		woodland birds			0	35	**	15	
European Blue Tit		woodland birds			33	98	***	100	***
European Crested Tit		woodland birds			0	4		6	
European Pied Flycatcher		woodland birds			0	4		26	*
Firecrest		woodland birds			0	2		4	
Goldcrest		woodland birds			0	20		18	
Great Spotted Woodpecker		woodland birds		1	0	94	***	56	***
Hawfinch		woodland birds			0	6		18	
Lesser Spotted Woodpecker		woodland birds		1	0	2		2	
Long-eared Owl	VU	woodland birds			0	18		4	
Marshtit		woodland birds		1	0	22	~	15	
Short-toed Treecreeper		woodland birds		1	13	88	***	66	***
Spotted Flycatcher	CE	woodland birds			7	25		26	
Tawny Owl		woodland birds		1	0	29	*	13	
Carrion Crow		woodland-edge birds			60	98	***	91	*
Common Chiff-chaff		woodland-edge birds	1		47	98	***	98	***
Common Redstart		woodland-edge birds		1	7	8		7	

English name	Red List	Bird guild	ground-nesting	strict tree-hole nesting	Business site	Urban green space		Residential area	
Eurasian Magpie		woodland-edge birds			60	86	~	95	**
European Goldfinch		woodland-edge birds			47	35		44	
European Green Woodpecker	VU	woodland-edge birds		1	0	51	***	27	*
European Greenfinch		woodland-edge birds			33	55		86	***
European Serin		woodland-edge birds			0	0		6	
Great Tit		woodland-edge birds			33	98	***	100	***
Grey Heron		woodland-edge birds			0	20		0	
Mistle Thrush		woodland-edge birds			0	27	*	29	*
Rook		woodland-edge birds			0	6		2	
Rose-ringed Parakeet		woodland-edge birds		1	0	31	*	11	
Tree Pipit		woodland-edge birds	1		0	2		4	
Yellowhammer		woodland-edge birds			0	4		6	

The ‘habitat backbone’ as strategy to conserve pioneer species in dynamic port habitats: lessons from the natterjack toad (*Bufo calamita*) in the Port of Antwerp (Belgium)

3 The ‘habitat backbone’ as strategy to conserve pioneer species in dynamic port habitats: lessons from the natterjack toad (*Bufo calamita*) in the Port of Antwerp (Belgium)

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Abstract

Biodiversity conservation in economic areas like ports has recently become more important in the European Union due to a stricter interpretation of nature protection laws. In this study we develop a planning and design strategy—the ‘habitat backbone’— with which to support the long-term survival of pioneer species that occur in ports and have low dispersal abilities. For those species, long-term survival in port areas is uncertain because supply of their habitats (on vacant lots) is capricious and depends on land use dynamics. By gaining knowledge about spatial and temporal characteristics of these dynamics we were able to develop a solution to conserve such species. Our solution is based on the creation of permanent habitat—defined as a ‘backbone’— on (semi-) public land with an overall carrying capacity sufficient to support persistent populations. This best ensures long-term survival, and the backbone may also act as refugium. Satellite populations that emerge on adjacent vacant lots will thereby add to the persistence of the overall metapopulation.

Management of permanent habitat is focused on retaining early-successional stages of vegetation. Implementing this strategy in the case of the natterjack toad in the Port of Antwerp taught us that realization of a habitat backbone is possible only if landowners, local governments and environmental NGOs cooperate. In the case at hand, such cooperation resulted in a plan that should ensure a coherent and persistent habitat network in which a chorus of some 1,400 natterjack toads could be accommodated— more than the number of toads currently observed.

Introduction

The US Wildlife Habitat Council promotes conservation and development of wildlife habitat on corporate lands (Cardskadden and Lober 1998). Practical experience has shown that industrial areas and business sites offer great opportunities for biodiversity conservation, an important issue since the 1992 Convention on Biological Diversity in

Rio de Janeiro (CBD 1992). Nonetheless, biodiversity conservation on these economic areas currently in use is still relatively unknown in scientific literature (e.g. Timmermans and Snep 2001; Yang and Lay 2004). Snep et al. (chapter 2.) suggest that the value of business sites as habitat for wild plants and animals lies in their peri-urban location, the typical architecture of the buildings, the highly dynamic land use and the fact that human disturbance is usually restricted to office hours. Little is known, however, about the conditions under which business sites and industrial areas could contribute to the preservation of biodiversity.

Among the range of business site types, port areas stand out due to their large size, their use of heavy industry and their coastal location (IBIS 2007). These vast industrial areas often contain large vacant parcels, ready to be developed if necessary. Because these vacant lots are often raised with sandy in-water slurry and greenery management is minimal, these terrains usually develop like real pioneer biotopes. Plant and animal species that have their ecological niche in colonizing open and hostile environments have discovered these—artificial—habitats (Stienen et al. 2005).

Some of these species are protected by international nature conservation directives, because of their status as endangered species at the international level. The occurrence of protected species in areas where economic activities have precedence creates a potential conflict between economic demands and the urge to conserve biodiversity values (De Langen 2007). This raises questions about how in the longer term, under variable economic conditions, economic development can be balanced with the persistence of valuable species in ports and industrial areas.

In Europe, authorities from various countries have joined informal cooperation platforms to explore how to deal with protected nature occurring in industrial port areas. Moreover, in some ports in the United Kingdom, Belgium, the Netherlands and Germany actual compensatory habitat has already been created, an obligation originating from EU Habitat and Bird Directives (Morris and Gibson 2007). This includes the development of inter-tidal and sub-tidal habitats (e.g. mudflats and sandbanks) in estuarine environments and species-specific measures like the creation of the Tern island in the port of Zeebrugge (Stienen et al. 2005).

These practices, however, focus on aquatic, plant and bird life. Insights are still lacking on how to protect terrestrial animals that occur in these dynamic urban environments and have a medium to low dispersal ability. For these species, the spatial land use patterns common in ports and industrial lands, with their high density of barriers (like roads, railroads and fences), create an obstacle for migration. In addition, the land dynamics resulting from economic activities cause a high turnover in the availability and configuration of habitat patches, adding to the difficulties for these animals to sustain a persistent population. Ports and industrial sites, therefore, present a challenge for the long-term survival of pioneer animals residing in dynamic habitats and not benefiting from high dispersal abilities. A good example of such a situation is the case of the Natterjack toad (*Bufo calamita*) population in the Port of Antwerp

(Belgium). This case can be considered as the immediate cause of our study in which we aim: to explore a planning and design strategy that—without obstructing ongoing economic activities—provides a sustainable habitat structure for ground-dwelling animals and other species with low dispersal abilities that occur in dynamic habitats in ports and similar industrial areas.

In so doing, this study encompasses two steps:

(1) Defining a planning and design strategy focused on the specific land use of ports and industrial areas and the ecology of ground-dwelling and other low- and medium-dispersing pioneer animal species.

(2) Testing this strategy in the practical case of the Natterjack toad in the Port of Antwerp, in which the strategy principles developed in step 1 and empirical data are used to create and discuss a site-specific land use management plan with local stakeholders.

This paper contributes to the existing literature by elaborating landscape ecological principles for biodiversity conservation in dynamic urban environments (such as ports and industrial sites). It defines, in particular, the spatially explicit 'habitat backbone' strategy, designed especially for urban areas with a high turnover in land use due to economic activity. This strategy takes advantage of opportunities for biodiversity conservation that dynamic urban environments may offer and integrates areas with permanent habitat and those with temporary habitat into one planning and design concept.

It thereby focuses on animal species with low or medium dispersal abilities (<5 km) that occur in habitats at early successional stages. It further demonstrates how the habitat backbone strategy can be implemented in practice by describing the case of conserving the natterjack toad in the Port of Antwerp, Belgium. Overall, this study provides new directions for integrating biodiversity conservation goals into the management of dynamic environments, especially urban landscapes like ports and other industrial sites.

The habitat backbone as biodiversity conservation strategy

Port characteristics in space and time

Structures and dynamics, on a local, regional and international scale, give ports and the adjacent cities their characteristic interlocking pattern of water and docklands, designed to optimize the size and economic functionality of the waterfront (Ducruet 2005). Infrastructure (roads, rails and pipelines), to connect the port area with the hinterland, provides a whole network that passes through all parts of the port (World Bank 2003). Port areas and similar large scaled industrial sites develop in several stages (e.g. Weigend and New Brunswick 1973; Luxford and Chandra 2005). Thus, a spatial pattern of developed and undeveloped land interlinked with different types of infrastructure emerges. On the developed land parcels, port companies transfer containers, natural gas and oil products and commodities between ships and the hinterland. The undeveloped parcels are reserved for future expansion or are left over from earlier activities. Altogether, although the plan of each port area is unique as a result of location, history and type of port activities, the spatial mix of developed and undeveloped land (in different proportions), interlinked with infrastructure, is seen in every port.

Ecological concepts for pioneer habitats in port areas

How could port areas provide a sustainable habitat structure for pioneer animal species that have low or medium dispersal abilities and occur in early successional habitats? What ecological concept could provide a theoretical basis for developing a conservation strategy? As described by Trepl (1995), both the theory of island biogeography (MacArthur and Wilson 1967) and the metapopulation theory (Levins 1970; Opdam 1991) are presented in studies that try to explain how species abundance and richness are dependent on the habitat patterns in cities. Niemelä (1999) argued that the theory of island biogeography may best serve to describe the relationship between characteristics of urban habitat patches and species richness.

However, as also discussed in that paper, there are quite distinct differences between islands (on which the theory was based) and the urban matrix. For instance, urban areas often lack a large source area (as assumed in the theory of island biogeography), and also the permeability of the urban matrix may be highly variable (being less homogenous than the sea separating islands) (Niemelä 1999a). The basic principles within the metapopulation theory, however, seem to offer a much better understanding of species abundance in highly fragmented landscapes, where there are no large ‘core areas’ and dispersal between patches is still possible (Niemelä 1999a; Wood and Pullin 2002). Cities may in this perspective be seen as extremely fragmented areas, with many species occurring that are sensitive to fragmentation of their habitats (e.g. Bastin and Thomas 1999; Bolger et al. 2000; Crooks et al. 2004).

As our focus is on species abundance in ports (areas where there are opportunities to increase habitat connectivity), we here consider the metapopulation theory to be a good starting point for discussing species-specific planning and designing strategies for conservation.

Conditions required for sustainable pioneer habitat structures in port areas

Although ports and industrial areas make up part of the urban environment, they are seldom incorporated in officially zoned urban green structures. This is perhaps because these areas contain few traditional green spaces (urban lawns, shrubs and woods), and they probably poorly fit the standard aims of official green structures. Nevertheless, a network (like these green structures) of functionally connected patches containing pioneer habitats could provide a sustainable habitat structure for pioneer species with low or medium dispersal abilities. The spatial land use configuration of ports and industrial areas thereby holds a key to developing strategies that offer such a network.

Pioneer species that live in port areas can be considered species with dynamic populations living in dynamic landscapes. For the persistence of those species extrinsic habitat dynamics (creating appearance and disappearance of habitat) thereby are much more important than intrinsic (i.e. within available patches) colonization and extinction processes, as disturbances in a metapopulation area may directly result in a lower amount of empty patches to be colonized (Vuilleumier et al. 2007). For port areas we consider 'disturbance' as those (economic) activities that have a negative impact on habitat quality and availability of pioneer habitats. As the impact of those disturbances is lower in some parts of the port area (the urban green structure at (semi)public land) than in others (the parcels at private land), habitat available at the (semi-)public land could act as a refugium. A refugium is an area in which species will be more capable to survive in adverse conditions, making those areas to act as sources for recolonization of neighboring patches after the disturbance has taken place (Lancaster 2000).

Areas in ports that have a permanent function as a green area (e.g. verges or utility sites) are less likely to be disturbed and may therefore better provide permanent availability of pioneer habitats, given that the management of pioneer areas is focused on retaining early stages of succession. As such, they could function as refugia in times of natural or human-caused disturbance (Lancaster 2000).

To be effective as a refugium such a permanent habitat structure should support persistent populations. As argued by Verboom et al. (2001) persistence of populations occurring in human-dominated landscapes may best (i.e. with the least network area) be obtained by a network of habitat patches that includes so-called 'key patches'. A key patch accommodates a 'key population', which is a population that is persistent because of its low extinction rate (due to its large size), compensated by an equally small recolonization rate. For pioneer species, habitat quality seems to be a key factor for the persistence of populations (Kildaw et al. 2005; Stefan et al. 2001). This is because due to natural succession or other factors habitat quality may decrease quickly, lowering the overall carrying capacity of the habitat network to the point that naturally occurring environmental and demographic stochasticity leads to extinction. For port areas this means that the carrying capacity of a permanent habitat structure should significantly exceed the minimum level for persistence and thus provide a buffer against changes in habitat quality and impacts of natural stochasticity. Incorporating several key patches (we recommend at least three) in this permanent habitat structure is one way to spread risk and better ensure persistence of the population.

From a conservation viewpoint, sites on land used for economic purposes and owned by private companies would not seem to ensure conditions for persistence (as for companies in the end economic aims have higher priorities than biodiversity conservation). But they could nonetheless temporarily contribute to the conservation of plants and animals by creating a population buffer, allowing species to increase their numbers in favourable periods beyond the carrying capacity offered by the permanent habitat structure. Thus, though not incorporated into a permanent habitat structure, they can be seen as extra insurance against extinction of the metapopulation.

Definition of the habitat backbone strategy

Here we define the ‘habitat backbone strategy’ as a planning and design approach aimed to create a network consisting of stable (key) patches surrounded by patches of a more temporary nature. This mix of permanent and temporary habitat should be able to provide a sustainable habitat structure for ground dwelling animals and other species that have low or medium dispersal abilities and are found in dynamic habitats. The permanent part of this habitat structure (including the key patches) may function as a refugium, and therefore is referred to as the ‘backbone’.

The temporary habitats may support satellite populations for a certain period of time and thus boost the persistence of the population (without the population depending on them). Altogether the ‘habitat backbone strategy’ should meet five criteria:

(1) *Backbone layout* A continuous or well-connected structure of habitat patches (for the target species) should be zoned within the port or industrial area (Fig. 1a).

(2) *Backbone destination* In terms of planning this backbone should be permanent in nature, so layout and type of land use should remain the same for many years.

(3) *Backbone management* The habitat management of the backbone should focus on the requirements of the target species, keeping the vegetation in a pioneer stage by regular management.

(4) *Backbone size* The carrying capacity of the backbone should be well above the minimum level for persistence (with the norm depending on the target species) (Fig. 1b), with at least three key patches (Fig. 1a).

(5) *Backbone location and temporary habitats* The location of the backbone should enable the target species to colonize temporarily available pioneer habitat on lots that are currently or in the future vacant adjacent to the backbone (Fig. 1a).

Spatial and temporal aspects of the habitat backbone strategy (demonstrated for a simplified plan of a port) could support the long-term survival of ground dwelling animals in dynamic habitats (Fig. 1).

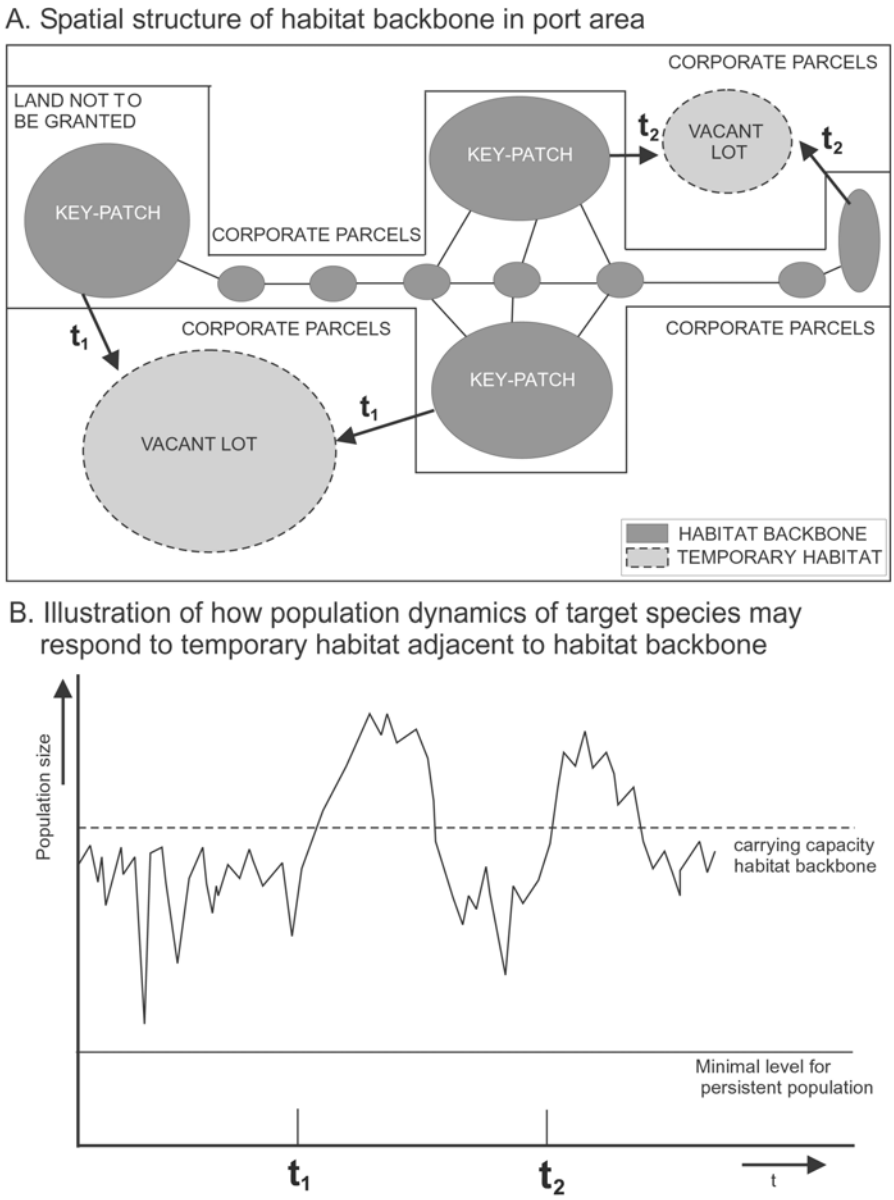

Figure 1. *Spatial and temporal aspects of the habitat backbone for a ground-dwelling pioneer species occurring in port areas. The schema (Fig. 1a) illustrates how the spatial structure of the habitat backbone (permanent habitat), adjacent to vacant lots (temporary habitat) on corporate lands, may impact the population dynamics of the species. At the moments t_1 and t_2 there are next to the habitat backbone also some vacant lots available, leading to a temporary increase in the population size (Fig. 1b). At other moments, the only habitat available is located in the habitat backbone, however this is still sufficient to accommodate a persistent population..*

Results: the case of the natterjack toad in the port of Antwerp

Context

In this case study, we focused on the natterjack toad (*Bufo calamita*) population on the left bank of the Port of Antwerp, Belgium. The natterjack toad is mainly found in pioneer habitat, especially those where during the day the ground warms up quickly (Denton and Beebee 1993). Since in dynamic habitats the natterjack toad is strongly dependent on its dispersal ability for its survival, when studying the species consideration must be given to the barrier effect of roads and other (infra)structures.

In Belgium, natterjack toad populations have declined dramatically during the past decades (Bauwens and Claus 1996). The natterjack toad population in the Port of Antwerp is one of the largest in Belgium today. This explains the concern among environmental NGOs about planned developments in the port which may threaten the long-term survival of the large population of natterjack toads there. The Annex IV of the EU Habitat Directive (HD) defines the natterjack toad as an endangered species that is strictly protected in their natural range (EU 1992). For species listed in the HD a favourable conservation status should be maintained. The conservation status will be regarded 'favourable' when (among other restraints) ''there is, and will probably continue to be, a sufficiently large habitat to maintain its populations on a long-term basis'' (EC 2007). In this study we have interpreted this as the need to conserve a habitat structure able to support a persistent population of the natterjack toad.

Current state and future of the natterjack toad in the Port of Antwerp

Our study area is the left bank of the Scheldt River, part of the Port of Antwerp. The majority of the Antwerp natterjack toads are found in this area. Data from inventories of calling males conducted in 2003–2004 plus data from a field visit in 2005 offered insights into the current distribution of natterjack toads there (Fig. 2). Based on these counts in successive years, the number of natterjack toads was estimated at 1,250 calling males for the current situation, occurring on 555 ha. Habitat size was measured at the parcel level (defining the whole parcel area as habitat), with the understanding that the net habitat size would be much lower.

Port developments in the coming years, especially the expansion of the North Waasland Port industrial area, will lead to a shrinkage of the habitable area available to the natterjack toad. The survival of this large natterjack toad population will, therefore, inevitably be jeopardized if no protective measures are taken.

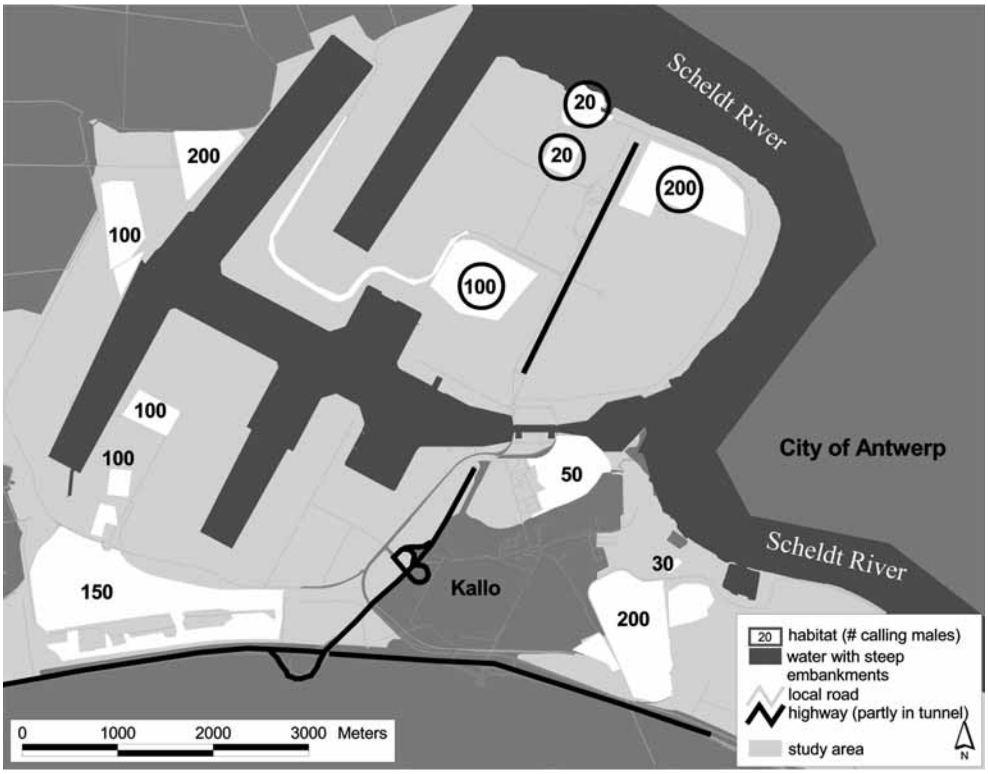

Figure 2. *Current distribution of natterjack toad (habitat and chorus size) at the Left bank of the Port of Antwerp (study area). Encircled numbers of calling males in the northern part indicate those populations that will disappear in the future situation*

Assessment of the persistence of current and future natterjack toad populations

We assessed the persistence of the natterjack toad population in the Port in Antwerp for two scenarios: the current and the future situation. The current situation was defined as that observed in 2003–2005 (Fig. 2). The future situation was defined as that in which the habitats located in the northern part of the study area (North Waasland Port) had completely disappeared, while the habitat in the southern and western port areas remained. We hereby assumed that the populations in the northern part of the study area become extinct (Table 1). These populations are encircled in Fig. 2. How can we assess the persistence of the natterjack toad populations? The spatial pattern of presence and absence of natterjack toad populations is probably best described as a metapopulation (Schmidt and Pellet 2005), a constellation of local populations mutually connected by dispersers. To assess the current and future situation of the natterjack toad in the Port of Antwerp, we defined several spatial population norms based on field data, the literature and simulation models (assumptions). We then assessed the persistence in three steps (as in Groot Bruinderink et al. 2003; Verboom and Pouwels 2004).

Table 1. *Results of persistence analysis of natterjack toad population in the current and future situation. Three spatially isolated networks were distinguished. A persistent network population with a key population requires at least 500 RU (reproductive units: being one male and one female, Vos et al. 2001), see Appendix A for details. In this paper we considered 1 RU to be represented by one calling male.*

	Population size (#RU)	Key area presence	Persistent
CURRENT SITUATION			
Network 1 (north)	350	Yes	No
Network 2 (south/west)	650	Yes	Yes
Network 3 (south/east)	250	Yes	No
Total	1250		
FUTURE SITUATION			
Network 1 (north)	0	-	-
Network 2 (south/west)	650	Yes	Yes
Network 3 (south/east)	250	Yes	No
Total	900		

As a first step we selected the subpopulations that together could be considered one local population (Stefan et al. 2001). This selection was based on the species' home-range distance and the presence of barriers between the subpopulations. The size of local populations was calculated as the sum of subpopulations belonging to the same local population. Subpopulation size was represented by the numbers of calling males observed. Local populations with a certain minimum size (see Appendix A) were thereby considered as acting as key populations.

In the second step we calculated based on norms for dispersal distance and dispersal barriers which of the local populations might be considered as belonging to the same network population. Finally, in a third step, we assessed the persistence of the network populations found in the study area. For this we used persistence norms for network populations with and without key populations. Appendix A provides details about the norms and arguments used in our persistence analysis.

For the current and future situation we found, respectively, three and two network populations. Network 1 is located in the northern peninsula (encircled numbers of calling males); this network population is found only in current situation. Network 2 is in the west/south-west (west of the urban settlement of Kallo). Network 3 is located east of Kallo. For both situations only one network population (network 2) meets the norm for persistent metapopulations (based on the presence of a key patch and the overall metapopulation size) (Table 1).

If the persistence norm is varied with a maximum of 30% no changes in persistence status occur (still based on the presence of a key patch), as the population size of network 2 was 130% of the persistent norm, and networks 1 and 3 reached only 70 and 50%, respectively. However, if the key-patch norm was increased, no network population would contain a key patch, and none would reach the norm for a persistent network population without a key patch. The outcome of the persistence analysis was, therefore, sensitive to the uncertainty in the key-patch norm.

Designing a long-term solution: the habitat backbone

Our analysis suggests that in the future situation one persistent population will remain, but the total number of natterjack toads and their distribution throughout the whole port area will decline. From the Antwerp Port Authority we learned that additional economic developments, unfortunately not included in our 'future situation' analysis, may threaten the habitat network of the only persistent population. Altogether, the long-term existence of a large natterjack toad population in the Port of Antwerp is unlikely if no action is taken. At a stakeholder meeting, government officials and representatives of private companies and environmental NGOs declared their intention to conserve a large and persistent population of natterjack toads in the Port of Antwerp for the long term. They agreed on a minimum target of 1,250 calling males (as representatives of the population size) which should remain in the port area, this being the actual population size as it was known in 2005. This is more than actually needed for a persistent population, but the stakeholders preferred to keep the population at its current level.

As researchers we studied under what conditions a persistent population of natterjack toads could be conserved in the Port of Antwerp. To best guarantee the long-term presence of such a large population of natterjack toads, we proposed implementation of the 'habitat backbone' strategy in the Port of Antwerp, including the extra target: the population should not only be persistent but also continue to include a population size similar to the current situation. The strategy was discussed at a meeting with the Antwerp Port Authority, the Belgium Research Institute for Nature and Forest (INBO) and the Belgium environmental NGO Natuurpunt and agreed upon by all stakeholders.

We describe here how the habitat backbone criteria were met in the site-specific land use management plan proposed.

Criteria 1 and 2: backbone layout and destination

Only on public lands can appropriate land management for the natterjack toad be guaranteed into the future. For this reason, privately owned properties (corporate lands) were left out of consideration in the construction of the 'habitat backbone' structure. The Port of Antwerp, however, has already planned an ecological infrastructure (EI) initiative, an outcome of broader nature conservation aims. To conserve the large number of natterjack toads in the port area, the stakeholders decided that the habitat backbone would be realized wholly within the EI, which is located on public land within the port area. Satellite populations on adjacent private lands would function as additional to the large and persistent population that should occur on the backbone.

Criteria 3 and 4: backbone size and management

Implementation of the habitat backbone strategy in the Port of Antwerp meant designing a spatial habitat structure including key patches. This required defining size, design and management of key patches. Population dynamics of amphibians are largely stochastic (Schmidt and Pellet 2005), which makes it difficult to indicate how patch size is related to population size. We used literature (Kuzmin 1995) and expert judgments of Dutch field herpetologists to estimate the number of hectares of optimal habitat necessary for a key population (set at 200 RU, see Appendix A). In some cases 100 or even 200 natterjack toads (males and females) were found on 1 ha of terrestrial habitat. Also, in another case, 233 egg strings were found in a ditch only some few dozen meters long. To include a safe margin, we defined a minimum of 5.5 ha of optimal terrestrial habitat and 1.5 of optimal breeding water as the size of a key patch. Active habitat management in these patches should preserve the desired succession stage to keep the habitat optimal. In so doing, particular attention should be paid to the availability of spawning grounds, as the availability of these (together with the mortality rates of juveniles) have the greatest influence on the natterjack toad's survival (Stefan et al. 2001).

At a stakeholder meeting in the Port of Antwerp, experts indicated where key patches could be situated. Four larger areas within the port's EI were assigned to contain one or two key patches each. As these large areas are already managed for nature conservation purposes, the overall biodiversity-oriented management means that the size of available habitat for natterjack toads will actually be larger than only the surface area of the key patches. Ecological corridors should connect different areas within the EI, so natterjack toads will be able to migrate from one patch to another. As during our study no exact location of these corridors could be set, we defined search zones in which the corridors could best be developed. The corridors were defined as containing continuous habitat strings with mitigation measures at locations where major barriers, such as roads, have to be crossed. In the end, a habitat backbone structure was determined that contained a constellation of four larger natural areas for biodiversity conservation (including seven key patches for natterjack toads) interconnected by ecological corridors.

Criterion 5: backbone and temporary habitats

Additional to this habitat backbone, a plan was developed to make optimal use of a large parcel of land with temporary pioneer habitat located outside of the habitat backbone (to the west of our study area). This was done because habitats there will be available for the next 20 years, after which industrial development is planned. By connecting temporary habitats with the habitat backbone, the total size of the natterjack toad metapopulation might increase during this period (illustrated in Fig. 1b). The location of an ecological corridor between the temporary habitats and the backbone was indicated by the defined search zone. Because the total length of the zone will be approximately 3 km, the ecological corridor should contain an additional five 'stepping stone' patches.

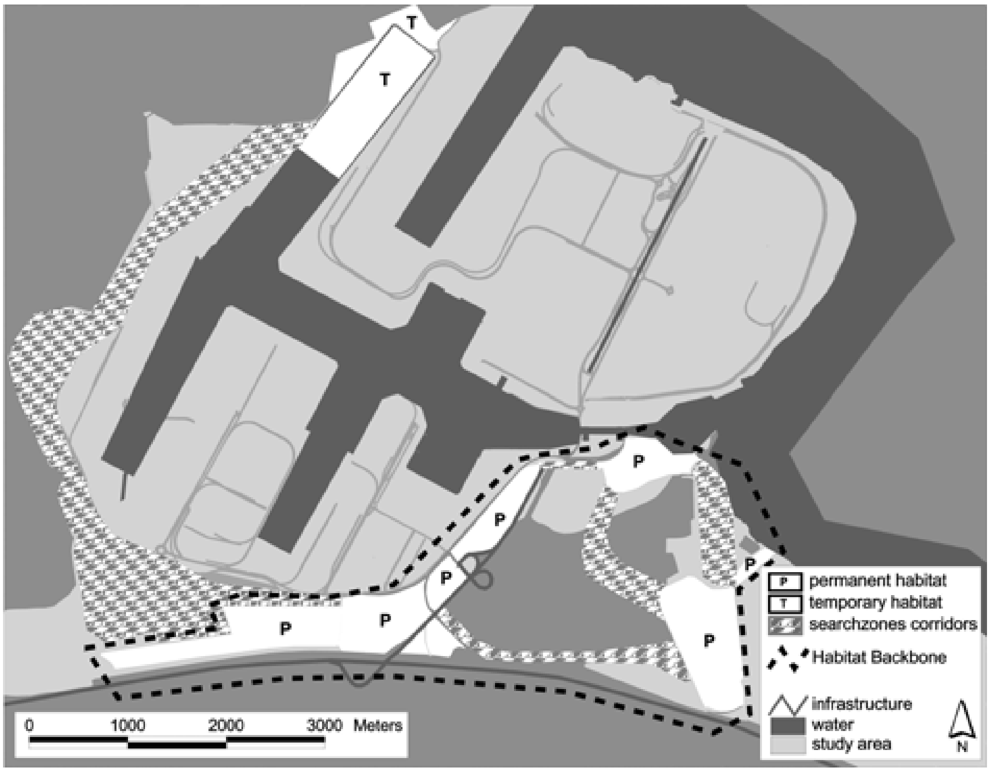

Figure 3. *Location of the habitat backbone for the natterjack toad in the Port of Antwerp. The backbone consists of existing (see Fig. 2) and to be developed natural areas (both part of the port's ecological infrastructure). In total it will include seven key patches with permanent habitat, sufficient to guarantee the long-term survival of a large population. The natural areas (including an additional temporary habitat patch in the north-west of the study area) will in the near future be connected by ecological corridors for which the location is roughly indicated (by search zones).*

The proposed habitat backbone is situated in the southern part of the port area, with a connection with the temporary habitat in the western part of the port (Fig. 3). The total picture should ensure a coherent and persistent habitat network in which at least 1,400 natterjack toads can be accommodated—more than the current population. More details about this case study can be found in Ottburg et al. (2007).

Discussion

The habitat backbone strategy

In this study we developed a planning and design strategy—the 'habitat backbone'—with which to support the long-term survival of ground-dwelling animals and other pioneer species that have low or medium dispersal abilities and occur in habitats of early successional stages within port and industrial areas. As such, we explored conservation strategies for species with dynamic populations that occur in dynamic landscapes (e.g. Wahlberg et al. 2002). Pioneer species' long-term survival in port areas is uncertain because the supply of their habitats (predominantly present on vacant lots) is capricious and completely depends on land use dynamics in port areas.

By gaining knowledge about the spatial and temporal characteristics of land use dynamics in port areas we were able to develop a solution to conserve these species. Our solution is based on the creation of permanent habitat (including key patches) with an overall carrying capacity sufficient to support persistent populations. This permanent habitat, the so-called 'backbone', should be strategically located on lands that preferably have a (semi-) public function, and will not be usurped for commercial activities. This best ensures a species' long-term survival (no interference by economic activities) and enables the backbone to act as a refugium in which organisms have a high probability of survival during adverse conditions, and from which individuals recolonize or provide recruits for areas affected more severely (Lancaster 2000). Vacant lots outside the backbone may thus be colonized by individuals from the backbone, and the satellite populations that emerge in these temporary habitats will add to the persistence of the overall metapopulation. Management of the backbone should be focused on retaining early successional stages of vegetation, which provides the suitable habitat for pioneer species.

Implementing the habitat backbone strategy in the case of the natterjack toad in the Port of Antwerp taught us that realization of a habitat backbone is possible only if landowners, local governments and environmental NGOs cooperate. Flexibility within the strategy (with multiple configurations of the backbone possible) helped to facilitate agreement upon a plan for the port area where biodiversity conservation is to be integrated with other functions.

The habitat backbone is based upon the key-patch approach (Verboom et al. 2001). Other studies referring to the key-patch approach do not use the approach for conservation strategies in dynamic (urban) landscapes. The habitat backbone strategy differs from other biodiversity conservation studies (e.g. Bryant 2006) conducted in urban environments in two main respects: (i) it links permanent and temporarily available habitat and (ii) it requires a different approach to habitat management. Regarding the first, traditional urban green structures focus only on public land to fulfill ambitions of biodiversity conservation. The habitat backbone draws on the best advantages of the port layout, ownership and dynamics by combining permanent and temporary opportunities for biodiversity conservation. Regarding the second aspect, habitat management, other conservation strategies for pioneer species focus on rehabilitation of natural disturbances (e.g. flooding, fire). Pioneer habitats in ports are human-created, and conservation of these habitats is possible only with active management. As pioneer vegetation naturally transforms into later successional stages, a constant and more intensive management (compared to traditional urban green management) is required to retain an optimal habitat situation. The management thereby should replace natural dynamics (e.g. floods) by frequently removing the topsoil to create large areas of bare land.

Both aspects make the habitat backbone a more ‘custom-made’ planning and design strategy, with specific application value for species that occur in pioneer habitats, have low or medium dispersal abilities and live in ports and industrial areas. Conservation of these species in those economic areas has not yet been addressed in other studies.

When may the habitat backbone strategy be considered successful?

In the Port of Antwerp a first condition for the successful long-term conservation of the large natterjack toad population was met when stakeholders agreed on a joint overall design and management plan for the habitat backbone. However, as this plan only outlined the main structure of the backbone, constant attention to the toad’s habitat preferences will be needed in later stages of development to guarantee that the habitat backbone indeed functions as expected. Besides, apart from the assignment of specific parcels for nature conservation purposes, consistent management of the backbone is required to maintain optimal habitat quality (Stevens et al. 2006). By monitoring both the habitat quality and the natterjack toads’ distribution and population dynamics in the total port area, one could learn how successful the implementation of the habitat backbone may be in the long term.

In addition, we suggest that telemetric studies be conducted (e.g. Miaud et al. 2000), which could provide further insight into how natterjack toads migrate through the port area and the extent to which the habitat backbone supports their dispersal movements. Furthermore, temporary habitats could be included in an official conservation plan for protected species occurring in ports, although legal protection of ‘accidentally occurring pioneer habitats’ on lands with an economic purpose and owned by private companies seems difficult at the current time. In the Netherlands, the unexpected presence of animal species protected by EU Habitat and Bird

Directives on lands ready for urban development recently led to several legal suits (Smit 2006). This has reduced the willingness of companies to contribute to biodiversity conservation. It has also resulted in situations in which companies have taken measures to prevent the natural development of pioneer habitats in areas planned for economic development purposes. Although this is not yet common practice, a strategy in which private lands with an active economic function officially constitute part of a designated natural area would not seem a good idea.

Vacant lots, though not part of legally protected areas, may nonetheless provide habitats that enable pioneer species to establish satellite populations. These satellite populations could—at least during a certain periods—facilitate an increase in the overall metapopulation size in the port area. As the habitat backbone should provide sufficient habitat for a persistent population (as we have interpreted the legal requirement from the EU Bird and Habitat Directives to maintain the species' favourable conservation status), urban developments on vacant lots (on corporate lands) should not threaten the local persistence of the species, so we assume that legal procedures concerning habitat compensation and mitigation may be avoided.

Application value of the habitat backbone for other cases and species

In areas with a mix of dynamic and more stable biotopes, implementing the habitat backbone strategy could support the persistence of species that prefer both biotopes. In the case of the marsh fritillary butterfly (*Euphydryas aurinia*) in Finland, a butterfly that occupies forest clear-cuts (successional habitat) and meadows (static habitat), the constant supply of meadows appears to be important for the persistence of the species in the region (Wahlberg et al. 2002). Although most meadows in this case are probably managed for agricultural purposes (instead of biodiversity conservation), this nonetheless indicates the conservation value of permanently available habitats for the persistence of species that inhabit both dynamic and more static biotopes.

Concerning urban environments, industrial areas often share similar land use dynamics with a mix of developed and undeveloped land. Also, urban fringes with their business sites, urban neighbourhoods, allotment gardens, sport fields and peri-urban agriculture are well-known for their high turnover in land use. These areas may, therefore, be considered suitable for the implementation of the habitat backbone strategy.

Concerning species that might take advantage of the habitat backbone, these include not only natterjack toads but also other animals and plants preferring urban pioneer situations. Schadek (2007) described plant-environment relationships in Germany's urban brownfields, illustrating how pioneer plants depend on local availability of pioneer situations. Also, animal species including lizards, grasshoppers, spiders and butterflies, especially those with low or moderate dispersal capacity, may be supported by networks of pioneer habitat distributed throughout ports, industrial areas and urban fringes. Since birds and large mammals colonize new habitats more easily, they should depend less on the continuous character of the habitat backbone structure. However, the permanent availability of good pioneer habitats (through intensive management) may also support the persistence of populations of those mammals and birds that prefer early-successional vegetation (Kildaw et al. 2005). As conservation of plant and animal species, especially those that are well-protected, becomes a more integral part of port management (Stojanovic et al. 2006; Morris and Gibson 2007), planning and design strategies like the habitat backbone may provide solutions that enable planners and managers to combine economic and biodiversity conservation purposes into a single plan.

Acknowledgements

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Appendix A. Norms used in persistence analysis of natterjack toad network population

Our persistence analysis consisted of three steps: (i) definition of local population, (ii) definition of network populations and (iii) assessment of the persistence of these network populations.

Step 1: Definition of local populations

Our calculation of the size and configuration of local populations was based on three aspects: estimation of the number of natterjack toads per breeding site, identification and determination of the size of local (key) populations and identification of local barriers.

First, the number of natterjack toads per breeding site was estimated based on empirical data collected in 2003–05. During this period the chorus size (number of observed calling males) was monitored at each breeding site. Chorus size was considered the best predictor of the actual size of the different natterjack toad populations in the Port of Antwerp. Schmidt and Pellet (2005) proposed that population dynamic processes predict distribution far better than static habitat variables, because the dynamics of amphibian populations are largely stochastic. Nevertheless, using the number of calling males likely results in underestimation of the total population, as not all males may be calling in the same period (Schmidt and Pellet 2005). Our population size estimation therefore may be considered conservative.

Second, during the breeding season natterjack toads move easily among neighbouring breeding sites (if there are no barriers). Yet these ranging amphibians are considered part of a single local population (Marsh and Trenham 2001). We took 75 m as a maximum distance between subpopulations belonging to one local population. Miaud et al. (2000) found terrestrial movements of natterjack toads within the breeding season (home-range movements) of up to 500 m; Husté et al. (2006) recorded movements of 109 to 160 m. The home-range distance of 75 m in our study may therefore be considered rather cautious.

Size of local populations was obtained by summing the number of calling males in all subpopulations that were part of one local population. One calling male thereby represented a so-called ‘reproductive unit’ (RU) (Vos et al. 2001), that being a male and female toad. Verboom et al. (2001) defined 100 RUs as a key population minimum for small, short-lived vertebrates. However, they focused on birds and mammals in static landscapes. Much less is known about the population dynamics of the natterjack toad, which lives in highly dynamic areas with a high turnover in land use. To correct for extra stochasticity in this species we doubled the Verboom et al. norm and took 200 RUs as a minimum for a key population. Although this norm still contains uncertainty, monitoring results of field studies show this figure could be realistic. For example, Schmidt and Pellet (2005) found chorus sizes of 2–40 at 12 sites; Allentoft et al. (2008) found a chorus size between 5 and 250 (n=12) with only two chorus larger than 200. The maximum chorus size found in our study area was 200 (found for three local populations), so a higher norm would have meant no key populations in the Port of Antwerp.

Third, (rail)roads and other urban structures may act as real obstacles or danger zones for migrating amphibians. The probability of amphibians being killed by road traffic depends on traffic intensity (Hels and Buchwald 2001). Unfortunately no data was available on traffic intensity in the Port of Antwerp. However, we expect traffic density to be relatively low in this industrial port during evening and night hours (when most amphibian movements occur). Nevertheless, we considered all local (rail)roads and highways (based on Vos and Chardon 1998) and steep embankments (vertical structures) as able to obstruct home-range movements. We thereby probably underestimated the level of exchange between breeding sites. Data on exact locations of barriers and other landscape elements in the study area were derived from the basic map of the Antwerp Port Authority (scale 1:35,000).

Step 2: Network populations

Calculation of the size and configuration of network populations was based on dispersal distance and dispersal barriers.

We used a maximum distance of 3 km to assign local populations to the same network population. Miaud et al. (2000) recorded maximum overall movements of natterjack toads of up to 4411 m. Sinsch (1997) argued that 3–5 km may be expected for this species, and Dutch field herpetologists (pers. notes) reported colonization of new breeding sites in which natterjack toads covered distances of more than 3 km. The distances recorded by Husté et al. (2006) were much smaller, but as discussed in that paper this was probably a result of the small sample size and short recording period. A sensitivity-analysis to the impact of the 3 km length of the dispersal distance showed that only with a distance less than 2.5 km (and no dispersal barriers) could a change in the constellation of network populations be found (resulting in four rather than three network populations). Based on the literature as described above, we therefore consider our calculation to be realistic.

Highways (see Vos and Chardon 1998; Hels and Buchwald 2001) and steep embankments (vertical structures) were considered to be absolute barriers for natterjack toad dispersal movements. The impact of local roads is dependent on traffic intensity. This was expected to be low, so we considered local roads not to be barriers for dispersal movements (only for home-range movements). The fact that calling natterjack toads were found in 17 different habitat patches throughout the study area (fig. 2) supports this assumption.

Step 3: Persistence of network populations

Assessment of the persistence of network populations was based on the norm for a persistent network population. Verboom et al. (2001) proposed norms for persistent metapopulations with and without key populations. For short-lived, small vertebrates (not amphibians) in static landscapes these norms were 150 RUs and 200 RUs, respectively. As natterjack toads often live in highly dynamic areas, such as ports, we increased these norms to 500 and 800, respectively. These norms, however, remain expert estimations, as no good data on the minimum size of a persistent metapopulation of natterjack toads is known from the literature. The only norms found were those by Stephan et al. (2001). They used norms for modelling the persistence of local populations (not metapopulations) of the natterjack toad with a maximum of 100 adult females (they calculated a sex-ratio of 1:1.3 adult males:females, which would make our norms 385 and 615) and considered no exchange between neighbouring sites.

How peri-urban areas can strengthen animal populations within cities: A modeling approach

4 How peri-urban areas can strengthen animal populations within cities: A modeling approach

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Abstract

We explore the extent to which inner-city fauna can be enhanced by source areas in peri-urban zones as a response to a decreasing quality and size of green habitats within cities. The objectives were to get a better understanding of the interaction between animal populations of urban and peri-urban areas, and the role of urban green structures within this relationship, and to find out the extent to which peri-urban areas can contribute to urban animal populations. We illustrate the idea of peri-urban support by using a simulation model for individual animal movement, applied in a particular case-study with butterflies as model species. Results show differences in accessibility of inner-city areas between model butterfly species that differ in mobility. The impact of peri-urban individuals on populations of inner-city habitats differed among several peri-urban source-scenarios: the enlargement of the inner-city butterfly population by peri-urban individuals was determined as 7–36% for 'moderate dispersers' and 19–56% for 'good dispersers'. Results also show that well-connected habitat patches within existing urban green structures were more likely to be visited by peri-urban individuals than isolated habitat patches. We conclude that peri-urban nature areas, if large enough, can have a potentially positive influence on the presence of fauna in inner-city neighborhoods. In addition, results suggest that connectivity between inner-city and peri-urban habitat patches enhances contribution of peri-urban migrants to inner-city populations. By providing a range of different habitats, from inner-city up to peri-urban area, moderately mobile habitat specialists could better compete against the small set of successful habitat generalists that are increasing in urban environments all over the world.

Introduction

Since the 1950s, large areas within the Netherlands, and also within many other countries, have become rapidly urbanized. This urbanization process is still ongoing, and the proportion of people living in cities, spending most of their time in urban environments, is growing (United Nations 2001). As a result of both these trends urban nature has become a component of the human living environment and, to a lesser extent, an issue in nature conservation (UNEP 2001). Despite the increased importance of urban nature for humans, plants and animals, urban green structures, which provide the structures that accommodate for urban nature, are under pressure from urbanization processes (Niemelä 1999b). Urban green areas, such as derelict land that lack a designation as 'recreational or natural green space' are not protected by law or local policy, and are often used for new urban development (Breuste 2004). This means that, within the overall urban matrix, urban nature becomes increasingly confined to official 'urban green spaces' (parks, public gardens, road verges), especially in the inner-city part of cities. This official green space is managed by rules of visual attractiveness, low cost maintenance and traditional views on urban green management. This results in a low diversity of 'biotopes' (defined here as vegetation units describing the landscape) and limited naturalness (e.g., Rusterholz 2003). Consequently, the diversity in native plant and animal species of inner-cities is low and, in case of relatively high biodiversity levels, this is caused by the abundance of exotic and invasive species (Kloor 1999). This is undesirable from both a nature conservation and human perception point of view. A low diversity in biotopes and limited naturalness means lower species diversity and lower densities of species. It also means, compared to peri-urban and rural areas, less opportunities for humans to appreciate the (green) environment or to have personal contact with urban plant- and wildlife (Vandruff et al. 1995). 'Peri-urban' is defined here as '(rural) area adjacent to the town' (Clergeau et al. 2001). This definition emphasizes the contrast in land use within such urban–rural gradients. Those gradients are quite common in the Netherlands due to strict spatial planning practices.

Recent studies have shown that urban green areas (both urban parks and cemeteries as well as small green areas at street level) play an important role in the quality of the human living environment. The size, quality and spatial configuration of green areas are all positively correlated to health, perceptions of the quality of life and the recreation possibilities of citizens (e.g. Kaplan and Kaplan 1995). A high quality of urban green spaces is also important for many (sub)urban plant and animal species. Their occurrence and abundance are correlated with habitat and spatial cohesion of urban green space in and around cities (Melles et al. 2003; Drinnan 2005). A decrease of sufficient high quality green (in terms of diversity, richness, total surface and low disturbance of urban biotopes) may cause a negative trend in urban biodiversity worldwide. This trend, called homogenization, occurs as a limited set of (often exotic and invasive) species replaces richer and more diverse plant and animal communities within (urban) ecosystems (McKinney and Lockwood 1999).

We consider urban green areas as a pattern of ecosystems, encompassing a whole range of abiotic conditions and characterized by a specific area coverage and configuration. Plant and animal species within urban areas occupy all sorts of patches that provide habitats. Together these provide a local habitat mosaic. In population terms a set of ecosystem patches can provide a habitat network for a particular species, assumed that habitat sites are interconnected by the movement and exchange of individuals. For the urban context it has been proven that greenways in cities can be enhanced for wildlife to improve their role in strengthening networks (Linehan et al. 1995). Connected local populations in such habitat networks may show features of metapopulations (Levins 1970; Opdam et al. 2001). Evidence suggests that metapopulations are a common phenomenon in the urban context (e.g. Bastin and Thomas 1999). This implies that the occurrence of many species in cities may be dependent on coherent habitat networks. Such networks may be also located partly in peri-urban or rural areas outside city margins (Clergeau et al., 2001). This may imply that urban–rural relations are essential for long-term survival of many urban species.

During the last decades research on spatial relations in plant and animal populations has largely been restricted to rural and natural areas (Hanski 1999). This has led to more insights in the way populations act on a landscape level. However, the extent to which similar ecological processes occur in urban areas is largely unknown (Miller and Hobbs 2002). Ecological relations between urban and rural areas, for example the degree to which nature in peri-urban or rural areas may contribute to inner-city nature quality, have been largely disregarded by scientific research. Because green habitats within cities are under pressure from urban development, we explore to the extent to which the occurrence of species within inner-cities can be enhanced by good quality source areas at city margins. The objectives of our study were to get a better understanding of the interaction between animal populations of urban and peri-urban areas, and the role of urban green structures within this relationship, and to find out the extent to which peri-urban areas can contribute to urban animal populations.

We illustrate the idea of peri-urban support for inner-city nature quality by using a simulation model for individual animal movement, and by using animal model species of a selected species group. This was applied to Hoogvliet, a neighborhood in the Dutch city of Rotterdam, which is scheduled for a large-scale redevelopment, which will lead to the loss of much urban green space in this part of the city. The role of peri-urban areas was explored as a partial and potential solution for sustaining current levels of biodiversity and urban nature perception. In this case two specific objectives were (i) to estimate the size and range of the potential impact of peri-urban nature on nature quality within cities and (ii) to evaluate the way in which the spatial structure of urban green spaces contributes to this.

Methods

This pilot-study was conducted to explore the idea that peri-urban nature development could support inner-city nature quality. The methodology consisted of four steps. (1) The idea of peri-urban nature development was elaborated in the context of Hoogvliet. (2) A spatial model was chosen to simulate animal movements between peri-urban and inner-city habitats. (3) Model species were selected and species variables were collected through literature research. (4) Potential opportunities for peri-urban nature development were translated into spatial scenarios and those scenarios, together with species variables, were used as inputs for the model.

The Hoogvliet-case

Hoogvliet is a small neighborhood within the Dutch city of Rotterdam, with a human population of about 35,000 inhabitants. The neighborhood is surrounded by a river, highways, an industrial port area (Pernis) and the rural parts of Poortugaal village (fig. 1). The residential area of Hoogvliet is largely enclosed by a buffer zone of urban green space (called 'green belt'). A matrix of main roads, with wide green verges, divides the housing area into smaller districts. The originally small village of Hoogvliet was expanded in the 1960's and '70's to accommodate harbor workers. These laborer's cottages recently became obsolete and are due for replacement. The neighborhood was selected as the most suitable study area for this pilot-study, because of its scale (3x3 km, which is considered as being relevant for animals with a medium dispersal distance, such as amphibians, reptiles, most flying insects, most small mammals and some bird species), its proximity to rural areas surrounding the large city of Rotterdam and its status as a redevelopment area.

The proposed redevelopments are likely to lead to the loss of a large amount of the urban green space. Several design and management options were searched for within and outside the redevelopment area in order to sustain the current level of urban biodiversity and high quality of urban green space in Hoogvliet. One strategy for conserving local biodiversity could be a new, more natural, design of the peri-urban zone around Hoogvliet. It was thereby assumed that redesign of the rural and industrial areas in and around Hoogvliet would be able to help sustain current urban biodiversity levels by providing essential biotopes which could act as source habitats for certain (peri-)urban animal species. From these source habitats in the peri-urban zone individuals of animal species should be able to reach the residential areas in Hoogvliet. In addition, to increase the potential success of peri-urban nature the planning of urban green within Hoogvliet itself should be designed with wildlife in the peri-urban and rural areas in mind, using habitat patch size, shape and connectivity as design principles.

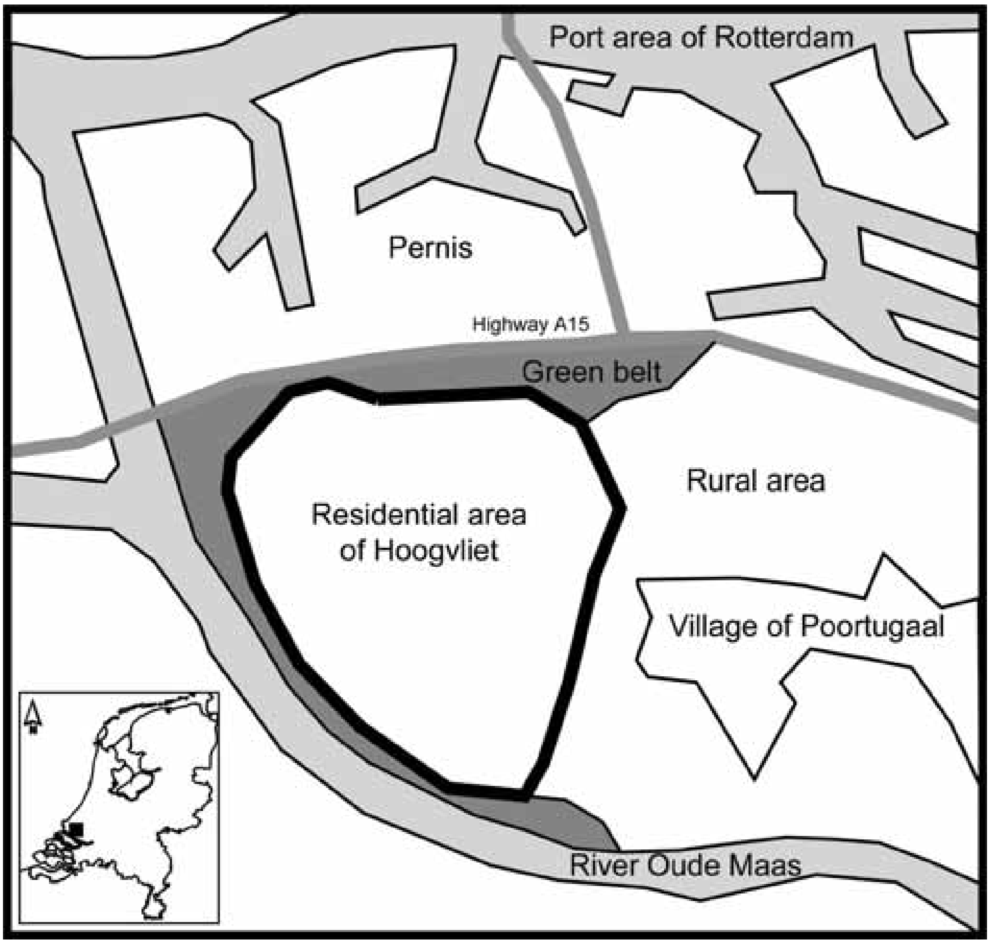

Figure 1. *Map of the case study area of Hoogvliet and its surroundings. The map shows the residential area of Hoogvliet, a neighborhood within the city of Rotterdam. This neighborhood is largely surrounded by urban green (the 'green belt'), a river (Oude Maas) and highway A15. Furthermore, the location of the industrial port area (Pernis) and the rural parts of Poortugaal are shown. Rotterdam is located at the coast of the Netherlands.*

The model experiment

We explored the potential for dispersal from rural to urban areas using a movement model, taking into account the urban landscape. The SmallSteps model (http://purl.oclc.org/NET/alterra/movement) simulates movement as a fixed time step-based correlated random walk (Kareiva and Shigesada 1983). The length and turning-angle of each move are obtained from probability-density functions. For each type of landscape element, a negative exponential move-length distribution is defined, characterized by its mean, and a Gaussian turning-angle distribution is defined with a zero mean, characterized by its standard deviation. When the path of a simulated correlated random walk hits the boundary of its current landscape element (represented as a polygon in spatial database), the path either crosses this boundary or is reflected back. For this purpose, boundary-crossing probabilities that predict this boundary behaviour need to be defined. These probabilities express relative preferences of species for certain landscape types.

We use the model to obtain an estimate of the probability that a path taken by a butterfly originating from a peri-urban source area, will visit the residential area. This probability is calculated as the number of (unique) paths visiting each landscape element in the residential area, divided by the total number of paths originating from a source area. However, as we want to estimate the chances of 'experiencing' butterflies by the inhabitants of the residential area, rather than landscape connectivity per se, we also keep track of the total number of visits (multiple visits per path allowed) and the residence times for each element. Residence time is defined as the number of time-steps an individual remains within this landscape element. Using visiting frequency and residence times, we define a measure of the chances of experiencing butterflies in landscape element (polygon) *i* as:

$$E_i = \frac{V_i}{N} \cdot \frac{1}{A_i} \cdot R_i \quad (\text{min ha}^{-1} \text{ ind}^{-1}),$$

where Vi refers to the observed number of visits to landscape element *i* in the simulation, *N* is the number of paths simulated, Ai the area (ha) of the element, and *Ri* the observed average residence time (min). Thus, *Ei* represents the expected butterfly minutes per hectare, per butterfly originating from the source area. Note that *Ei* is related to the whole dispersal period and expressed per individual. It therefore needs to be divided by the duration of the dispersal period to obtain a daily estimate (min ha^{-1} ind^{-1} day^{-1}) and further multiplied by the number of dispersers produced in the source area to obtain the total daily expected butterfly minutes (min ha^{-1} day^{-1}).

Butterflies as model species

First, a species or species group was selected to act as an indicator for the specific context of Hoogvliet. From all species groups that are present in this urban environment butterflies were believed to represent the best option for this exploration of the peri-urban source habitat concept. Butterflies are one of the few species groups that can easily be linked with nature perception by humans (New 1995; Asher et al. 2001); they operate on the medium scale level like many other animals do; they include a wide range of species from common to highly rare species (Van Swaay and Warren 1999); they can be seen as good indicators for quality of urban green space (Asher et al. 2001; Van Swaay and Van Strien 2005) and; their mobility falls between that of poor dispersers, like ground-dwelling animals, and excellent dispersers, such as birds and bats. Furthermore, the ecology of butterflies and their dependence on certain plant species (as host or nectar plants) conforms to the idea that peri-urban habitats could act as real sources for dispersers (Vickery 1995). Such source habitats could more easily contain vegetation of non-attractive host plants (e.g., stinging nettle, Urtica dioica) while in the residential area necessary nectar plants (flowers, trees and shrubs) are commonly present.

Secondly, we searched for movement parameters, life span data and data on habitat preferences of butterflies. The ecology of individual butterfly species is often complex and dependent on the specific type and distribution of plant species. Therefore, within this study we chose to use, not real species but composed 'model species' in order to explore the concept of peri-urban areas as source habitats. Three types of butterfly species can be distinguished, according to their mobility (Bink 1992; Pollard and Yates 1993; Dennis and Shreeve 1997) classified in terms of poor, moderate and good dispersers. Poor dispersers tend to be relatively rare habitat specialists, while good dispersers are often common and more abundant habitat generalists and moderate dispersers are intermediate in this respect (Dennis et al. 2000). Poor dispersers were not considered here, as these are not usually found in urban areas. From this perspective, Meadow brown (*Maniola jurtina)* and Small tortoiseshell (*Aglais urticae)* may be seen as representative for the moderately mobile and mobile species, respectively. To simulate the butterflies' movements within the SmallSteps model several parameters were distinguished regarding mobility, life span and border crossing probabilities (between biotope types). Data for those parameters were collected from the literature. The parameters used to simulate butterfly movements in the model are listed in Appendix A (movement parameters and life span) and Appendix B (boundary-crossing probabilities). Using correlated random walk equations for animal dispersal (Byers 2001), we judged that with the step sizes as defined in Appendix A, an amount of 600 time steps per day gave a realistic match with observed flight distances, as reported by Shreeve (1981), Baker (1984), Dover et al. (1992) and Conradt et al. (2000). Therefore, we used 600 time steps per day in the model simulations, in combination with the life span given in Appendix A.

Scenarios used in modeling

Several scenarios were used in this pilot-study to explore potential impact of peri-urban source habitats. The most likely area for nature development in the peri-urban zone was the large-scale rural environment of Poortugaal, directly east of Hoogvliet. This location has sufficient space to accommodate a large semi-natural area. A less obvious location was the industrial area of Pernis (part of the Port of Rotterdam) where a shift in urban green management could potentially provide new habitat for urban species. In all scenarios the centroid of one of these peri-urban locations was designated as the source location from where model butterflies would start to disperse through the model landscape in all directions; test-scenarios showed that changing the exact location of the source did not influence the results.

For source locations we focus on two variables: size of source habitat (large and small) and different types of management (creating sub-optimal or optimal habitat). Suboptimal habitat was set at half the carrying capacity of optimal habitat. The industrial location (Pernis) has no potential for optimal habitat, so here only the size of source habitat differs. Altogether there are six different scenarios per model species, as indicated in Table 1.

Table 1. *Different spatial scenarios for a peri-urban nature development area, used to simulate butterfly movement from peri-urban habitat to inner-city habitats. Each scenario was used twice, successively for each model species (good disperser, moderate disperser). Because of industrial land use of the Pernis port area, Pernis-scenarios include only suboptimal habitat management of currently existing grasslands surrounding storage tanks..*

	Location	Size	Management
A	Pernis	25 ha	Sub-optimal
B	Pernis	50 ha	Sub-optimal
C	Poortugaal	25 ha	Sub-optimal
D	Poortugaal	25 ha	Optimal
E	Poortugaal	50 ha	Sub-optimal
F	Poortugaal	50 ha	Optimal

An assessment of existing butterfly habitats within the study area was needed to produce scenario-maps that would function as inputs for the model. For this purpose a digital topographical map of the study area was translated into a model landscape showing habitats and non-habitats for butterflies, using GIS-software (ESRI 2000). This translation was based on known habitat preferences of butterflies (Tax 1989). Appendix B shows those (non)habitat types and boundary-crossing probabilities between them.

The present-day carrying capacity for butterfly species of the Hoogvliet residential area was estimated using several parameters; land use within the residential area in Hoogvliet, carrying capacity per existing land use type (Van Swaay 2003) and management of urban green space (quality of butterfly habitat). We estimated that about 750 individuals of ‘good dispersers’ and about 470 individuals of ‘moderate dispersers’ could be expected to occur in Hoogvliet. Next, the model was used to calculate the percentage of individuals that reach the residential area of Hoogvliet and this figure was indexed with the current capacity of the residential area.

For each scenario we calculate expected butterfly minutes per hectare, *Ei*, for all landscape elements in the Hoogvliet area, as a fine-grained, spatial indicator of the influence of peri-urban sources. We use the probability of reaching the residential area as a whole, multiplied by the estimated number of dispersers produced by the source area and divided by the expected number of 'autochthonous' butterflies as a second, rough, indicator of the total, relative, importance of the peri-urban sources. Simulation results are based on 100,000 paths for each scenario. We assume a time-step of 1 minute, with 600 steps representing one (10 h) day of movement. For the mobile species we assume a 40 day period of dispersal, for the immobile species a period of just 7 days (Appendix A).

Results

Accessibility of the residential area of Hoogvliet for peri-urban butterflies

Results from the model show differences in the accessibility of the residential area of Hoogvliet between both model species. Good dispersers were able to cover the whole residential area, but moved rather quickly from one patch to another. Moderate dispersers were only distributed over about one third of the residential area, but stayed longer at any particular patch than good dispersers. Fig. 2 shows distribution ranges of butterflies from each source location for each model species.

Although 'good dispersers' covered the whole residential area of Hoogvliet, there was a range in accessibility of habitat patches within the residential area. This was higher closer to the source location and declined towards the most distant side of the residential area. The same trend was observed amongst 'moderate dispersers'. As expected, the chances of a certain habitat patch within the residential area of Hoogvliet being visited by butterflies were correlated with distance from the source location. However, this relationship was not a simple exponential. Certain patches at the same distance from the source were more likely to be visited than others. Fig. 2 shows the likelihood of butterfly visits per landscape element (both habitat and non-habitat patches), for both source locations, for each model species.

Figure 2. *Expected butterfly minutes per hectare urban habitat (min ha^{-1}) per 1000 peri-urban butterflies for four scenario's. For every patch within the study area the amount of minutes of visiting butterflies was calculated for good dispersers (a and b) and moderately dispersers (c and d). The simulation started at the source location (S) which was situated in the north (Pernis) or east (Poortugaal). Good dispersers were able to colonize the whole study areas, but habitat patches close to the source area and road verges throughout the whole area were favorite. Moderate dispersers only colonized approximately a third of the study area.*

Impact of peri-urban dispersers on urban butterfly population

Of the original model populations only 14% of ‘good dispersers’ and 5% of ‘moderate dispersers’ were able to distribute themselves throughout the residential area of Hoogvliet. Most individuals from the peri-urban source location distributed themselves in other directions, got lost or experienced road mortality.

Secondly, the impact of peri-urban butterflies on the existing butterfly population of the residential area of Hoogvliet (defined here as the percentage of individuals originating from the peri-urban source location and indexed with existing carrying capacity of the residential area) differed among several scenarios: from 7% to 36% for ‘moderate dispersers’ and; from 19% to 56 % for ‘good dispersers’. These ranges were due to differences between scenarios; especially related to the size and habitat quality of the peri-urban source location (see Table 2).

Table 2. *Population impact of peri-urban butterflies within the Hoogvliet residential area. This table indicates the impact of migrating peri-urban butterflies on the estimated size (carrying capacity) of current inner-city populations. The carrying capacity was based on land use within the residential area in Hoogvliet, carrying capacity per existing land use type and management of urban green space (quality of butterfly habitat). We calculated that about 750 individuals of ‘good dispersers’ and about 470 individuals of ‘moderate dispersers’ were expected to occur in Hoogvliet. These estimates of existing populations present individuals were used as baseline values (index = 100%) for the estimation of the impact of migrating peri-urban butterflies to the residential area of Hoogvliet.*

Scenario	Impact of Good disperser on existing population (%)	Impact of Moderate disperser on existing population (%)
A	19	9
B	38	18
C	19	7
D	28	18
E	38	14
F	56	36

Urban green space as butterfly habitat

As Fig. 2 shows, not every patch within the residential area of Hoogvliet had the same likelihood of butterfly visits. Although the population of ‘good dispersers’ spreads over the whole area, there was a clear gradient in the number of visits, correlated with the distance from the source location. Correcting for the size of the landscape element (ha) we observed preferences for some elements above others, thus delineating the elements that most determine connectivity. More detailed observations of model results confirmed this idea and, as Fig. 3 shows, grassland road verges and other well-connected habitat patches within the existing urban green structures were more likely to be visited by butterflies than habitat patches that were isolated from the urban green structures by distance, barriers, or both.

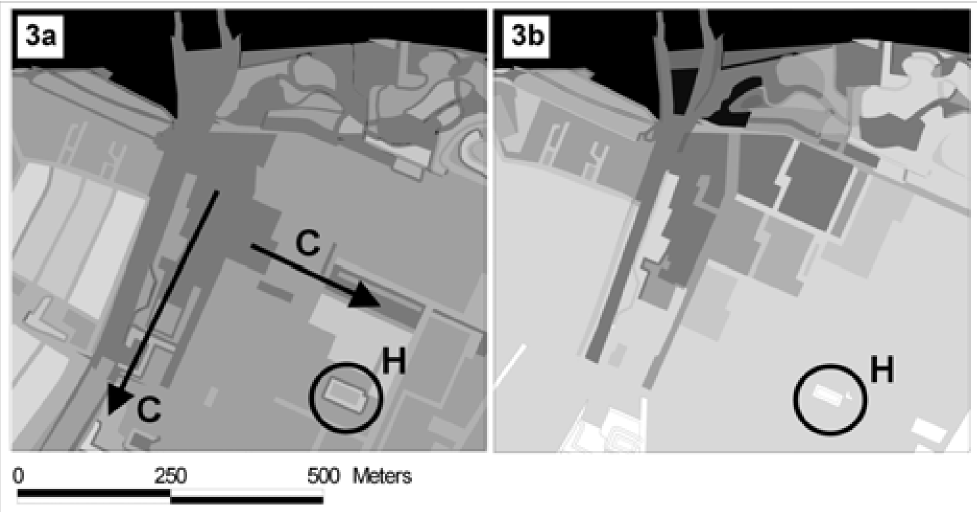

Figure 3. *Detailed map of the northern part of the residential area of Hoogvliet, showing likelihood of visiting peri-urban butterflies per patch. This figure is presented as a two-panel graphic comparing likelihood of visit by good dispersers (a) versus moderate dispersers (b). As the figure shows grassland road verges and other linear habitat patches in urban areas were used by good dispersers as corridors (C), able them to colonize urban habitat patches (H); whereas moderate dispersers lack the dispersal capability to use those road verges and subsequently are less likely to colonize those urban patches. The likelihood varies gradually from a low likelihood of butterfly visit (light color) up to a high likelihood of butterfly visit (dark color), see Fig. 2 for legend.*

Discussion

Role of peri-urban zone

We explored the conditions under which peri-urban nature areas could act as source locations for animal species within inner-cities, and thereby increase urban biodiversity. The model we used simulated movements of selected model species (butterflies) from peri-urban areas into adjacent residential areas. We compared the relative effectiveness of this strategy between species with different mobility and for various source areas. This model experiment enabled us to explore the relation between urban and peri-urban areas as habitats for (sub)urban species at the individual level, and to estimate the impact of peri-urban individuals on inner-city populations.

The results provide insights into (i) the distribution range of peri-urban species within inner-city residential areas, (ii) the impact of peri-urban species on current residential species populations and (iii) the support-function of urban green structures within urban–rural exchanges of fauna. We conclude that peri-urban nature areas, if large enough, can have a positive influence on the presence of butterflies in inner-city neighborhoods. This suggests that large peri-urban source populations close to residential areas will be required to support inner-city nature quality if this is to make a noticeable impact on residential populations. Migrating peri-urban individuals will distribute in all directions, not only towards the city center. With a large number of migrating individuals (positively related to the size and management of peri-urban habitat patches) and a careful design of the source area and its boundary with the residential area the impact on the density of residential populations will be relatively large (up to about 50% for good dispersers). The future urban environment of Hoogvliet will contain less urban green space than at present, which means a lower carrying capacity. The contribution of peri-urban immigrants to small populations within the residential area will therefore increase in importance. Our results also suggest that the connectivity between inner-city and peri-urban habitat patches, due to linear corridors like green road verges, enhances the contribution of peri-urban migrants to inner-city populations. This emphasizes the potential importance of urban green structures in connecting peri-urban and inner-urban network patches, as discussed by Rudd et al. (2002).

Only species that readily disperse, like birds, bats, dragonflies and butterflies, would be able to reach the residential area of Hoogvliet. Of these species, butterflies seem to be good indicators for the quality of urban green space and its spatial configuration (Asher et al. 2001; Wood and Pullin 2002; Van Swaay and Van Strien 2005). They are also easily linked with human's perception of nature (New 1995; Asher et al. 2001) and are capable of producing large numbers of individuals. Because their habitat requirements differ among life phases, butterflies are an ideal target species for a more sophisticated planning of urban nature in peri-urban areas: on the one hand more semi-natural areas in the peri-urban zone can act as a habitat for caterpillars, on the other hand flowering inner-city backyards which provide nectar sources attract butterfly adults. In this paper, we focused on butterfly dispersal from peri-urban habitat to urban areas. From the viewpoint of the inhabitants, this is satisfactory, as the analysis yields insight on the probability of encountering butterflies in the city. From the perspective of butterfly population dynamics, things are more complex as the urban area may function as a sink and the encountered butterfly may well have a very low probability to reproduce successfully in the urban environment. For less mobile species, larval and adult resources should be available within a short distance from each other (Dennis et al. 2003). If the spatial separation occurs over too large a distance, then abundant nectar sources in urban areas may well operate as detrimental sinks rather than as beneficial habitat for moderate dispersers. This highlights the importance of establishing complete habitats in urban areas, including both larval and adult resources. To achieve this, the management of public green areas should be adapted, e.g., by rotational management (New 1995; Morris 2000), to accommodate a wider range of habitat structures.

Butterflies, birds, bats and dragonflies often have different habitat requirements during their life cycle or between seasons. Bats, for instance, need particular places during summer and winter, to forage and, in addition, corridors between those places. Whereas most urban green spaces in inner-cities provide only a selection of those habitats, peri-urban natural areas could offer missing habitats and thereby support the whole spectrum of habitats to complete the bats' life cycle. For ground-dwelling mammals (Forman and Alexander 1998), amphibians, reptiles and insects, the supporting function of peri-urban natural areas for their inner-city populations seems less obvious. With the exception of large mammals, such as foxes and deer, most of these animal species are not able to migrate easily through (semi) urban areas over larger distances, because of their low dispersal capacity and the negative characteristics (e.g., high density of houses and roads) of urban areas. Nevertheless, peri-urban nature development linked with connectivity zones (like road and railway verges) could support urban populations of those species: by acting as sources for dispersal and by stimulating colonization of (empty) habitat patches over several generations.

The idea that peri-urban nature development can improve nature quality within cities may provide an effective strategy against the worldwide phenomenon of 'homogenization'. By providing a range of different habitats from inner-city up to peri-urban area (instead of a restricted area of intensively and uniformly managed urban green space within the inner-city), moderate mobile habitat specialists could better compete against the small set of successful habitat generalists that are increasing in urban environments all over the world. Increasing diversity in biotopes (Breuste 2004), connectivity between habitats on a larger scale and variation in the sizes of natural areas, are all essential elements for supporting a substantial level of urban biodiversity. Besides the source role that peri-urban areas can have for animal populations in cities, in some cases urban areas can also support peri-urban and rural nature. King fishers (*Alcedo atthis*) for example are well-known in some European countries like the Netherlands for their urban habitat preference during winter. It is assumed that those birds prefer the urban environment at that time of the year because of its higher temperature, a phenomenon known as the 'urban heat island' (Goward 1981; Arnfield 2003).

Does the model provide a reliable picture?

Simulation of individual movements is an often-used method to obtain an estimate of connectivity of patches in the landscape. We chose butterflies as indicators of biodiversity in the urban environment, because they are highly responsive to habitat structure at a scale that is relevant for urban areas (e.g., Crone and Schultz 2003). However, only a few model studies have focused on butterfly movements in realistic landscapes (e.g., Haddad 1999; Crone and Schultz, 2003). Chardon et al. (2003) and Sutcliffe et al. (2003) applied grid-based cost-distance models for butterflies. Cost-distance models are related to movement models, but assume that individuals follow the route of the least (total) costs, instead of basing their decisions on local information only. Compared to grid-based models, vector-based movement models like SmallSteps and the models described in Tischendorf et al. (1998), Kindvall (1999), Haddad (1999) are more easily parameterized from field studies tracking butterfly flight paths (e.g., Root and Kareiva 1984; Haddad 1999; Turchin et al. 1991) or studying butterfly movements on a landscape-scale (Conradt et al. 2000; Crone and Schultz 2003). Other species groups, such as birds, bats and dragonflies have different indicator values but may be studied by following the same methodology.

The mechanistic approach followed in the SmallSteps model appears to offer a promising direction for predicting butterfly movement in designed landscapes. Despite the assumptions made regarding some landscape variables of butterfly movement it was altogether thought that the simulation results were providing a good impression of what the impact of several alternative peri-urban design measures would be. However, validation of the model assumptions and predictions are ultimately necessary through additional field studies. These, in turn, may be used to further improve the model.

Acknowledgements

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Appendix A Movement parameters and life span data for two model species of butterflies

	Movement parameters		Life span (average number of days)
	Step size	SD rotation angle	
Good disperser	22.5 ± 17.6[1,2] (habitat[a]) 49.4 ± 29.2[2] (non-habitat[b])	50[1,2] (habitat) 22.5[4] (non-habitat)	40[5]
Moderate disperser	2.5 ± 0.6[1,3] (habitat) 7.2 ± 1.1[3] (non-habitat)	90[2,3] (habitat) 56[3] (non-habitat)	7[6]

a Open-space development and (semi-)detached building complexes (including gardens), extensively managed grasslands and forest edges were assumed to function as butterfly habitat.
b Large stand-alone buildings, parking lots, road infrastructure, intensively managed grasslands (including lawns), forest, large surface water and arable land were considered as non-habitat.
1 Root and Kareiva 1984; 2 Haddad 1999; 3 Turchin et al. 1991; 4 estimation based on Baker (1984); 5 Bink 1992; 6 Warren 1992.

Appendix B1 Boundary-crossing probabilities for 'good dispersers'

From / to	Semi-detached housing	Enclosed housing	Infrastruc-ture level 1	Infrastru cture level 2	Infrastruc ture level 3	Grassland, intensively managed	Grass-land, extensi-vely managed	Forest	Forest edge	Water	Arable land	Orchard
Semidetached housing	X	1	1	1	1	0.5	0.4	1	0.3	1	1	0.5
Enclosed housing	0.3	X	0.3	0.5	0.7	0.3	0.3	0.5	0.3	0.5	0.5	0.3
Infrastructure level 1	0.95	1	X	--	--	0.95	0.95	0.95	0.5	0.95	0.95	0.95
Infrastructure level 2	0.86	1	--	X	--	0.86	0.86	0.86	0.43	0.86	0.86	0.86
Infrastructure level 3	0.74	1	--	--	X	0.74	0.74	0.74	0.37	0.74	0.74	0.74
Grassland, intensively managed	0.5	1	1	1	1	X	0.4	1	0.4	1	1	0.5
Grassland, extensively managed	0.9	1	1	1	1	0.9	X	1	0.7	1	1	0.9
Forest	0.3	1	1	1	1	0.3	0.3	X	0.3	0.5	0.4	0.3
Forest edge	0.9	1	1	1	1	0.9	0.9	1	X	1	1	0.9
Water	0.4	1	1	1	1	0.4	0.4	0.5	0.4	X	0.5	0.4
Arable land	0.4	1	1	1	1	0.4	0.4	0.7	0.4	0.5	X	0.4
Orchard	0.9	1	1	1	1	0.5	0.4	0.9	0.4	1	1	X

Appendix B2. Boundary-crossing probabilities for 'moderate dispersers'

From / to	Semi-detached housing	Enclosed housing	Infrastruc-ture level 1	Infrastruc-ture level 2	Infrastruc-ture level 3	Grass-land, intensively managed	Grass-land, extensi-vely managed	Forest	Forest edge	Water	Arable land	Orchard
Semidetached housing	X	1	1	1	1	0.5	0.25	0.75	0.2	1	0.75	0.5
Enclosed housing	0.05	X	0.3	0.5	0.7	0.05	0.05	0.3	0.05	0.3	0.1	0.05
Infrastructure level 1	0.67	1	X	--	--	0.67	0.67	0.8	0.5	0.67	0.67	0.67
Infrastructure level 2	0.45	1	--	X	--	0.45	0.45	0.6	0.34	0.45	0.45	0.45
Infrastructure level 3	0.37	1	--	--	X	0.37	0.37	0.5	0.28	0.37	0.37	0.37
Grassland, intensively managed	0.5	1	1	1	1	X	0.25	0.75	0.2	1	0.75	0.5
Grassland, extensively managed	1	1	1	1	1	1	X	1	0.5	1	1	1
Forest	0.05	1	1	1	1	0.05	0.05	X	0.05	0.5	0.25	0.05
Forest edge	1	1	1	1	1	1	0.75	1	X	1	1	1
Water	0.1	1	1	1	1	0.1	0.05	0.5	0.05	X	0.4	0.1
Arable land	0.1	1	1	1	1	0.1	0.05	0.75	0.05	0.75	X	0.1
Orchard	0.5	1	1	1	1	0.5	0.25	0.85	0.2	1	0.75	X

Explanation of some land use categories: semidetached housing = (half)open configuration of houses; enclosed housing = block of houses with backyards inside; infrastructure level 1 = main road within city; infrastructure level 2 = neighborhood street; infrastructure level 3 = residential street; forest edge = 5 m zone of grassland adjacent to forest

Argumentation

Source	*Assumption*
Butterflies as 'Good dispersers'	
From grassland to forest: 0.3 (Haddad, 1999)	Assumption: idem for enclosed buildings
Between several herb vegetations: 0.5 (Root and Kareiva, 1984)	
Infrastructure level 2: Munguira and Thomas, 1992	Assumption: boundary crossing probability for infrastructure level 1 is root P (infrastructure 2).
Butterflies as 'Moderate dispersers'	
From grassland to forest: 0.05 (Fry et al. 1994; Sutcliffe and Thomas 1996)	Assumption: idem for enclosed buildings
Infrastructure level 2 and 3: (mobile level 2: 0.86, level 3: 0.86 x 0.86; moderate mobile level 2: 0.45 en level 3: 0.37) Munguira and Thomas, 1992.	Assumption: boundary crossing probability for infrastructure level 1 is square root P (infrastructure 2).; for infrastructure 3 it is P(infrastructure 2)^2
From grassland to open agricultural areas: 0.1 (Dover et al., 1992)	

In general
Higher boundary crossing probability to preferred habitat, lower to avoided habitat (assumption)
Mortality at crossing provincial roads 1%; at crossing highways estimated at 2% (Munguira and Thomas 1992)
Between days there's a random angle in direction of first flight (Jones et al. 1980)
Turning in left or right direction has similar probabilities (Jones 1977; Root and Kareiva 1984; Turchin et al. 1991)

Conservation where people work: A role for business districts and industrial areas in enhancing the sustainability of neighboring populations of endangered butterflies

5 Conservation where people work: A role for business districts and industrial areas in enhancing the sustainability of neighboring populations of endangered butterflies

R.P.H. Snep, M.F. WallisDeVries & P. Opdam

Abstract

Urbanization is often identified as a primary cause of species decline. Yet little is known about biodiversity conservation in human settlements, the 'places where people live and work'. In this study, conducted in the Netherlands, our main objective was to examine the potential impact of conservation measures at business sites—places where people work—on biodiversity in the wider landscape. We selected eight endangered butterfly species inhabiting low-productive, early-successional vegetation, because vacant lots, lawns and green roofs at business sites offer potential habitat for these butterflies. Combining national data on butterfly populations and business site distribution, we explored the extent to which additional butterfly habitat at business sites could enhance the sustainability of vulnerable butterfly populations nearby. We thereby defined 'butterfly network areas', being contiguous areas where the species was observed'. In addition, we identified priority sites where habitat improvements would be most effective for butterfly conservation. We found 187 butterfly network areas which were situated within dispersal distance of business sites large enough to offer potential habitat for local populations and 87 network areas where adjacent business sites offered potential habitat for 10 local populations, together sufficient for an independent, sustainable metapopulation. A subset of 93 business sites (2.5% of all Dutch sites) fit into this latter category, with in some cases multiple business sites in the vicinity of the same butterfly population. For four butterfly species (*A. agestis*, *H. semele*, *I. lathonia* and *O. faunus*), additional habitat developed at nearby business sites could support a substantial proportion (19–33%) of vulnerable populations on a national scale. In conclusion, although more detailed study is necessary before our findings can be applied in practice, the present study nonetheless suggests considerable potential for business sites to contribute to biodiversity conservation in the surrounding landscape.

Introduction

Conservation in urban areas

Urbanization is often identified as a primary cause of species decline. Yet little information is available about ways to conserve biodiversity in human settlements, the 'places where people live and work' (Miller and Hobbs 2002). Most contemporary conservation strategies are based on the idea of protecting areas that have a long-term record of biodiversity wealth as remnants of 'nature' amidst an urbanized landscape (e.g. areas with indigenous vegetation, Florgard 2007). Protection is then mainly considered from the point of view that these isolated remnants are vulnerable to anthropogenic influences like recreation (Lehvävirta et al. 2006) and new urban developments (Breuste 2004).

Urban areas, however, may also accommodate (endangered) species because their landscapes resemble species' natural habitats (e.g. for carabids see Eversham et al. 1996). In some cases urban habitats play an obvious role of significance for the regional survival of a species. In the Dutch-Belgium Rhine-Meuse-Scheldt delta, 40% of the major populations of the common tern (*Sterna hirunda*), a seabird species listed in Annex IV of the EU Habitat Directive (EC 2007), is found in (industrial) ports. Natural breeding areas (sand banks, beaches) in the region have disappeared or are disturbed by recreation. For these species, gravel roofs on office buildings and large areas of derelict land within industrial zones now provide a secondary breeding habitat that is vital for species persistence (P. Schippers, unpublished data). Another EU Habitat Directive species, the natterjack toad (*Bufo calamita*), has its largest population in Belgium's Port of Antwerp. For the long-term protection of this population, a conservation strategy has been proposed that is compatible with the area's economic dynamics (Snep and Ottburg 2008). This strategy is today one of the few to take the urban context, with its typical land use and dynamics, as a starting point for conservation. Other opportunities for conservation in urban areas are now gradually being recognized (e.g. Burghardt et al. 2008; Hunter and Hunter 2008).

The role of business sites in biodiversity conservation

In this paper we focus on business sites, defined as areas designated by local or regional governments to accommodate multiple firms. Business sites abound in urban landscapes. They are often located near city peripheries, close to highways and other infrastructure (Frej et al. 2001). Other terms for these localities are business parks, business districts, industrial estates and industrial areas (e.g. Nahm 2000; Frej et al. 2001). Increasingly, public attention is focused on the roles that businesses can play in contributing to a better world (e.g. Laszlo 2003). Recent approaches to business site development, known as 'careful industrial land use' and 'industrial ecology', look at ways companies can integrate sustainability into their management plans (Erkman 1997; Pellenbarg 2004). Some companies have cooperated with conservation organizations to preserve biodiversity on their property (Kelly and Hodge 1996; Cardskadden and Lober 1998). These initiatives on 'corporate land' have tended to take place at large, single-firm locations, which are very unlike 'business sites', where municipalities assign a delimited area to multiple firms. Furthermore, conservation activities on corporate land have often been limited to the site in question, neglecting opportunities to contribute to biodiversity on a larger spatial scale. Nonetheless, populations of many species depend on conditions on the scale of landscapes and regions, instead of just the individual local site (Opdam et al. 2003).

With this study, we aim to demonstrate the potential impact of conservation measures at business sites on biodiversity in the wider landscape. Current business site planning, development and management hardly address biodiversity conservation (Frej et al. 2001; Timmermans and Snep 2001). Business sites, however, have features that could provide a basis for small to medium-sized biotopes (1–5 ha), especially for pioneer and grassland vegetation (e.g. Schadek 2007). Few business sites maintain all of their land in permanent use by enterprises. Vacant parcels offer good conditions for species of early-successional vegetation. Together with landscaped greens (e.g., lawns and green roofs) this early-successional vegetation could be managed as habitat for a variety of endangered plant and animal species (e.g. Snep and Ottburg 2008).

Focus on butterflies

To examine opportunities for biodiversity conservation at business sites, we take butterflies as an example, for several reasons. Wood and Pullin (2002) emphasized that habitat availability is a key factor in butterfly persistence in urban areas. In addition, according to Smallidge and Leopold (1997) many butterfly species depend on early-successional vegetations. As business sites offer good potential for these vegetations, creating additional habitat at business sites may therefore be an apt conservation strategy to enhance butterfly populations occurring in urban landscapes.

As a species group, butterflies are highly appreciated by the public (Stewart et al. 2007; Kühn et al. 2008), and butterflies can sustain local populations with comparatively small amounts of habitat (Warren 1992) which can be developed by creating habitat on vacant lots at business sites. However, many butterfly species fail to persist on single habitat patches and require networks of habitat patches, sustaining networks of populations, so-called 'metapopulations', on a landscape scale (Hanski 1999; Ehrlich and Hanski 2004). In conservation terms, this presents interesting opportunities for strengthening existing population networks of endangered butterfly species by creating additional habitat at business parks located nearby.

Butterflies have obvious conservation value, because many butterfly species are endangered and protected at the national and continental levels (EC 1992; Van Swaay et al. 2006). Moreover, butterflies can be considered indicators of the invertebrate diversity in European ecosystems. They have been studied sufficiently that adequate knowledge of their distribution status and ecological relations is in the literature, they occur in a broad range of vegetation types (especially grasslands and pioneer vegetation), they are sensitive to environmental change, and they can be monitored by an established quantitative method (Thomas 2005; Van Swaay et al. 2008).

Research questions

In this paper we assume that habitat for butterflies can be created at business sites, and subsequently we explore to what extent business sites can enhance neighboring populations of endangered butterfly species in the highly urban country of the Netherlands.

To this end, we formulate three research questions:

1) Can we illustrate the potential that business sites offer for butterfly conservation, based on their location and size?
2) To what extent may business sites be able (by offering additional habitat) to improve the sustainability of vulnerable butterfly population networks in the surrounding landscape?
3) Can we identify priority business sites where habitat improvement would be most effective for butterfly conservation?

With the first question we show the number of occasions in which business sites can be relevant for butterfly conservation if butterfly habitat could be created there. Are there enough locations where business sites and endangered butterflies occur in the same area, so we could consider to further take up this idea? With the second question we demonstrate the potential impact of creating additional butterfly habitat at business sites on the persistence of the butterfly populations occurring in the direct vicinity of these sites. This impact is expressed in the number and proportion of vulnerable butterfly populations that can be substantially enhanced by creating habitats at business sites. Finally, with the third question we identify which business sites could potentially make a crucial contribution to butterfly conservation in the Netherlands, and how these sites can be characterized (in terms of location, type of business, size).

With this, we present a new approach to conservation: (i) We take the urban context as an opportunity for conservation. (ii) We focus on conservation measures for ‘business sites’. (iii) We explore a new conservation strategy for endangered butterflies, consisting of the development of additional habitat at business sites located adjacent to vulnerable butterfly network populations. We thereby show how private enterprises could contribute to the public interest of biodiversity conservation by new means of managing their land.

Methods

Study species and distribution data

We selected eight butterfly species for which habitat (pioneer, heathland and grassland vegetation) can be created at business sites and which are considered threatened in the Netherlands (Red List species) (Table 1). Except for *Ochlodes faunus*, these species are considered habitat specialists, that is, confined to habitat islands with specific host plants in the modern landscape. Their dispersal range is typically no more than two kilometers. The exception is *Issoria lathonia*, a widely dispersing vagrant, but its mobility within established populations appears to be more restricted (D. Maes, unpublished data). We therefore adopted a conservative estimate of its dispersal range.

***Table 1**. Dispersal ranges, patch size requirements for a local population, and abundance (# km squares) in the Netherlands for eight butterfly species. Red list status according to Bos et al. (2006). Dispersal ranges after Bink (1992), Cowley et al. (2001) and Bos et al. (2006). Local population areas after Warren (1992) and Bink (1992). Species nomenclature after Karsholt and Razowksi (1996). Km square: location where the species was observed between 2000-2008, at a resolution of 1x1 km.*

Scientific name	Red List status	Dispersal range	Area required for a local population (ha)	Preferred vegetation	Abundance
Aricia agestis	Near threatened	< 1.0 km	1.0–2.0	Dry calcareous grassland	1215
Hesperia comma	Endangered	< 1.0 km	0.5–1.0	Dry open grassland	260
Hipparchia semele	Near threatened	1.5 km	1.0–2.0	Dry open grassland	1134
Issoria lathonia	Vulnerable	1.5 km	2.0–5.0	Dry pioneer vegetation	623
Lycaena tityrus	Vulnerable	< 1.0 km	1.0–2.0	Low-productive grassland	748
Ochlodes faunus	Near threatened	1.5 km	0.5–1.0	Moist, low-productive tall grassland	3042
Plebeius argus	Near threatened	< 1.0 km	0.5–1.0	Heathlands	905
Pyrgus malvae	Endangered	< 1.0 km	0.5–1.0	Heathlands and low-productive grassland	151

We obtained butterfly data for the Netherlands from the national database of butterfly records managed by the Dutch Butterfly Conservation Society. Only records after 1999 were considered, at a resolution of 1x1 km (defined here as a 'km square'). Our selection contained a total of 1.06 million records from 25,233 km squares, that is, from 84% of the predominantly terrestrial km squares. The kilometer squares without records consisted mainly of intensively farmed lands or densely populated urban areas, where the selected species were unlikely to occur. Observers were especially keen to record Red List species. Therefore, we feel confident that the data accurately reflect the current distribution of these species.

We distinguished three classes of population size based on the maximum number of individuals recorded in a km square by a single observer on a single day and on the number of years in which the species was recorded in a given km square. 'Small' populations included less than 6 individuals seen on a single date or fewer than 3 individuals per day seen in different years. 'Moderate' populations numbered 6–50 individuals per day and 'large' populations consisted of more than 50 individuals per day. These size class boundaries are more or less arbitrary, but do agree with indications of butterfly abundance from monitoring data (see Van Swaay 2003).

Assessing the habitat potential of business sites

We set out to determine which business sites could make a significant contribution to establishing sustainable metapopulations of endangered butterflies. For this, national data on the distribution of business sites in the Netherlands was obtained, which included information of the exact location, size and type of each business site (Table2).

Table 2. *Typology of all business sites in the Netherlands.*

Business site type	Number of sites	Percentage of total	Total area (ha)	Average size ± SD (ha)
Distribution centers	50	1.4%	3,298	66.0 ± 63.5
Heavy industrial area	121	3.4%	8,419	69.6 ± 106.6
High-quality business parks	119	3.3%	4,176	35.1 ± 79.4
Industrial seaports	48	1.3%	10,784	224.7 ± 405.0
Mixed business sites	2,780	76.7%	53,207	19.1 ± 33.7
Miscellaneous	505	13.9%	16,657	33.0 ± 95.7
TOTAL	3,623	100%	96,542	26.6 ± 74.6

Next, we focused on populations in need of additional habitat patches, that is, leaving out the larger, apparently stable populations as well as incidental records and populations too small to be considered a basis for a metapopulation (more details in the section below on ‘questions 2 and 3’). We estimated the area of habitat required for a sustainable metapopulation as roughly 10 times the minimum size for a local population, after Hanski (1999) and Ehrlich and Hanski (2004).

In a recent study of breeding birds at Dutch business sites, short vegetation land cover (e.g. lawns, vacant lots and green roofs) averaged 20% of the business site areas (R. Snep, unpublished data). Given that part of this short vegetation consists of patches unsuitable for butterfly reproduction, we took a value of 10% as a realistic proportion of the available area at business sites that could be transformed into butterfly habitat. Besides, we considered 1 ha of butterfly habitat as a minimum size for a local population, thus excluding business sites smaller than 10 ha. For *I. lathonia* the minimum value adopted was 2 ha (Table 1), setting the threshold for business sites at 20 ha for this species.

To answer our questions, we conducted a series of overlay, buffer and other procedures with the butterfly and business site data using geographical information systems (ArcView 3.3, ESRI) (Fig. 1).

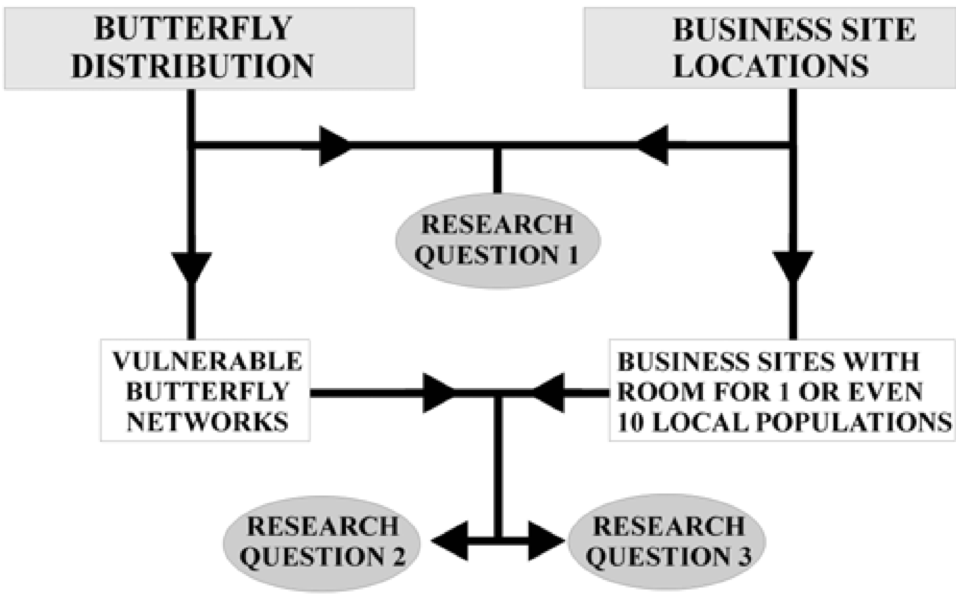

Figure 1. *Methodology flow chart. The starting point for analysis was the separate datasets on butterfly distribution and business sites in the Netherlands. Input and intermediate data are depicted by rectangles, and output data by circles.*

Question 1: Identifying which business sites are within the dispersal range of butterflies

We identified which of the km squares with observed butterfly species between 2000 and 2008 were located in the direct vicinity of a business site that could potentially offer suitable butterfly habitat. To determine maximum distances between business sites and existing butterfly populations, we used maximum dispersal distances (Table 1). For butterflies with a dispersal range of less than 1 km, we selected only business sites located in the same km square. For butterflies with a 1.5 km dispersal range, we also considered business sites in a 0.5 km buffer area around the butterfly site as accessible.

This analysis provided, for each butterfly species, a number of 'km squares' where butterflies could benefit from the creation of additional habitat at neighboring business sites. This number was expressed as a percentage of the total number of km squares where the species occurred. These figures provided insight into the number of business sites that could contribute to conservation of the butterfly species.

Questions 2 and 3: Identifying business sites with potential for butterfly conservation

We analyzed butterfly distribution data at the network level, since the persistence of butterfly populations is usually determined at the level of metapopulations or population networks (Hanski 1999; Ehrlich and Hanski 2004). We defined 'butterfly networks' as complexes of contiguous km squares where a butterfly species was observed (illustrated in Fig. 4). We classified the network areas as 'small' (1 km square), 'moderate' (2–3 km squares) and 'large' (>3 km squares). As an indication of the population size of the butterflies in each network, we took the highest value among the contributing km squares. We prioritized the sites for conservation by eliminating butterfly networks with a small area and small population size, as well as those with a large network area and large population size (Table 3). The former category was considered to reflect an uncertain population status, since the records might pertain to occasional visitors or migrating individuals. The larger populations were considered to have low conservation priority, as these were likely already sustainable. This left those butterfly networks that were vulnerable but had sufficient potential for effective conservation measures (Table 2). 'Vulnerable butterfly network areas' are thereby defined as 'contiguous areas where the species was observed, with populations considered as vulnerable for extinction based on population size and network area size'.

Table 3. *Overview of butterfly population networks considered potentially vulnerable and thus relevant for this study. Classification is based on a combination of the parameters 'network area size' and 'population size'. Population size is the highest number of individuals observed in the network area on a single day. Km square: location where the species was observed between 2000-2008, at a resolution of 1x1 km.*

	Population size		
	Small (<6 butterflies)	Medium (6–50 butterflies)	Large (>50 butterflies)
Network area size			
Small (1 km square)	—	vulnerable	vulnerable
Medium (2-3 km squares)	vulnerable	vulnerable	vulnerable
Large (> 3 km squares)	vulnerable	vulnerable	—

Business sites with sufficient potential habitat for an independent, sustainable metapopulation (i.e. meeting the requirements for 10 local populations) could make a substantial contribution to the sustainability of endangered butterfly populations in the adjacent landscape. Here, there is sufficient room to create a network of 10 patches at the business site itself. Such business sites were therefore earmarked as sites where conservation measures would be most effective for butterfly conservation (question 3).

Results

We found that at more than 400 business site locations, creating butterfly habitat could substantially strengthen neighboring populations of vulnerable butterfly species (Fig. 2). These 400 locations (11% of the Dutch business sites) were within the dispersal range of places where one or more of the eight selected Red List butterfly species were observed. There was large variation in the number of suitable locations found per species, and also in the proportion these locations represented relative to the national butterfly distributions.

Our next step focused on the network level, where butterfly (meta)populations may occur in several contiguous km squares. Here, we found i) 187 butterfly network areas which were situated within dispersal distance of business sites large enough to offer potential habitat for local populations and ii) 87 network areas where adjacent business sites offered potential habitat for a network of 10 local populations, together sufficient for an independent, sustainable metapopulation. For four butterfly species (*A. agestis*, *H. semele*, *I. lathonia* and *O. faunus*) this selection proved to be a substantial proportion (19–33%) of the number of vulnerable populations (Fig. 3). These species can be characterized as butterflies with a moderate dispersal ability.

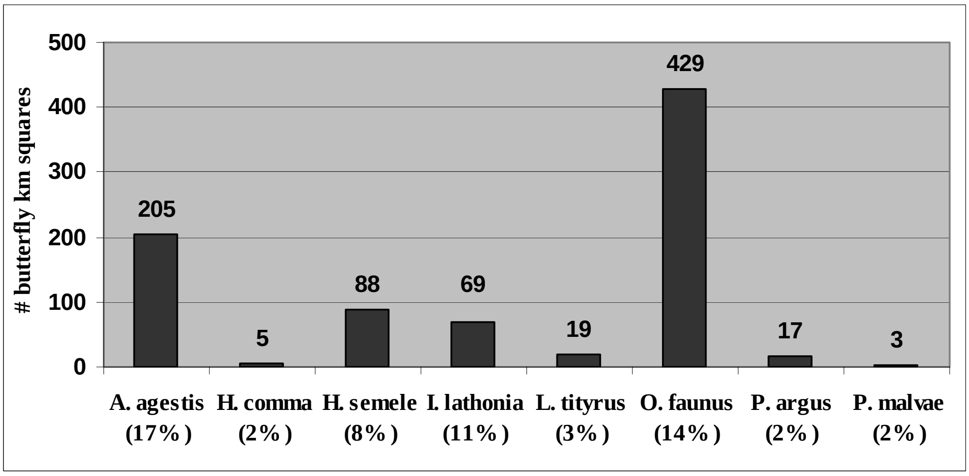

Figure 2. *Number of butterfly km squares, where butterfly habitat (>1 ha) for additional local populations could be created at neighboring business sites (>10 ha); also expressed as a proportion (%) of the total distribution of the species in the Netherlands. For I. lathonia only business sites larger than 20 ha were included, as this species requires a minimum of 2 ha for local populations (Table 1). Km square: location where the species was observed between 2000-2008, at a resolution of 1x1 km.*

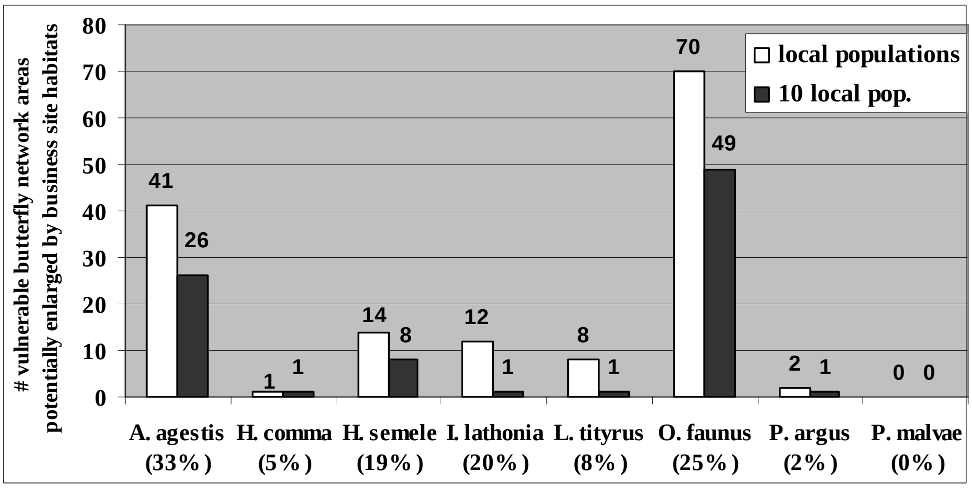

Figure 3. *Number of vulnerable butterfly network areas that can be strengthened with additional habitat (for at least 1 local and for 10 local populations) at a neighboring business site. This number is also given as proportion (%) of the total number of vulnerable network areas. Vulnerable butterfly network area: contiguous area where the species was observed, with population considered as 'vulnerable for extinction' based on population size and network area size.*

Figure 4 illustrates for the brown argus (*Aricia agestis*) where vulnerable butterfly networks are located in the Amsterdam region, and in which cases additional habitat at business sites could enhance their persistence.

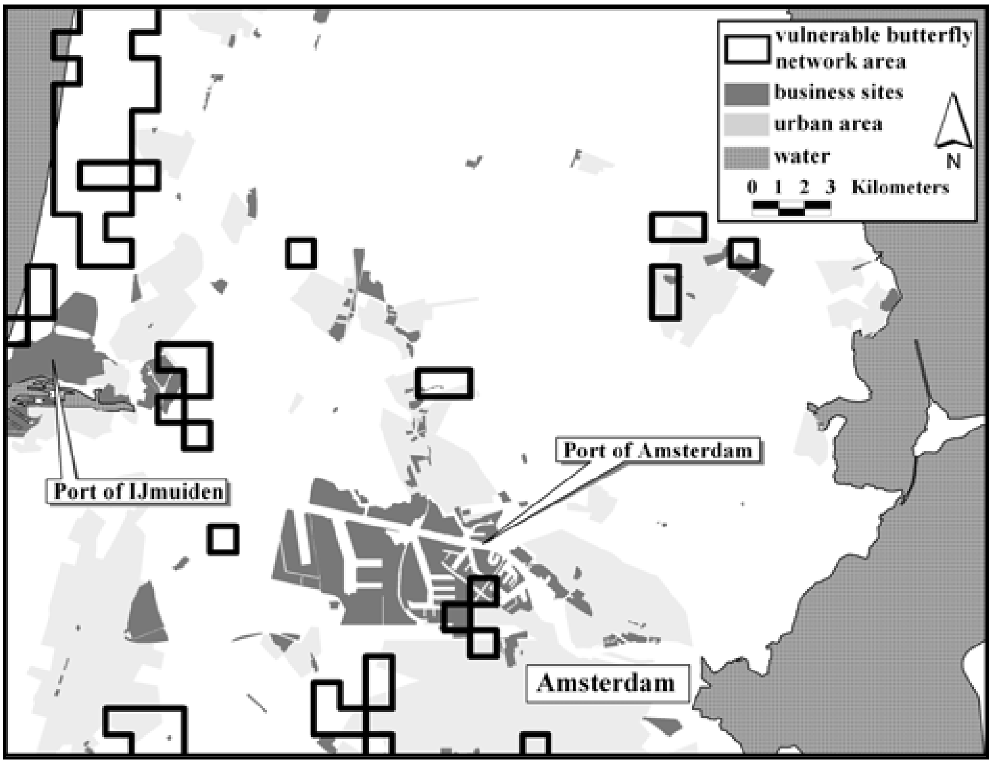

Figure 4. *Elaborated example showing where population networks for the brown argus (A. agestis) in the Amsterdam region are in close proximity to business sites. The ports of Amsterdam and IJmuiden have the potential to strengthen vulnerable brown argus network areas with sufficient extra habitat patches (10x) to obtain sustainable metapopulations. Vulnerable butterfly network area: contiguous area where the species was observed, with population considered as 'vulnerable for extinction' based on population size and network area size.*

Furthermore, we identified a subset of 93 business sites (2.5% of all Dutch sites) with the potential to contribute very substantially to butterfly conservation, as these sites could accommodate a cluster of 10 local populations (Table 4). Of those 93 sites, 75 could support a cluster of habitat patches for a single species, 17 could support two species and 1 could support five species. At this last location, a heavy industry area, creating 20 ha of butterfly habitat would mean transforming 3% of this 660 ha business site into butterfly habitat. The 93 business sites are associated with only 87 corresponding butterfly network areas because in some cases different business sites adjoin the same butterfly network area. The 93 business sites were evidently larger than the average business site in the Netherlands (Table 2), because they were large enough to develop a cluster of habitat patches for 10 local populations (consisting of 5–20 ha of butterfly habitat in total). Thus, we expect these patches, in combination with the adjacent vulnerable butterfly populations, to support a sustainable population network for the concerned species. Compared to the overall national situation, heavy industry areas, high-quality business parks and industrial seaports were better represented in this selection than other types of locales.

Table 4. *Dutch business sites (numbers and proportion) with substantial potential to enhance the persistence of vulnerable butterfly population networks, because these business sites are located in the vicinity of these populations and are large enough to offer habitats for a sustainable population of butterflies. Some sites can support more than one species.*

Business site type	Number of sites	Percentage of total	Average size (ha)	Maximum number of species per site
Distribution centers	2	2.1%	122.1	1
Heavy industrial area	15	16.1%	221.0	5
High-quality business parks	9	9.7%	187.7	2
Industrial seaports	9	9.7%	883.0	2
Mixed business sites	58	62.4%	126.3	2
Total	93	100%	220.7	

Discussion

Quantifying business site potential for conservation

Butterflies that depend on nutrient-poor, early-successional grassland or heathland vegetation may find suitable habitat at business sites, which typically have vacant lots, extensively managed lawns and green roofs. For this study, we selected eight butterfly species that prefer such habitats and are listed as endangered in the Netherlands. Our findings demonstrate that for some of these species a substantial (up to 33%) proportion of vulnerable populations could be made (more) sustainable by developing butterfly habitats at business sites located in the direct vicinity of these butterfly populations. This conservation strategy is based on the idea that the development of additional habitat patches (at business sites) will enlarge existing networks of neighboring butterfly patches, and thus increase the butterflies' probability to persist. In a number of cases this enlargement could be so extensive (developing a series of 10 patches at a large business site) that the expanded network of new and old patches could support a sustainable metapopulation. Some 2.5% (93 sites) of the Dutch business sites meet these conditions in relation to butterfly species with moderate dispersal abilities and a preference for early-successional or grassland vegetation (*A. agestis*, *H. semele*, *I. lathonia* and *O. faunus*).

In our approach we adopted a comparatively coarse resolution as to the exact location and size of the butterfly habitats. This was inevitable in order to achieve national coverage, which would have been impossible with available data at a finer resolution. Therefore, we were deliberately conservative in our assumptions concerning butterfly dispersal and requirements for sustainable metapopulations. For example, we showed that some business sites may offer sufficient space to accommodate a network of 10 habitat patches at the sites itself, each able to support a local population. However, as numerous examples show (e.g. Hanski 1999; Ehrlich and Hanski 2004), this number of patches is by itself sufficient for a sustainable metapopulation, independent of the habitat already available in the vicinity. In reality, the environs of the business sites probably contain substantial additional existing habitat supporting the current butterfly populations, which, in our estimate of sustainability, we left out of consideration (as, indeed, we did not have the data). By aiming for 10 patches at a large business site we therefore included a buffer in carrying capacity, for example, in case optimal habitat quality cannot be obtained at the business site.

Another methodological choice, the grouping of butterfly populations in size classes, appeared to have little impact on the application value of our approach. An evaluation of the sensitivity of the class boundaries showed that small changes in the boundaries did not significantly alter the results. We are therefore confident that the main finding of this study, that is, 'developing additional habitat patches at business sites could support the sustainability of neighboring butterfly populations', is supported at least for several Dutch Red List butterfly species preferring early-successional vegetation.

Business site habitats as a promising support for butterfly conservation

When discussing the implementation of the idea of this study, two questions raise: i) is it possible to create or restore butterfly habitats (in urban areas), and ii) what conditions do business sites have to meet to provide butterfly habitat? Regarding the former, butterfly conservation has conventionally focused on nature and, to a lesser extent, agricultural areas (Asher et al. 2001; Van Swaay et al. 2006). Success in restoration of habitat for butterflies here has been obtained in a variety of settings, especially in existing but degraded habitats (Marttila et al. 2000; Ries et al. 2001; Saarinen et al. 2005; Field et al. 2005, 2007; Pfitsch et al. 2008) but also in newly made habitats on former agricultural lands (e.g., WallisdeVries and Ens 2008) and in post-mining areas (e.g., Rosemund et al. 2004). Recent studies have thereby emphasized the need to define a habitat as a combination of vital resources (Dennis et al. 2003; Vanreusel et al. 2007). Habitat restoration studies teach us that the colonization success of new habitats by butterflies depends, just as for existing habitat patches, mainly on the abundance of host and nectar plants and a suitable microclimate (e.g., WallisdeVries and Ens 2008).

So, if in general habitat creation or restoration can be successful for butterfly populations, what does this imply for the creation of butterfly habitats at business sites? Various studies have stressed the role of habitat quality and connectivity for butterfly persistence in built environments, suggesting that local factors are more important than landscape factors (e.g., Wood and Pullin 2002; Collinge et al. 2003; Angold et al. 2006; Snep et al. 2006). Koh and Sodhi (2004) found that the number of potential larval host plant species and the degree of isolation from forests were important determinants of butterfly species richness in urban parks, thereby providing similar results as in rural studies. Accordingly, we selected business sites in the direct vicinity of actual butterfly populations with the idea of developing suitable habitat there. Hence, when designing and managing business sites for site-specific conditions required by butterflies, it should be possible to create habitat patches that contribute substantially to neighboring butterfly populations.

Next, how to obtain butterfly vegetations at a business site? When the land designated for business site development is prepared for construction (i.e. covered with a layer of sandy soil), ideal conditions for pioneer plants are created. If however non-pioneer plant species are aimed for, planting is an option in the case of business sites, but one that would hardly be considered in more natural areas. At butterfly gardens such planting practice is common. However, unlike the relatively large butterfly habitats (1–2 ha per patch for a local population) we propose to develop at business sites, most butterfly gardens are small (<0.5 ha) and act mainly as nectar sources and stepping stones rather than as a permanent habitat for a local population (Di Mauro et al. 2007). This means that the planting of complete habitat patches to support local populations at business sites would be a novelty in butterfly conservation.

Butterfly habitats as means to improve quality of life at business sites

Current business sites are not known for their butterfly richness, rather the contrary is true (Blair and Launer 1997). However, corporate initiatives to contribute to biodiversity conservation on their property have demonstrated the wider benefits of such efforts, beyond providing habitat for butterflies and other wildlife. A recent study on nature in the working environment showed that employees valued a varied and green appearance of their working environment, with some especially appreciating a high probability of wildlife encounters (Kaplan 2007). In addition, employees involved in the management of wildlife habitat at their business site appeared more committed to their employer (Cardskadden and Lober 1998). For property owners too, creating butterfly habitat at a business site may offer benefits (R. Snep, unpublished data). For example, most business districts are known as being unattractive in appearance, which shortens their useful lifespan and renders real estate investments less attractive (Feehan and Feit 2006). Urban green, including butterfly habitats, could increase the attractiveness and thus the profitability of business districts. Contributing to biodiversity conservation at business sites could also provide companies a way to demonstrate their corporate environmental responsibility (Kelly and Hodge 1996). The practices of the US Wildlife Habitat Council (WHC 2008) and the Business Challenge of the British Trust for Ornithology (BTO 2008) provide examples of companies actively promoting biodiversity conservation on their properties.

Adding to these arguments, the approach and findings of this study can be drawn upon to identify specific business sites where implementing conservation measures (creating butterfly habitat on vacant lots, green roofs and lawns) can provide enterprises and public authorities with opportunities to make a substantial contribution to biodiversity conservation in the wider vicinity.

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Enhancing biodiversity at business sites: What are the options, and which of these do stakeholders prefer?

6 Enhancing biodiversity at business sites: What are the options, and which of these do stakeholders prefer?

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Abstract

Biotic aspects of business site environments – flora and fauna and the landscape they inhabit – are not yet fully addressed in sustainable business site design. In this study a multi-criteria analysis (MCA) framework was developed with which scenarios were assessed that include various measures (elaborating five defined design and management principles) to enhance biodiversity at business site. Discrimination among the scenarios was based on socioeconomic and environmental criteria, both monetary and non-monetary. With this MCA framework, it was illustrated how different stakeholder groups (companies, employees, local governments, neighbors and environmental NGOs) in the Netherlands may rank scenarios for enhancing biodiversity at business sites, based on stakeholders' preferences. This ranking of scenarios proved rather robust, as in an uncertainty analyses (run for a large range of both weights and scores) the ranking remains the same for most runs.

Scenarios that include a large amount of urban green emerged as the favorite of all stakeholders, including companies and local governments. Besides it was found that implementing measures to enhance biodiversity may be acceptable only if combined with other 'urban green' functions (predominately related to 'recreation' and 'health and well-being') and if tailored to the required functional appearance of the business site environment (in terms of 'external appearance' and 'tidiness'). Thus, the study broadens the concept of sustainable business site development by focusing on strategies to enhance biodiversity and landscape values at business sites.

Introduction

Metropolitan areas have grown rapidly in recent years, both in size and in importance as places for people to live and work (United Nations 2003). Within urbanizing regions, planners and decision-makers often face an increasing shortage of land available for new residential areas, business sites or greenways (e.g. Ackerman 1999). To better fit a diversity of ambitions and developments into one area, multifunctional land-use planning was proposed by Rodenburg and Nijkamp (2002). Multifunctional land use can be considered a successor of the mixed land use concept (Louw and Bruinsma 2006). Whereas traditional zoning spatially divides different land uses and gives each function its own area (Neuman 1998), 'multifunctionality' allows various functions to be combined. Rietveld and Rodenburg (2003) define a land-use pattern as 'multifunctional' when there is an increase in the area considered, the number of functions, the degree of interweaving or the spatial heterogeneity.

This study focuses on business sites: areas designated by local, regional and in some cases national governments to accommodate multiple companies that produce, transfer or store goods or provide services. These economic areas can according to their functional qualities, economic requirements, spatial-visual qualities and flexibility be further divided in high-quality business sites, mixed business sites, distribution areas, heavy industrial areas and seaport areas (IBIS 2007). Other classifications used in different countries refer to these sites as business districts, business parks, industrial sites or industrial estates (e.g. Frej et al. 2001). Business sites can be distinguished from commercial areas (like shopping malls) as there governments accommodate companies that (in stead of producing or transferring) sell products or services to visiting consumers. Business sites are also different from office sites where work is focused on the (administrative processing) of information and not on producing, transferring or storage of goods (IBIS 2007).

Business sites are a land-use type for which sustainable development is increasingly being called for (Bontje 2004; Pellenbarg 2002). Policymakers, NGOs and citizens demand that businesses take 'corporate responsibility' and give more priority to the damaging effects of economic activity on local and global society and on the ecosystem (Bontje 2004). 'Industrial ecology' (Erkman 1997) and 'careful industrial land use' (BCI 2001 cited in Pellenbarg 2004) are strategies that aim to diminish the negative effects of business and industrial areas on the abiotic aspects of the environment. They provide ways to address air and soil pollution and to use water, energy and building materials more efficiently.

Biotic aspects of the business site environment, that is, flora and fauna and the landscape they inhabit, are often not fully addressed in these sustainable business site concepts. Yet the threat to landscape and biodiversity values makes the ongoing development of traditional, mono-functional business sites an increasing point of contention among urban planners, governments and environmental NGOs (e.g. Louw and Olden 2004). Environmentalists and local citizens often view new business sites as colossal, unnecessary urban developments that destroy historical landscapes and biodiversity values (e.g. Fortin and Gagnon 2006).

Multifunctional land-use designs that are able to combine corporate and biodiversity interests may offer new directions to solve these problems. This prospect is already recognized by environmental NGOs (e.g. the US Wildlife Habitat Council and British Trust for Ornithology). Based on practical cases, Cardskadden and Lober (1998) even state that business sites have the potential to provide habitat for plant and animal species. This paper elaborates this idea further, and suggests that this potential is based on four characteristics:

- Business site location on the edge of the city. Most business sites are situated on a strategic place in the urban-rural gradient (McDonnell and Pickett 1990), and therefore may act as ecological corridors (Löfvenhaft et al. 2002) or source for inner-city biodiversity (Snep et al., 2006).

- Design of business buildings. Unlike residential houses, business buildings tend to be designed with flat roofs, which offer a potential biotope for many plant and animal species (Grant et al. 2003).

- Land dynamics at business sites. Because there is a high turnover of firms at business sites, and established firms tend to reserve extra land for future expansions, these sites have a constant supply of areas not currently in use for business purposes. Because these vacant lots receive little attention from urban green managers (due to the high cost of such maintenance), they provide opportunities for pioneer vegetation (Kattwinkel et al. 2006) and pioneer animals such as the Natterjack toad (*Bufo calamita*) (Smit, 2006).

- The human uses of business sites. Due to the nine-to-five culture common at most business sites, these areas are relatively undisturbed during twilight and at night, at least compared to other urban areas. This makes them ideal places for nocturnal species like amphibians and urban mammals (e.g. the urban fox, see Gloor et al. 2006).

Decision-makers in business site development, who in fact should balance the interests of ‘people, planet and profit’ (Elkington 1998), have not as yet taken up the idea of business sites that include specific measures for biodiversity conservation (Jensen et al. 2000). Among other reasons this may be due to the lack of scientific knowledge on how exactly business sites could contribute to biodiversity conservation without obstructing the economic functioning of the area (Miller and Hobbs 2002).

In this paper multi-criteria analysis (MCA) was used to analyze scenarios for enhancing biodiversity at business sites. MCA is a decision aid and mathematical tool allowing the comparison of different alternatives or scenarios according to many criteria, often contradictory, in order to guide decision-makers towards a judicious choice (Roy 1996). Although MCA techniques have been employed in (urban) land-use studies (e.g. Saroinsong et al. 2007; Giordona and Riedel 2008), they have not been applied to the question of how to combine economic and biodiversity interests at business and industrial sites. The aim of this study is to illustrate how an MCA framework for sustainable business sites might be used to analyze how biodiversity can be enhanced at a business site. The analysis explores (socio)economic and environmental effects of different business site scenarios that include a range of biodiversity-oriented design and management measures. In doing so, it provides alternatives for traditional business site design and supports the decision-making process among public and private actors seeking sustainable business sites.

The paper contributes to the literature on multifunctional business sites in a number of ways: (i) by identifying categories of MCA criteria; (ii) by identifying relevant categories of stakeholders; (iii) by defining, based on questionnaires and literature, sets of weights that characterize the preferences of different stakeholder groups; (iv) by providing an effects table for a series of alternatives for business sites; and (v) by defining and ranking these alternatives. With this the paper illustrates how biodiversity conservation issues can be integrated in the decision-making process for multifunctional business sites, and thus how business sites can contribute to sustainable development.

Material and Methods

In this paper the socioeconomic and environmental effects of integrating biodiversity conservation in business site development are explored in six steps: (i) compilation of a set of scenarios for business sites that could enhance biodiversity, (ii) selection of an evaluation tool able to assess theses scenarios for different criteria, (iii) definition of socioeconomic and environmental criteria, (iv) construction of an effects table, (v) definition of stakeholders' preferences with regard to biodiversity conservation aspects and (vi) ranking of the business site scenarios for each stakeholder. Apart from the selection of the evaluation tool, each step led to a single result.

Compilation of business site scenarios

Business sites in the Netherlands vary in design and management (Louw 2000). These sites are therefore better described according to their function than their homogeneity in land use. Nonetheless, there are several features that most such sites share and make them potentially interesting from a biodiversity conservation point of view. This paper elaborates these features using Dutch guidelines for biodiversity conservation. These guidelines are: to improve the quality of existing habitats, to enlarge the size of existing habitat patches and to connect different habitat patches to create a sustainable habitat network (e.g. Reijnen and Koolstra 1998). In the case of enhancing biodiversity at business sites, this results in five principles, focused on the specifics of their land use.

1. *Make maximum use of the large potential of flat roofs for habitat*.
   As several cases illustrate, flat roofs of business buildings can play a useful role in biodiversity conservation and development, with appropriate design and management (Grant et al. 2003). For instance, green or gravel roofs can function as breeding or feeding habitat for flying animals and provide space for certain plant species (see e.g. Bauman 2006; Brenneisen 2006).

2. *Maximize the ecological quality of existing green at business sites.*
   At traditional business sites, urban green is managed intensively so as to maintain a clean and structured appearance (Frej et al. 2001), limiting the variety of plant species present. Moreover, most planted species are exotic and of little use to local wildlife.

3. *Make maximum use of the potential for temporary habitats on vacant lots*.
   Business sites tend to have high a proportion of derelict land, which then becomes temporarily available for flora and fauna during certain periods in the life-cycle of the sites (mainly in the beginning and end phases). In fact, derelict lands often have high ecological value. They often offer pioneer situations which are ideal for colonization by endangered plant and animal species. This type of biotope can thus contribute significantly to the overall habitat potential of a business site (Schadek 2007).

4. *Enhance the green infrastructure at business sites with additional green areas.*
   As indicated by Sandström et al. (2006b) and Clergeau et al. (2006) the size of urban habitats matters. The larger the urban green area, the greater the species richness that may be expected.

5. *Implement habitat corridors in the design and management of business sites.*
   Ecological corridors are used by plant and animal species to migrate between habitat patches (Jordán 2000). Business site habitats could support ecological corridors when these are located near the business site. A simple geographical information system (GIS) overlay procedure of national land-use maps showed that 606 (mainly suburban) business sites in the Netherlands are located adjacent to or in the direct vicinity of ecological corridors or areas important for biodiversity conservation (unpublished data).

To assess socioeconomic and environmental impacts of implementing these five principles at business sites, a set of scenarios was designed. Six scenarios were considered: one scenario for each of the five principles and one serving as a basic scenario representing current – more traditional – practice in business site design. These encompass the variation in biodiversity-oriented business site development that this paper wants to explore. Scenarios that appear most promising can be further refined in future studies. To compare the scenarios only on their differences in enhancing biodiversity measures, the setting of the business site (based on a conventional mixed business site) was kept the same among all scenarios, as presented in a background report (Appendix A).

Selection of the evaluation tool

Evaluation techniques can be categorized as monetary and non-monetary, an example of the former being cost-benefit analysis and of the latter multi-criteria analysis (Janssen and Munda 1999). Monetary evaluation attempts to measure all effects in monetary units, whereas non-monetary evaluation uses a wide variety of measurements to assess effects. As argued by Munda et al. (1994), Cameron (1997), Goulder and Kennedy (1997), Joubert et al. (1997) and Prato (1999) non-monetary evaluation techniques are best equipped for complex subjects, such as those in which interactions between economics and ecology play a key role. Cost-benefit evaluation techniques are less suitable in these situations because they reduce problems to a single dimension objective function (real net present value) and because in CBA all impacts and expressed preferences are converted into common units (money) (Joubert et al. 1997). In this particular case it was difficult to provide a monetary estimation of all items, as reliable data on some items was not available. MCA was therefore considered to be the most suitable method. The major strength of multi-criteria methods is their ability to address problems marked by various conflicting interests or multidimensional aspects. Multi-criteria evaluation techniques cannot solve all of these conflicts, but they can offer insights into the biodiversity of the conflicts by providing systematic information and ways to arrive at political compromises. Particularly in cases of divergent preferences in a multi-group or committee system the MCA can make trade-offs in a complex situation more transparent to decision-makers (Munda et al. 1994).

MCA requires generation of a set of alternatives or scenarios, definition of a number of criteria (including their units of measurement) to construct a systematic evaluation framework, attachment of scores to each criteria for all scenarios, construction of an effects table for all scores, standardization of the effect scores (to make them comparable), determination of a set of weights representing each stakeholder and ranking of the scenarios based on the effects table and weight scores (Janssen 2001). In this paper the software DEFINITE (Janssen et al. 2001) was used to conduct the multi-criteria analysis, as these software has the facility for performing testing procedures that can examine the stability of rankings for different options across stakeholder groups (Qureshi et al. 1999).

Definition of socioeconomic and environmental criteria

As this paper wanted to describe the socioeconomic and environmental effects of integrating biodiversity-enhancing measures into the design and management of business sites, a list of criteria based on the literature was formulated (e.g. Cardskadden and Lober 1998; Grant et al. 2003; Porsche and Kohler 2003; Van Herzele and Wiedeman 2003; Buck Consultants International 2006) and expert knowledge (Dutch specialists from the Delft University of Technology, Radboud University Nijmegen, Erasmus University Rotterdam, Etin Consultancy and Landscape Management Netherlands). The criteria selected represent only those aspects in which biodiversity-oriented business sites differ from traditional business sites. Other aspects of business sites, such as location, which are the same for traditional and ecologically-minded sites, were not included as criteria. The selected criteria were categorized into three dimensions: economic, social and environmental.

Construction of the effects table

Using the (socio)economic and ecological criteria, it was possible to evaluate the effects of implementing measures to enhance biodiversity at the business sites. The land-use characteristics of the various scenarios were evaluated for all the criteria. For monetary criteria, scores could be quantified, as they were calculated based on the design of the scenarios and standards from literature. For other criteria, effect scores (considered to be 'qualitative' scores) were estimated, again based on literature and expert knowledge. These scores were expressed on a relative scale (0 / +++++ or - - - - - / 0). Each step on this relative scale was considered equal in size (e.g. the step from + to ++ is equivalent to that from ++++ to +++++), and thus effects were assigned on a linear scale. Details about this evaluation can be found at Appendix B. The results provide an overview of all effects (the effects table), though not yet weighted or ranked.

Selection of stakeholder groups

Next, the stakeholder groups were defined that would be confronted with the biodiversity-oriented measures, and identified how they might experience the measures. As Gamboa (2006) argued, it is necessary to specify stakeholders and their specific needs and expectations. Based on Spiller (2000), Bontje (2004) and Sacli (2004) five categories of primary stakeholders were defined: (i) companies, (ii) employees, (iii) local government, (iv) neighbors and (v) environmental NGOs. Thus, not only those parties involved in the final decision to develop a business site (local government) and to establish on the site (companies) were selected, but also those who will experience the actual business site after it has been developed (according to Grimble and Wellard 1997). This was done because decision-making in the Netherlands is usually the result of a broad democratic process involving all relevant stakeholders. Planners, developers and park managers were considered to have a neutral position when it comes to valuing the implications of biodiversity-minded measures, and therefore they were not included as stakeholders. We here define these groups as ‘neutral’ because they (must) represent interests of all the community members in a society and are keen to maintain different economic, environmental and social values and perceptions.

Preferences of stakeholders

For the five stakeholder groups needs and interests were compiled regarding business sites in general and the application of measures to facilitate biodiversity at these sites in particular. Representatives of the local government, companies and environmental NGOs were interviewed because it was assumed that these professionals were capable of understanding the context of the research as described in this paper. They received questionnaires, providing general information about the research and about the selected criteria (tab.1), and then were asked to indicate their preferences by distributing 100 points over the 13 selected socioeconomic and environmental criteria (e.g. Boudreau et al. 2001). For local governments civil servants in municipal departments (n=11) involved in business site planning and development were contacted. For companies, entrepreneurs at business sites designated for small and medium-sized enterprises (SMEs) were randomly contacted. For environmental NGOs, regional representatives of several organizations involved in business site planning and development were interviewed.

For employees and citizens living in close proximity to business sites, a direct approach was considered unfeasible in the context of this study. Therefore, data from (inter)national literature provided a proxy for these stakeholders’ interests in the green environment of business sites. In the United States, Kaplan (2007) studied the satisfaction and desires of employees working at a business site corridor extending 4 km along a main entranceway into Ann Arbor, Michigan, concerning urban green in their working environment. These employees particularly valued the presence and size of trees at the sites, as well as views of (natural) landscapes, biodiversity located nearby and the opportunity to sit outside surrounded by flowers and to see birds and other animals. An optimum situation for employees would thus seem to include more flowers, trees and landscaping and in general better visual and physical access to the available green. The presence of lawns (despite their costly management) appeared to have no impact on employees’ satisfaction with their working environment. Jókövi et al. (2002) interviewed employees and neighbors of four ‘green’ business sites in the Netherlands. They found that the majority of employees used (89%) and appreciated

(92%) their green working environment. The opportunity to walk (94%), stretch (79%), socialize (72%) and eat lunch (67%) in natural surroundings were most appreciated, as well as the opportunity to see local wildlife (61%).

For neighbors of the business sites, Jókövi et al. (2002) found that the availability of the business site green for recreational use was highly valued (85%), as well as the contribution of the business site green to the overall green in the neighborhood (95%). The opportunity to use the business site green to walk or cycle (92%), walk the dog (62%), play with children (36%) and enjoy local wildlife (59%) was most appreciated. Disturbing aspects associated with recreational use of business sites were views of business buildings (22%) and the fact that neighbors' recreational activities could be observed by business site employees (19%).

Ranking of scenarios for each stakeholder: Standardization
The effect scores were standardized using the interval method (cf. Janssen 1992). In the interval method the scores are normalized with a linear function between absolute lowest score and the highest score. In a benefit effect the absolute highest score is indicated with a 1, and the absolute lowest with a 0. For a cost effect it is the other way round. This linear method was well suited for the qualitative scores (all non-monetary scores). For the quantitative effects (monetary scores), various standardization methods were explored (interval, concave, convex). As no large differences were found, the interval method was used for the quantitative scores as well.

Weight sets
To gain insight into the stakeholders' opinions on each of the scenarios, the preferences derived from interviews and literature were used (listed in fig. 2 in the results section of this paper). These preferences were expressed on a quantitative scale (using the 'direct assessment method', Janssen 1992). This method not only enabled in ranking of the various effects (as in the 'regime method'), but also in quantifying the relative importance of each effect for each stakeholder.

Ranking of scenarios
Janssen (2001) provided an overview of MCA-studies in which different methodologies to calculate effects and to deal with preferences in ranking alternatives (e.g. Weighted summation, Regime Method, Evamix Method) were used. In this paper a ranking of the various scenarios was generated by using the weighted summation method. This method first multiplies each standardized effect score by its appropriate weight, followed by a summation of the weighted scores for all effects (Janssen 1992).

Uncertainty analysis
The extent to which the ranking of scenarios may be considered as robust, was explored in an uncertainty analysis. In the MCA-analysis it already appeared that for all stakeholders the ranking was similar, with some differences in the order of numbers 1 and 2 and the numbers 5 and 6. As preference weights used in an MCA can greatly affect the results (Strager and Rosenberger 2006), we added some uncertainty in the weight scores and effect scores. Results from Monte Carlo Analysis show that the ranking remains the same for most runs and differs for a limited number of runs. Since the analysis was run using a large range for both weights and scores it can be concluded that the rankings are quite robust.

Results

Scenarios illustrating how biodiversity can be enhanced at business sites
Based on the principles formulated in section 2.1 six scenarios for business sites were constructed: the traditional scenario, the green roof scenario, the eco-green scenario, the dynamic habitat scenario, the stepping stone scenario and the eco-corridor scenario (fig. 1).

Traditional scenario
The 'traditional' scenario reflects the current situation of most SME business sites in the Netherlands. A main road throughout the site provides access to all business parcels (n=28). Each parcel contains a flat-roof building (e.g. a construction hall), some parking and store space and a minimum of urban green. More details on the traditional scenario are described in Appendix A.

Green roof scenario
In the 'green roof' scenario, the flat roofs of all buildings are designed and managed as green roofs. Other features of the scenario are similar to the traditional scenario.

Eco-green scenario
In the 'eco-green' scenario all ground-level green area is maximized for biodiversity purposes: lawns are replaced by flower-rich grasslands, and native and species-valued plant groups are used for shrub and trees. The total surface and configuration of urban green are similar to that in the traditional scenario.

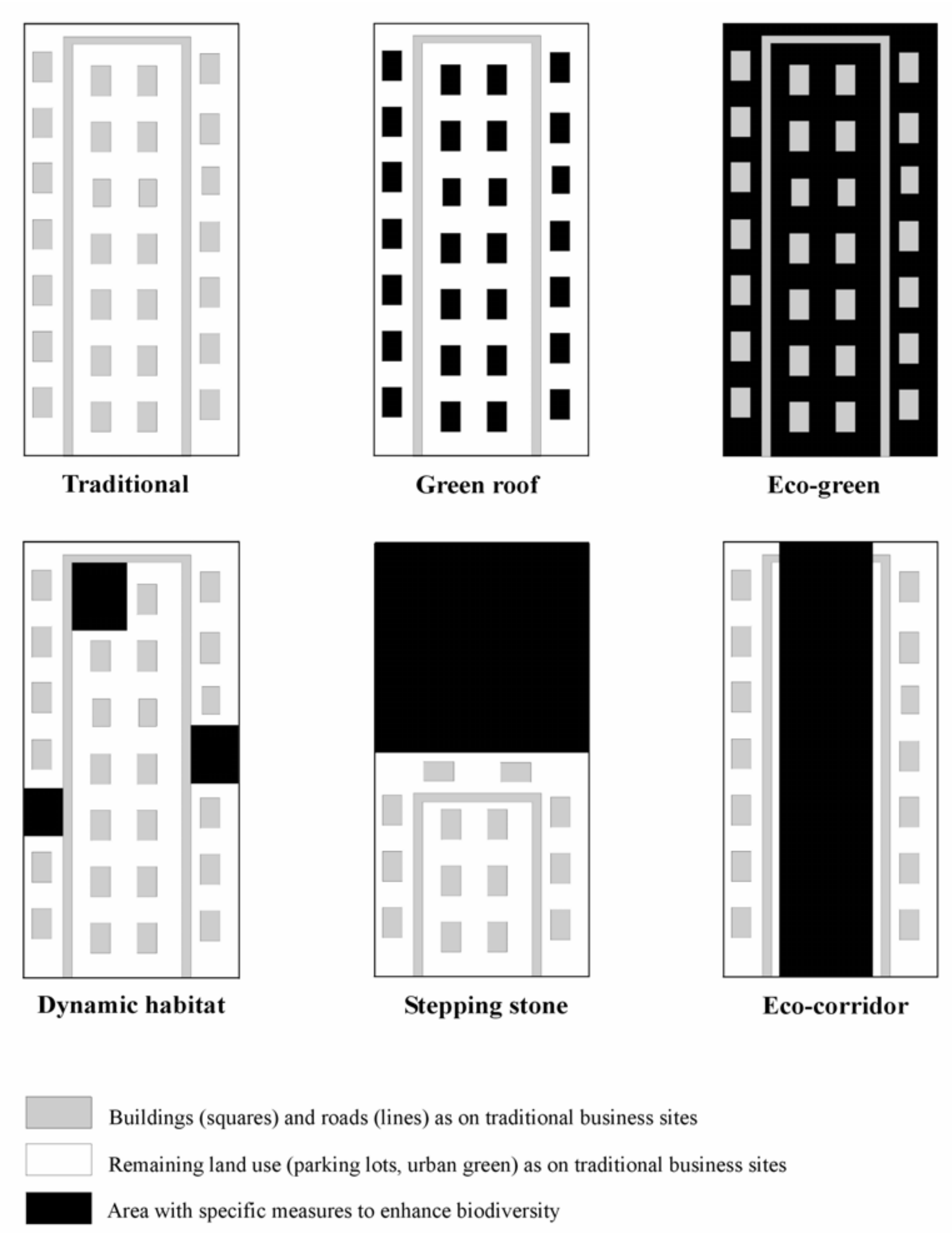

Figure 1. *Differences in design between the business site scenarios used in this study regarding their contribution to enhance biodiversity. The scenario 'Traditional' represents a conventional business site, each other scenario illustrates a single principle for biodiversity conservation (location of conservation measures emphasized by a darker color). The plan of each scenario consists of a main road with adjacent business lots. All features of the site (e.g. types of businesses, size of site, accessibility to road traffic) are kept similar among all scenarios.*

Dynamic habitat scenario
Our 'dynamic habitat' scenario contains three parcels of derelict land in the form of vacant lots between buildings. Other features of this scenario resemble the traditional scenario.

Stepping stone scenario
The 'stepping stone' scenario features a green area measuring 50% within the business site, managed as biodiversity and open to the public. This means that the remaining land can accommodate only 14 business parcels. Other features of this scenario are similar to those in the traditional scenario.

Eco-corridor scenario
In the 'eco-corridor' scenario, an ecological corridor bisects the business site, so as to fully utilize the potential of peri-urban business sites to link urban and rural biodiversity. Company buildings are situated along a main road with the ecological corridor located in-between the rows of buildings. Where the main road crosses the corridor zone, fauna passages are constructed to mitigate the road's barrier and mortality effects on ground-dwelling animals.

Socioeconomic and environmental criteria
This paper proposes that the 13 criteria listed in table 1 are adequate for comparing the six scenarios regarding opportunities to enhance biodiversity at business sites.

Effect-table: overview of effect scores for business site scenarios
Effect scores for the socioeconomic and environmental aspects of the business site scenarios were calculated (criteria A1-A5) and assigned (criteria B-M) (details in Appendix B). Table 2, the 'effects table', provides an overview of these scores. For the 'eco-green' scenario maintenance costs are lower than in the traditional situation, resulting in a 'minus' figure (-€ 1.545.000 euro). In general, the scenarios with large amounts of extra green (the 'stepping stone' and 'eco-corridor' scenarios) result in high social and environmental scores, but also high costs (€29.126.000 and €19.426.000, respectively).

Stakeholders and their preferences regarding biodiversity at business sites
Based on interviews with local governmental officials, companies and environmental NGOs and literature by Kaplan (2007) and Jókövi et al. (2002), an overview of the preferences of each stakeholder group was created (fig. 2). This provided a basis for weighted rankings of the scenarios.

Table 1. *Criteria for evaluating socioeconomic and environmental impacts that arise from implementing measures to enhance biodiversity in business site design and management.*

	Economic indicators	
A	total direct cost and benefit	total of A1–A5.
	(A1) investments in ecological design	– expenses incurred for extra design measures like green roofs
	(A2) biodiversity maintenance costs	– extra costs or savings derived from more ecological management of green
	(A3) lost revenue from land sales	– lost earnings because a lower number of parcels can be sold, as more space is devoted to urban green (leaving less room for firms)
	(A4) added revenue from land sales	– additional market value of business parcels in a green environment (as they have higher status and command a premium price)
	(A5) savings derived from energy conservation	– fuel or electricity expenses saved by using green design (e.g. green roof)
B	estate value stability	long-term benefit for owner of business site because green design prolongs the site's lifespan
C	employment	additional value provided by the site as it is a more attractive place to work
	Social indicators	
D	health and well-being	contribution of 'green' environment to workers' health and feelings of well-being
E	appearance	impacts on the appearance of the site to visitors and neighbors
F	environmental awareness	contribution of green design to raising employees' environmental awareness
G	environmental status of company	contribution of a firm's establishing at a 'green' business site to its 'environmental image'
H	recreation opportunities	opportunities created for recreation (for employees and the public)
I	tidiness	extent to which the business site is perceived as tidy
	Environmental indicators	
J	biodiversity quality	quality of business site to act as local habitat for plant and animal species
K	regional ecological function	extent to which measures to enhance biodiversity at the business site contribute to regional ecological networks
L	storm water retention	extent to which measures to enhance biodiversity reduce storm water peaks at the site
M	air quality	extent to which measures to enhance biodiversity at the business site reduce air pollution at the site

***Table 2**. Effects table: Scores per socioeconomic and environmental indicator for each business site scenario. Details on calculations are given in Appendix B. All scores are non-monetary, apart from the direct costs and savings (A1–A5). These costs are displayed in units of 1000 euros.*

	Indicators	Cost / Benefit	Unit	Traditional	Green Roof	Eco-Green	Dynamic Habitat	Stepping Stone	Eco-Corridor
	Economic								
A1	* investments in green design	*C*	*1000 euro*	*0*	*8370*	*0*	*0*	*26*	*26*
A2	* maintenance costs green (NPV)	*C*	*1000 euro*	*0*	*45*	*-1545*	*0*	*0*	*0*
A3	* lost sale revenues	*C*	*1000 euro*	*0*	*0*	*0*	*0*	*38,800*	*38,800*
A4	* added sale revenues of parcels	*B*	*1000 euro*	*0*	*0*	*0*	*0*	*9,700*	*19,400*
A5	* savings from energy conservation (NPV)	*B*	*1000 euro*	*0*	*3656*	*0*	*0*	*0*	*0*
A	total direct costs and savings	C	1000 euro	0	4,760	-1,545	0	29,126	19,426
B	estate value stability		0 / +++++	0	+	0	0	+++	+++++
C	employment		- - - - - / 0	0	0	0	0	- - - - -	- - - - -
	Social								
D	health and well-being		0 / +++++	0	+	0	0	+++	+++++
E	external appearance		0 / +++++	0	+	0	0	+++++	++
F	environmental awareness		0 / +++++	0	+	+	+	+++	+++++
G	environmental status		0 / +++++	0	++++	+	++	+++++	+++++
H	recreation opportunities		0 / +++++	0	0	0	+	+++++	++
I	tidiness		- - - - - / 0	0	-	- - - - -	- -	0	- - -
	Environmental								
J	biodiversity quality		0 / +++++	0	+++	++	+++	+++++	++++
K	regional ecological function		0 / +++++	0	++	+	++	++++	+++++
L	storm water retention		0 / +++++	0	++	0	0	+++++	+++++
M	air quality		0 / +++++	0	++	0	0	+++	+++++

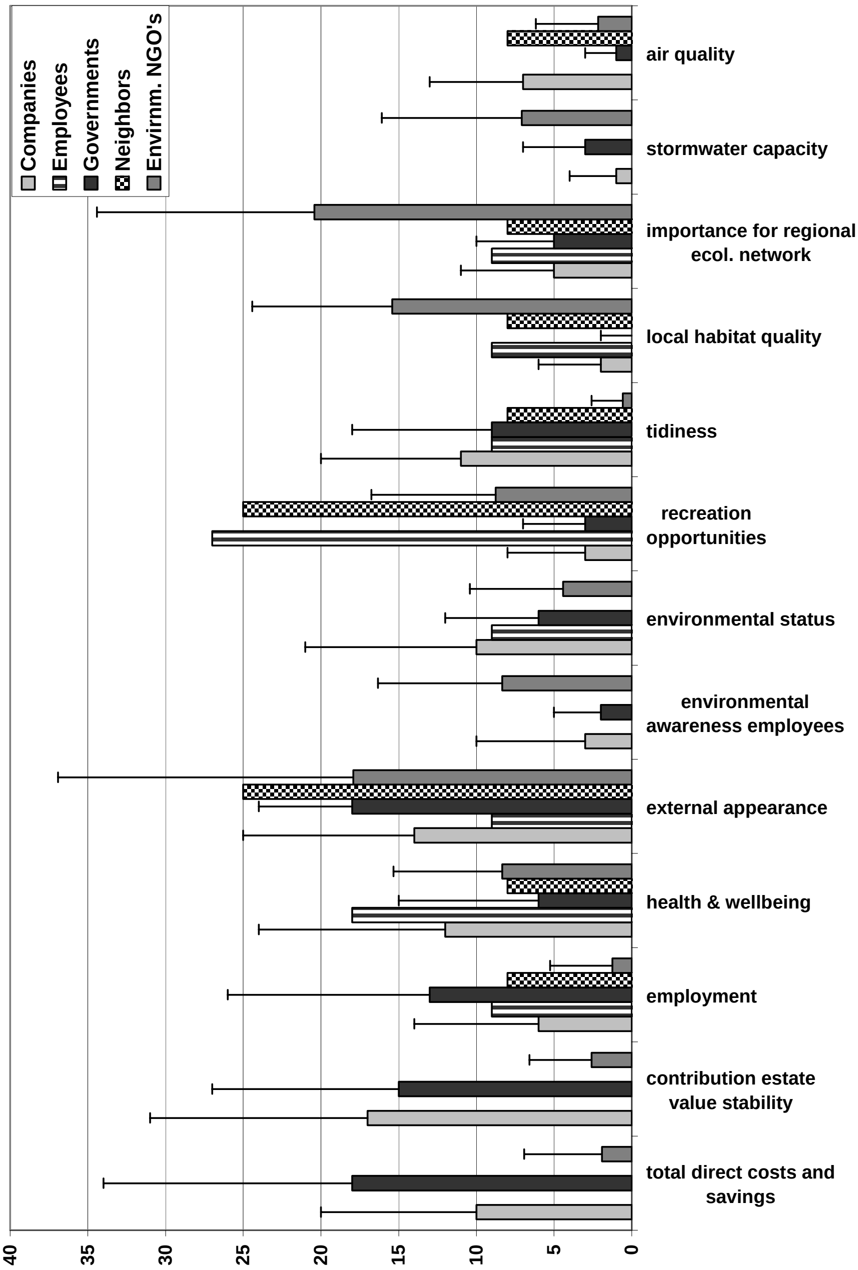

Figure 2. *Preferences of each stakeholder for all socio-economic and environmental criteria (x-axis) regarding biodiversity conservation at business sites. On the y-axis the preference is indicated in percentage, with the total of all preferences per stakeholder being 100%. As data was collected on the preferences of companies (n=10), local governments (n=11) and environmental NGO's (n=12) via questionnaires, the graph shows the standard deviation for those bars.*

As figure 2 shows, some criteria are preferred by only one or two stakeholder groups, whereas others are preferred by more stakeholders. A remarkable outcome is that financial aspects (direct costs and benefits and contribution to estate value stability) figure less prominently than expected for companies (10% and 17%, respectively) and for economic departments of local governments (18% and 15%, respectively). On the other hand, 'external appearance of the business site' is most important for all stakeholders (17% on average), including companies and local governments. Also 'health and well-being', 'recreation opportunities' and 'importance for regional ecological networks' were among the aspects valued most highly (9–13% on average). In addition, the fact that measures to enhance biodiversity at business sites may also increase the 'environmental awareness of employees' and 'storm water retention capacity on the business site' were – on average – the least valued aspects (2–3% on average). Overall, standard deviation shows that for every criterion there is a large range in the preferences assigned by the individual representatives of the companies, local governments and environmental NGOs.

Ranking of scenarios in terms of preferences of stakeholders

Figure 3 shows the ranking of the scenarios based on weighted summation. The 'stepping stone' and 'eco-corridor' scenarios were clearly favorite among all stakeholders (fig. 3). These scenarios, with their large tracts of urban green, featured most of the preferences indicated by all parties. 'Green roof' was third in the overall ranking, because it has a large green area (viewed as positive) which however is not accessible for recreation (which would be preferable to employees and neighbors). In addition, the environmental and long-term economical benefits of green roofs led to a relatively high ranking by local governments. The 'traditional' and 'eco-green' scenarios are ranked last by all, but local governments (and to a lesser extent, companies) are more partial to them than employees, neighbors and environmental NGOs. This seems consistent with current business site practices. Of all stakeholders, environmental NGOs (a single-topic stakeholder) were most outspoken, whereas local governments were least outspoken (a multi-topic stakeholder).

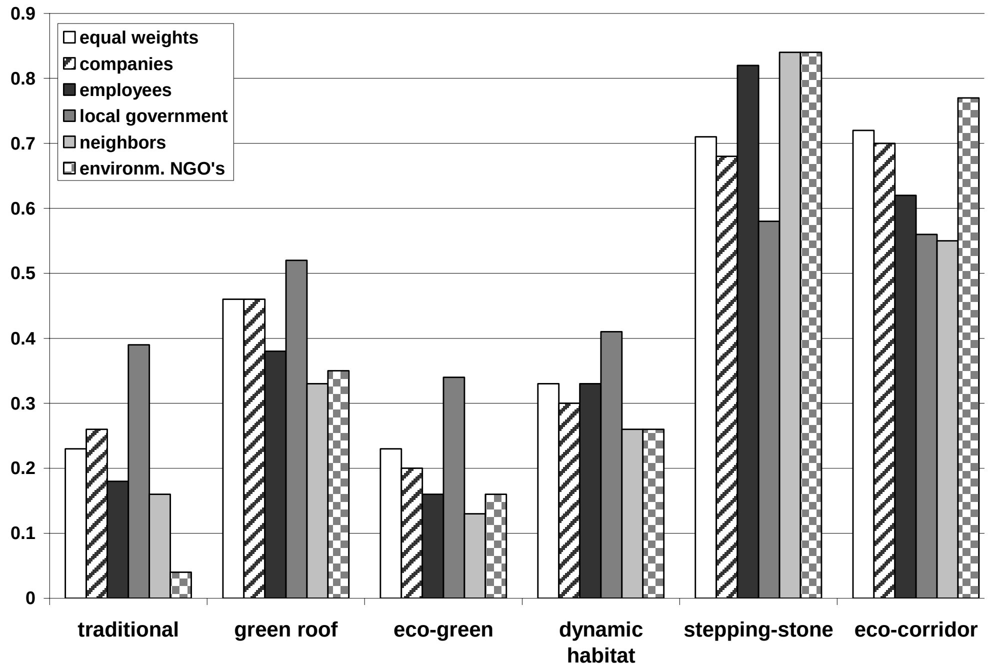

Figure 3. *Result of the ranking (using weighted summation) of business site scenarios (x-axis) that may enhance biodiversity, given for all stakeholder groups. On the y-axis the outcome of the weighted summation is provided. The white bar (left) at each scenario shows values calculated with equal weights, illustrating the situation in which every indicator is equally important.*

Discussion

Conclusion

The aim of this study was to illustrate how a multi-criteria analysis (MCA) framework for sustainable business sites might be used to analyze how biodiversity can be enhanced at a business site. With the MCA framework developed here various measures for biodiversity conservation at business site (elaborated in different scenarios) were assessed for a range of socio-economic and environmental criteria. The scenarios were then ranked based on stakeholders' preferences for the criteria. This ranking appeared rather robust, as 100% uncertainty analyses with effect and weight scores gave no differences in original ranking order. Scenarios in which a large amount of urban green was included in the design appeared to be favourite among all stakeholders (employees, neighbours and environmental NGOs and remarkably also companies and local governments). Furthermore, our results suggest that implementing measures to enhance biodiversity may be acceptable only if combined with other green functions (predominately 'recreation' and 'health and well-being') and if suited to the functional appearance of the business site environment ('external appearance' and 'tidiness'). The study broadens the current concept of sustainable business site development by focusing on strategies to enhance biodiversity and landscape values at business sites.

MCA as a decision-support tool

MCA appeared in this study to be a valuable tool for comparing the various design and management scenarios. The MCA research method provided a structured and consistent procedure to define criteria, scenarios, stakeholder groups and weights.

With regard to the effect scores of the criteria used in this paper, qualitative evaluations are as a rule predominant in multi-criteria analyses of socioeconomic and physical planning problems (Nijkamp et al. 1990). The qualitative effect scores described in this paper were estimations based on expert knowledge and best practices. Though these estimations are well-considered (Appendix B), other experts may assign different effect scores. The effects table in this paper can therefore be interpreted as providing an overview of effects on a rough scale (yet suitable for comparing scenarios) rather than as precise figures pinpointing the extent of each effect in each scenario.

Defining a solid set of weights proved more troublesome than expected. Entrepreneurs were an especially difficult group to gain cooperation (they were often reluctant to answer inquiries). Indeed, it was understood why others (e.g. Okamoto 2007) use models instead of questionnaires to obtain preferences for such groups. As usual, concerning the answers of those respondents (as for all selected stakeholders) who did cooperate, some 'socially acceptable' answers may have been provided; and some may not have completely understood the questions, despite the provided explanations. Furthermore, persons with some affinity with the green business site theme were probably more willing to cooperate (as also suggested by Kaplan 2007).

With an uncertainty analysis the impact of such side-effects on the outcome of the analysis was explored. Although the 100% uncertainty for both effect and weight scores resulted in no shifts in the ranking of scenarios, this paper nonetheless recommends further research including a much larger sample of respondents for all stakeholder groups.

Implications for business site policy

This study was conducted in the Netherlands, a highly urbanized and densely populated country. In such a context, more green space at business sites would often lead to improvements in the overall liveability of the sites, as green space supports many socioeconomic and environmental functions, including offering wildlife habitat (Burgess et al. 1988). Especially in metropolitan regions with a shortage of urban green this argument of liveability improvements could justify extra investments in green space at business sites.

In general, urbanization means sacrificing rural (open) land for urban development (McKinney 2000). Because open land is scarce in metropolitan areas, many people view new developments as threats to local and regional landscape values (e.g. Theobald, 2001). In this study, scenarios that mix business and green functions emerged as favourites. Yet allowing space for extra green enlarges the business site area, thus, one might conclude, leading to the development of larger business sites and consuming even more valuable open space. However, opportunities to enhance biodiversity at business sites were explored for just a small set of extreme scenarios. There are alternative design options to explore, such as multilevel corporate buildings and underground parking lots, that may be able to accommodate conventional company densities at sites while also including large areas for urban green.

Although each stakeholder group in this study came up with its own set of preferences, 'external appearance of the business site' seems to be a favourite for all, presumably for different reasons. Regardless of the specific arguments each stakeholder brings, the preference for a green external appearance of the business site is in sharp contrast with the current state of business sites in the Netherlands and elsewhere. In reality, most such sites these days can be characterized as 'urban, with high amounts of paved area' (e.g. Blair 2001) and 'with little attention for architectural and landscape quality' (De Vreeze 2005). This gap between stated preferences and current reality is perhaps explained by the fact that for decades local governments competed with one another to provide the most attractive municipality for firms to settle (Louw 2000). This resulted in a lowest price strategy that paid little attention to urban green (considered as it was as merely an extra cost). Nonetheless a rising demand for green business sites in the Netherlands is expected in the future, as decision-making concerning business sites is set to become more a regional matter than a local one. Furthermore, the increasing primacy given to sustainability, conservation of remaining landscape values and quality of the working environment will also encourage the choice for green business sites.

An interesting question is how the findings of this study could be implemented in business site policy and practice. First, to take advantage of the opportunities that business sites offer to strengthen biodiversity, more attention to green values is required early on, in the design and development phase (Niemelä 1999a). This is when measures to create wildlife habitat can be included in an overall layout of a site and in building and urban green design. In some cases, legal regulations may support such a proactive stance. In addition, allowances for temporary biodiversity (on derelict lands or on lands cleared for building) is another way to optimally use the potential that business sites offer to enhance biodiversity. Pioneer situations on these lands provide – albeit temporarily – habitat for specific plants and animals, often including endangered species. Practical experiences of the Wildlife Habitat Council (Cardskadden and Lober, 1998) illustrate how such ecologically-minded measures can be implemented on a large scale at business sites. For the average SME business site, there are unfortunately few practical examples as yet.

For existing business sites in need of renovation, the greening of flat roofs has a huge potential. For example, Dutch business sites (3,600 sites on a total of 97,300 ha; Arcadis and STEC Group 2007) contain 5–25% (depending on the state of development) of flat roof surface area in the Netherlands. Besides, as many Dutch (mainly suburban) business sites are located adjacent to ecological corridors or areas of importance for biodiversity conservation, measures to enhance biodiversity at business sites may add value to existing ecological networks. Further research, however, should explore under what real-life conditions this added-value can be achieved. Overall, the application of the design and management principles (integrated in business site renovation and development projects) as presented in this paper seems to harbour the potential to strengthen (local) biodiversity at many locations.

Recommendations for further research

This paper described an initial exploration of the opportunities that business sites offer to enhance biodiversity. A range of scenarios were explored, including a few extreme situations. As the study leaves many questions open, especially concerning feasibility and practicability of its findings, further research into the most promising scenarios is recommended. These could be detailed further with different types and configurations of buildings, infrastructure and urban green, to learn which fit best in current spatial plans. Additional empirical studies would also be welcome, to better quantify the defined socioeconomic and environmental effects and the stakeholders' preferences. Besides, studies in which the impact of enhancing biodiversity at business sites is assessed at higher scale levels (beyond the local), could provide answers to the question of whether merging green functions into business sites is in fact an effective way to achieve more sustainability in a specific region.

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Appendix A Setting the business site scenarios

Business site development is a practice in which various public and private parties participate, often in different roles. In our study the situation in which a local government aims to develop a new business site and private development companies bring about this ambition was taken as a starting point. Such a situation is common in the Netherlands. Concerning the type, size and location of our scenario, we chose a mixed-use business site (aimed for SMEs) with a size of 100 ha, located at the city-edge near a highway entree. Suburban business sites with mixed use are by far the most common business sites in the Netherlands (IBIS 2007) and in other countries (e.g. Blair 2001). Despite the reality that these sites average about 20–25 ha, our business site scenarios had a much larger size (100 ha), as we wanted to include sufficient area for nature-oriented measures.

Based on land-use data from 50 mixed-use business sites (gross size 50–150 ha) in the Dutch province of Noord-Brabant (Etin Consultancy), we came to a gross/net rate of 77.6%. This meant that for traditional business sites, 77.6 ha of site lots can be distributed throughout a 100 ha site. The other 22.4 ha are designated for access and internal streets, fences, lighting and landscaping of public spaces (described by Frej et al. 2001). Based on the Noord-Brabant data, we calculated the average business lot size as 27,714 m2. This meant room for 28 firms at traditional business sites of 100 ha. Each lot within the model business site then contained 69,285 m2 building and 12,471 m2 parking and storage space, with the remaining 8,314 m2 for utilities, fences and landscaping (based on detailed land-use data of 30 mixed-use business sites in the Netherlands).

The lifespan of business sites is variable, and dependant on different factors such as spatial quality. In our study we chose a lifespan of 25 years, appropriate for a more sustainable business site. Concerning the financial aspects, revenues from sales of vacant lots come to €100 per square meter on average (Van Aalst 2004), based on the setting in the Netherlands. For our characteristic business site of 100 ha, this would mean €77.6 million in total, using the calculated gross/net rate of 77.6%.

Appendix B Assignment of effect scores to the business site scenarios

Indicators were described only if they were not self-evident. Where indicator values were similar to the scenario ´traditional´, no explanation is given.

´Traditional´ scenario
The values of all indicators are set to zero for this scenario, as we wanted to compare alternative business site designs with this scenario, which represents current common practice.

´Green roof´ scenario
The extra investment costs for constructing extensive green roofs instead of conventional roofs (bitumen) are estimated at €450,000 per ha green roof (Porsche and Kohler 2003). This means 19.4 ha roof x €450,000 = €8,730,000 for the total scenario.

The maintenance costs are calculated for annual optical inspection and removal of tree seedlings, estimated at €100 euro per visit per roof (Porsche and Kohler 2003). This means 28 roofs x €100 x 25 years = €45,492 for the total scenario (calculated with a discount rate of 4%).

Energy costs for buildings with green roofs are lower than for buildings with conventional roofs, as the vegetation has a better isolation function. Savings in fuel heating costs have been estimated at 20,000 liters of fuel oil/ha/year for a typical green roof in Germany (Zinco 2000 in Grant et al. 2003). With a price of a liter oil at €0.58 (January 2007), this means €11,600 x 19.4 ha x 25 years, being €3,656,217 for the total scenario (calculated with a discount rate of 4%).

Concerning the health and well-being of those living and working in or near the business site, green roofs may bring back a part of the lost nature to the citizens (who are isolated from rural nature) without requiring more space. We assigned the green roofs a ´+´ compared to conventional roofs (based on Porsche and Kohler 2003).
Concerning environmental awareness, we assigned green roofs a ´+´ as we assume they will contribute to a better environmental awareness in a passive way, however to small extent only because they are less visible than other nature measures.

Using green roofs on a large scale provides opportunities for actively participating in nature conservation, as a firm or total business site (e.g. the green roof of the Ford Motor factory in Michigan is monitored by the Wildlife Habitat Council). We assigned the green roof scenario a ´++´ for its opportunity to increase the environmental status of the firm.

Green roofs provide opportunities for many plant species and flying animals (Grant et al. 2003). We assigned the green roof scenario a ´++´ for its contribution to the quality of the business site as local habitat for plant and animal species.

Depending on the landscape context and the species present, green roofs at business sites could function as a permanent habitat patch (Grant et al. 2003) or as part of a connecting ecological structure within a regional habitat matrix. As most green roofs are inaccessible for ground-dwelling animals (for whom dispersal in urban areas is most difficult), we assigned the green roof scenario a ´+´ for its contribution to regional ecological networks.

A green roof reduces the amount of energy available for heating, which decreases the tendency towards thermal air movement and also filters air moving across it (Peck et al. 1999). Thus the air quality of the business site will increase. We assigned green roofs a ´+´ compared to conventional roofs.

Green roofs will reduce 50% of the runoff caused by precipitation on roofs (Porsche and Kohler 2003). The need for storm water retention is therefore lower than with the use of conventional roofs at traditional business sites, although other impervious surfaces (infrastructure, parking and storage) still exist. We assigned a ´+´ to this scenario for storm water retention.

'Eco-green' scenario

Costs for urban green maintenance vary, depending on country and type of urban green. For this study we used figures based on Dutch practice in 40 municipalities: intensively managed lawn = €7,300 ha/yr; natural grassland €3,100 ha/yr; intensively managed shrub €24,700 ha/yr; natural shrub €6,100 ha/yr; park forest €1,400 ha/yr; natural forest €2,000 ha/yr (De Jong et al. 2006). As an average business site contains 17% grassland, 1.5% shrub and 7% forest, we calculated the costs if the intensively managed urban green was replaced by more natural urban green. This meant a reduction compared with a traditional business site of €1,520,815 for a period of 25 years for the total scenario (including a discount rate of 4%).

If communicated properly the eco-management of the urban green at the business site will increase the environmental awareness of those who visit the business site. We assigned a ´++´ to this scenario for its contribution to a better environmental awareness.

Managing the urban green in an eco-friendly manner provides moderate opportunities to actively participate in nature conservation, as a firm or total business site. We assigned the eco-green scenario a ´+´ for its opportunity to increase the environmental status of the firm.

Eco-friendly management of urban green, with many native tree and shrub species and diverse grasslands, provide opportunities for plant species and flying animal species. We assigned the eco-green scenario a ´+´ for its contribution to the quality of the business site as local habitat for plant and animal species.

Depending on the landscape context and the species present, eco-friendly native green at business sites could function as a permanent habitat patch or as part of a connecting ecological structure within a regional habitat matrix. As the degree of fragmentation of urban green (though it may be eco-friendly managed) in this scenario is still high, we assigned the eco-green scenario a ´+´ for its contribution to regional ecological networks.

'Dynamic habitat' scenario

For the design and management of vacant lots, no extra costs are calculated, as we consider the establishment and succession of pioneer vegetation at these lots to be a natural process. As this situation is only temporary (for the time that no construction is being developed) we set the contribution to the estate value to zero. Employment is similar to the 'traditional' scenario, as no land is specifically reserved for enhancing biodiversity (instead of corporate activities).

If communicated properly, temporary vacant lots at the business site may contribute to the recreation opportunities and the environmental awareness of those who visit the site. As the effect of vacant lots is restricted to specific terrains within the site and the availability changes over time, we assign a ´+´ to both criteria.

Business sites may use their vacant lots for participation in nature conservation programs (e.g. those of the Wildlife Habitat Council). We assigned the business site in this scenario a ´+´, as its contribution is temporary and small in scale, so its opportunity to increase the environmental status of firms is small too.

Because the lack of management at the vacant lots, this scenario was assigned the lowest score for tidiness.

The pioneer habitats that appear if vacant lots are left untended, offer high potential for a range of endangered plant and animal species. Most of those species have medium to high dispersal qualities, making the vacant lots at the business site valuable for local and regional nature conservation goals. We therefore assigned a ´++´ to this scenario for quality as local habitat and potential contribution to regional ecological networks.

'Stepping stone' scenario

In the scenario we chose a natural area (50 ha) within the business site (100 ha), to act as a 'stepping stone' within a regional ecological network. This area was designed with full attention for landscape values, and included 5 ha of linear wooded banks, 5 natural ponds, 10 ha of young natural forest and 35 ha of small extensive grasslands. Investment costs are €500,000 for wooded banks, €15,000 for ponds and €1,3160 for forest. The Dutch Ministry of Agriculture, Nature and Fisheries (LNV) provides subsidies for the development and management of natural landscape elements and forests. This brought the investments costs to 5%, being €25,000, €750 and €658, respectively, in total €26,408.

We aimed for maintenance of the wooded banks and forest by volunteers, being employees of the firms established at the business site. The extensive grasslands and ponds require additional maintenance done by professionals, bringing the maintenance costs to €1,000 ha/year for extensive grassland and €100 per pond per year. This adds up to €525,000 for 35 ha of extensive grassland and €7,500 for the ponds, both for a period of 25 years. With current nature conservation subsidies these maintenance costs are 100% compensated, bringing the maintenance costs to zero.

In the 'traditional' scenario there are 28 parcels x €100/m2 x 27,714 m2 per parcel = €77,599,200 as sales revenue. As the 'stepping stone' scenario has only 14 instead of 28 parcels, a sum of €38,799,600 is calculated for lost sales revenue. However, as the remaining parcels are located in a much greener environment, we calculated a higher price (€125 instead of €100 per square meter). This added sale revenues (a benefit) of €9,699,900 extra.

The total of direct costs and benefits is the sum of the costs (€26,408 for investments, €38,799,600 for lost sales revenue) minus the benefits (€9,699,900 for added sales revenue), meaning a total cost of €29,126,208.

For the contribution to the estate value of the business site we assigned the 'stepping stone' scenario '+++', because the green area at the site may extend the quality of the business site over a much longer period than at traditional business sites. Employment was assigned a '- - - - -', as there will be space for only 14 instead of 28 companies.

For health and well-being, this scenario was assigned '+++', as the direct environment of the corporate buildings is much greener than in traditional cases. Half of the business site is a green area, so the external appearance is optimal and assigned a '+++++'. As the green 'stepping stone' areas provide plenty of opportunities for companies to contribute to enhancing biodiversity, we assigned their environmental status as '+++++'. However, since the green area is adjacent to the corporate parcels (and not mixed in-between) we expect the impact on the average employee concerning their environmental awareness to be much lower ('+++'). The stepping stone area offers as a large green area the most opportunities for recreation ('+++++'). The stepping stone area is next to the corporate part of the business site, so the impact on tidiness was zero.

Large habitat patches in urbanized areas offer good opportunities for local biodiversity (Clergeau et al., 2006), thus we assigned local habitat quality a '+++++'. The patches' function on a regional level is sub-optimal ('++++'), as the green area has no connectivity function. Storm water retention may be easy to construct in the stepping stone area ('+++++'), whereas for optimal air quality, the green is not ideally configured ('+++') .

‘Eco-corridor’ scenario

Most costs were calculated similar to the ‘stepping stone’ scenario, as the size of the urban green is similar. The one exception is the added sales revenue from the 14 additional parcels. We calculated €150 instead of €125, as the urban green was much better distributed over the site than in the stepping stone scenario. This means that the total costs came to €19,426,308.

As the urban green of the eco-corridor was well distributed throughout the site, the contribution to the estate value, health and well-being, environmental awareness, storm water capacity and air quality was optimal (‘+++++’). Employment was half that in the traditional scenario, being ‘- - - - -’, similar to the stepping stone scenario. External appearance was assigned a ‘++’, as only a part of the perimeter of the business site is green in this scenario.

Opportunities to contribute to the enhancement of biodiversity were similar to the stepping stone scenario, yielding a similar score for the environmental status. Recreation opportunities were fewer (‘++’) than in the stepping stone scenario, as the linear configuration of the urban green provided less opportunities for employees and neighbors to be away from the built environment.

As the urban green was configured at the rear of the corporate buildings, the impact on the tidiness (‘- - -’) was lower than in the ‘eco-green’ scenario.

The linear structure of the urban green caused on the one hand a sub-optimal (‘++++’) local habitat quality (negative impact of higher edge-effect), but on the other hand an optimal (‘+++++’) contribution to regional ecological networks.

Discussion and Conclusions

7 Discussion and Conclusions

Business sites are typically located at the city-edge, at the halfway point in the urban-rural gradient (McDonnell and Pickett 1990). Their designers, however, have seldom attempted to incorporate business sites into the urban landscape, nor have business sites been considered a potential part of the rural landscape. This thesis explored how by altering their design business sites can provide ecosystem services to both the urban and the rural landscape, thereby contributing to a more sustainable world (e.g. Anderson 2006). I have focused on 'supporting biodiversity' (one of the ecosystem services) and considered 'options and opportunities for biodiversity conservation at business sites'. In so doing, I addressed the potential contributions of these options and opportunities to the biodiversity in urban and rural habitats (chapters 2-6), and, in addition, to the quality of conditions for work (chapters 3 and 6) and to the quality of city life (chapters 4 and 6) (Fig. 7.1).

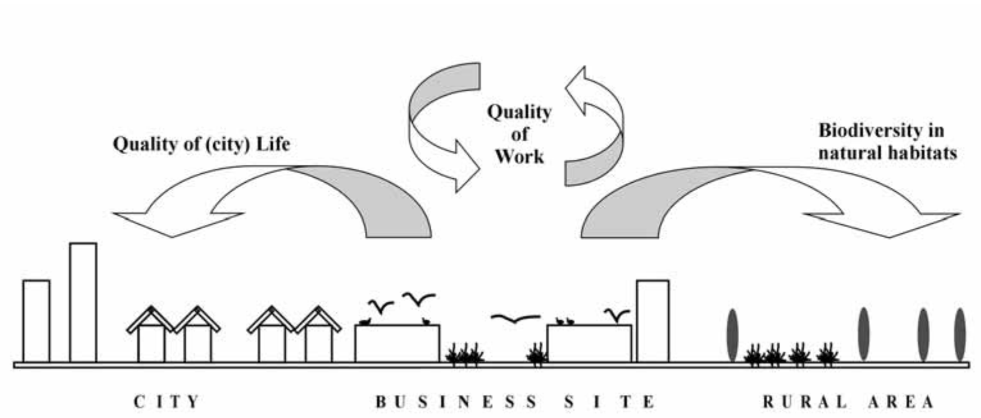

Figure 1 *Illustration of how biodiversity conservation measures taken at business sites may contribute to the biodiversity in urban and rural habitats, the quality of city life and the quality of conditions for work.*

Answering the research questions

Research question 1

How can the biodiversity of current business sites be characterized compared to other urban land use types? This question aimed to obtain insights into the current state of affairs concerning the biodiversity occurring at business sites, using breeding bird populations as representative of biodiversity. We formulated several hypotheses related to the preference of specific bird guilds for business sites. Dutch bird census data for business sites was compared with data from residential areas and urban green spaces. In general, a significantly lower abundance and species richness of breeding birds was found at the business sites, as observed at survey plots in the Netherlands. However, the bird guild level presented a more nuanced picture. Business sites seemed especially preferred by birds associated with early successional vegetation and open landscapes. Especially for coastal species and the Common Linnet (*Cardualis cannabina)*, a Red List species, business sites appear to be favourite urban habitats.

This explorative study demonstrated that breeding bird assemblages at business sites differ distinctly from those in residential areas and urban green spaces, specified up to the bird guild level. The study contributes to the existing literature by providing insights into the suitability of existing business sites as places for biodiversity conservation, in particular, for breeding birds, as illustrated by the Dutch situation. As such, it provides an indication of the added value of business site habitat for urban bird communities.

Research question 2

How can endangered species currently occurring at business sites be conserved despite the dynamic and economically oriented land use of these sites? Endangered plant and animal species, often legally protected by (inter)national law, present a conservation task for business site owners. This study developed a strategy combining the dynamics of business site habitat with the stability of protected habitat on public lands, with emphasis on early successional habitat. It showed how with this specific planning and design strategy (the 'habitat backbone') the long-term survival of an endangered species in these areas could be ensured. This strategy is based upon the spatial and temporal dynamics of both the species metapopulation and its habitat pattern in port areas, and includes the creation of permanent habitat strategically located on (semi)public lands with an overall carrying capacity sufficient to support persistent populations. Additional habitat in the port area, on private parcels, will be more temporal in nature but nonetheless increases the overall (meta)population size. The dynamics in this part of the network are stabilized by the habitat backbone. According to Opdam (1991), metapopulations are conceived as spatially structured populations consisting of distinct units (subpopulations), separated by space or barriers, and connected by dispersal movements. Metapopulations characteristically demonstrate turnover, with local populations going extinct and becoming re-established, resulting in a distribution pattern that shifts over time. Thus, the metapopulation concept can be used to design a strategy which links the local population(s) at the business sites with those in the surrounding region. Through such linkages, the risks of local extinctions are spread i) by making use of the opportunities offered by the relative stability of public land to act as refugium, and ii) because public and private land are spatially interconnected, so that from this refugium habitat dispersers can quickly (re)colonize habitats on privately owned lands.

Concerning the institutional aspects, implementing the habitat backbone strategy in the case of the natterjack toad (*Bufo calamita*) in the Port of Antwerp was deemed possible only if landowners, local governments and environmental NGOs cooperate.

Research question 3

Could peri-urban business sites strengthen inner-city nature and thus support citizens' quality of life? Most business sites are found at the city's edge. Here, due to their size and land use, business sites may contain relatively large areas of pioneer and brushwood vegetation, which is scarce elsewhere in cities. This raises the idea that business sites may act as source populations for plant and animal species further towards the central part of cities. This idea was explored with butterflies as species group, and with spatial scenarios based on a practical case. I conclude that peri-urban nature areas (e.g. at business sites), if large enough, can positively influence the presence of butterflies in inner-city neighbourhoods. With a large number of migrating individuals, positively related to the size and management of peri-urban habitat patches, and careful design of the source area and its boundary with the residential area, the impact on the density of residential populations will be relatively large. For butterfly species that are considered good dispersers, some scenarios showed the density of residential butterflies increased by 50% where there was a peri-urban population that acts as source. In the case of the settlement of Hoogvliet, the future situation will contain less urban green space than at present, which means a lower carrying capacity for butterflies. The contribution of peri-urban migrants to small populations of butterflies within the residential area will therefore increase in importance. As they raise the probability that -- despite the reduction in urban green -- citizens will continue to experience butterflies in their living environment. These results also suggest that the connectivity between inner-city and peri-urban habitat patches, via linear corridors such as green road verges, enhances the contribution of peri-urban migrants to inner-city populations. This emphasizes the potential importance of urban green structures in connecting peri-urban and inner-urban network patches for butterflies and similar species.

Research question 4

To what extent could business sites at city margins support populations in the adjacent rural landscape? In this study, conducted in the Netherlands, we selected eight endangered butterfly species inhabiting low-productive, early-successional vegetation, because vacant lots, lawns and green roofs at business sites offer potential habitat for these butterflies. Combining national data on butterfly populations and on business site distribution, we explored the extent to which additional butterfly habitat at business sites could enhance the sustainability of vulnerable butterfly populations nearby. We thereby defined 'butterfly network areas' as contiguous spaces where a species was observed. In addition, we identified priority sites where habitat improvements would be most effective for butterfly conservation. We found 187 butterfly network areas which were situated within dispersal distance of business sites large enough to offer potential habitat for local populations and 87 network areas where adjacent business sites offered potential habitat for 10 local populations, together sufficient for an independent, sustainable metapopulation. A subset of 93 business sites (2.5% of all Dutch sites) fit into this latter category, with in some cases multiple business sites in the vicinity of the same butterfly population. For four butterfly species (*A. agestis*, *H. semele*, *I. lathonia* and *O. faunus*), additional habitat developed at nearby business sites could support a substantial proportion (19–33%) of vulnerable populations on a national scale. In conclusion, although more detailed study is necessary before our findings can be applied in practice, the present study nonetheless suggests considerable potential for business sites to contribute to biodiversity conservation in the surrounding landscape.

Research question 5

What are the design and management options for biodiversity conservation at business sites, and which of these options are preferred by the business site stakeholders? Biodiversity conservation at business sites can be shaped in different ways, each with its own (socio)economic and environmental characteristics. What are the main options for biodiversity conservation in terms of business site design and management? How may stakeholders rank these options, given their preferences for the various characteristics? Does this ranking provide clues for the implementation of biodiversity conservation at business sites? Findings from this thesis illustrate how a multi-criteria analysis (MCA) framework for sustainable business sites might be used to analyse the opportunities for improving the conditions for biodiversity at business sites. First, different options for improving these conditions (green roofs, ecological management of conventional green, supporting early-successional vegetation on vacant parcels, design of ecological corridors and stepping stones) were elaborated in spatial scenarios for business site design and compared to a traditional design (with small amounts of urban green, managed with little attention for biodiversity conservation). Then, the scenarios were assessed for a range of socioeconomic and environmental criteria (e.g. the costs and financial benefits of conservation measures). Finally, using the MCA framework the scenarios were ranked based on stakeholders' preferences among the criteria. This ranking appeared rather robust, as uncertainty analyses with effect and weight scores gave in most cases no differences in the original ranking order. Scenarios in which a large amount of urban green was included in the design appeared to be favourite among all stakeholders -- employees, neighbours and environmental NGOs, but also companies and local governments. Furthermore, the results suggest that implementing measures to enhance biodiversity may be acceptable only if combined with other green functions (predominantly ‘recreation’ and ‘health and well-being’) and if suited to the functional appearance of the business site environment (‘external appearance’ and ‘tidiness’). This study thus broadens the current concept of ‘sustainable business site development’ to include strategies to enhance biodiversity and landscape values at business sites.

Discussion

Biodiversity research at business sites

The papers in this thesis indicate that business sites may contain biodiversity levels beyond those which one would generally expect based on studies like Blair (1996, 1997) and Alberti and Marzluff (2004). In these urban-rural gradient studies, the business site is presented as the land use type where biodiversity levels are lowest. These studies however sampled a very limited number of business sites (<5 in total). Other studies report examples of particular, often endangered, species observed at business sites (Sálek et al. 2004; Schadek 2007; BTO 2008; WHC 2008). These contrasting findings in the literature are likely caused by the fact that ‘business sites’ is a planning term for a very diverse collection of sites that vary widely in design, management and human use, and therefore in habitat conditions. In addition, business sites are urban areas that, probably because of their appearance and difficult accessibility, have hardly been the topic of ecological research, either in academic studies or in inventories done by volunteers. By analysing 16 business site cases distributed over the Netherlands (including one in Belgium), and incorporating data on species density and diversity (of breeding birds and amphibians), this thesis presented a more complete and nuanced picture of current biodiversity levels of business sites than reported earlier in existing literature. In terms of numbers and details on the business sites’ biodiversity, this thesis therefore seems to constitute the most extensive study conducted so far. Nevertheless, many topics are still left unaddressed in this thesis (see the section on further research, below). Besides, the empirical data on the breeding birds at business sites appeared insufficient to conduct regression analyses on bird-habitat relationships. I therefore conclude that this thesis demonstrates that limited data availability on the biodiversity levels at business sites restricts the extent to which explanatory factors (with respect to species abundance and diversity) can be identified.

Apart from studying biodiversity levels at existing business sites, this thesis also explored ideas that go beyond current practice. Especially the idea that business sites may – under certain conditions -- act as a source of biodiversity for the wider neighbourhood, was elaborated in this thesis (chapters 4 and 5). Yang and Lay (2004) mentioned the notion of incorporating ecological ‘stepping stones’ in new business sites in Singapore, but lacked ecologically based argumentation of why and how this would strengthen the surrounding nature. This thesis therefore contributes to the existing literature by exploring (from an ecological viewpoint) for the first time what can be done at business sites to support the biodiversity occurring outside the site.

Contribution to the science of urban ecology

These days the field of urban ecological research is shifting from mono-disciplinary pattern and process studies towards multidisciplinary studies which aim for a total understanding of the urban ecosystem (e.g. Rees 1997; Collins et al. 2000; Grimm 2000; Alberti et al. 2003; Shochat et al. 2006; Wu 2008). Also, there is an increasing call to integrate ecological knowledge in urban planning, design and development (Niemelä 1999b; Miller and Hobbs 2002; Felson and Pickett, 2005; Sandström et al. 2006b). This thesis shows for biodiversity how business sites could contribute significantly to environmental values. Apart from the fact that business sites are urban territories so far hardly touched by ecological science, the thesis also contributes to urban ecology by making use of various approaches, concepts and techniques not regularly applied in this field of science. For example, several studies in this thesis use spatial scenarios to gain insight into the options business sites may offer for (urban) biodiversity conservation (chapters 3, 4 and 6). In general, scenario studies are a popular means to deal with uncertainties in future situations (Peterson et al. 2003). Although quite common in spatial planning, their utilization in urban ecological research is rather unusual, probably because so far most urban ecologists have focused on current instead of future situations (see Olden et al. 2006 for an exception). Chapter 6 presented scenarios to illustrate future options for biodiversity conservation at business sites. These scenarios can be considered 'normative scenarios', because they allowed me, the researcher, to experiment with land cover patterns that are expected to have the selected ecological functions that society values (Nassauer and Corry 2004). Application of the metapopulation theory (Opdam 1991) in this thesis is another example of utilization of concepts not widely applied in urban ecology. The metapopulation concept, though considered useful for populations in urban areas (Niemelä 1999a), has so far hardly been used as a starting point in urban ecological studies (exceptions are Breininger 1999; Crooks et al. 2001). Nevertheless, in this thesis two studies (chapters 3 and 5) were based upon the metapopulation theory. In one case, specific metapopulation norms were used to assess the persistence of natterjack toad populations in the Port of Antwerp (chapter 3), illustrating that the application of the metapopulation concept can be useful in city environments. In conclusion, by this thesis I demonstrate how landscape ecological models are useful as tools in exploring future options and opportunities for biodiversity conservation in urban areas.

This thesis also highlights another hardly addressed topic in urban ecological science: that city landscapes, and business sites in particular, may offer opportunities for temporary habitat patches with early-successional vegetation (chapters 2, 3, 5 and

6). Early successional vegetation is normally found in rural areas at places where disturbances occur, for example, in forests after logging. In general, these kinds of disturbances are decreasing in human-dominated landscapes, resulting in less habitat for a range of species depending on this vegetation. This range includes -- for example -- many (endangered) butterflies, a fact that illustrates the added value of early-successional vegetation for biodiversity conservation (Smallidge and Leopold 1997). Urban areas may offer situations that resemble the specific habitat of these pioneer species. At city margins, early-successional habitats emerge after land is prepared for urban development. Although these urban pioneer habitats are only temporarily available for plants and animals (often for less than 10 years), they may nonetheless contribute to the abundance of pioneer species in urban landscapes.

Although the phenomenon of 'temporarily available early-successional vegetation' is not extensively mentioned in urban ecological science, some studies do recommend integrating temporary habitats in (urban) conservation strategies. Strauss and Biedermann (2006) emphasize the importance of urban brownfields, as these areas often provide habitat for species dwelling in early-successional vegetation. Koivalu and Kotze (2005) recommend including temporary habitat opportunities for carabid beetles in the management of road verges. From this perspective business sites may also function as a focal area for the conservation of (urban) pioneer species, because these economic sites usually contain large parcels of vacant land, present for multiple years. With this thesis I show that – under certain conditions – incorporating these temporary habitats into conservation plans may substantially contribute to achieving conservation goals for those species that occur in and near cities.

The role of business sites in providing ecosystem services

Urban parks support ecosystem services such as public health, recreation and the experience of nature for neighbouring citizens (Chiesura 2004). That business sites provide the added value of supporting ecosystem sustainability is less obvious. Business sites are often located at the city's edge, and thus in close proximity to both urban and rural landscapes. Besides, they have a distinctive character in terms of size and land use. Although they do not normally contain such large amounts of urban green as urban parks, they may because of their characteristics potentially be able to support ecosystem functioning (this thesis). Jókövi et al. (2002) focused on recreation opportunities at business sites in which the companies were located in a green business site environment. They demonstrated using questionnaires that employees and neighbouring citizens appreciate the green appearance of a business site. Their research also confirms the idea that developing vegetation in an urban area may result in providing additional ecosystem services to the area, even in the case of a mono-functional business site. This thesis explored business sites' potential to support biodiversity in neighbouring areas. With 'biodiversity' as the ecosystem service, it concludes that by altering business site design and management these economic areas could function as a source to enhance local, landscape and regional sustainability. Supporting biodiversity may deliver more benefits than only for plants and animals. For example, creating butterfly habitat at business sites located at the city's edge may support butterfly densities in cities and thus increase the probability that citizens experience these species, increasing the quality of their living environment (chapter 4). Further research should provide insight into what ecosystem services business sites are able to provide to their (urban) surroundings, given the character of the business site as an economic area.

Implications for practice and policy

The idea that, by implementing conservation measures at business sites, local -- and in some cases regional -- biodiversity levels can be enhanced is not yet widely known and accepted in business site development. This thesis shows that especially derelict land on vacant lots and green or gravel roofs on business site buildings may offer opportunities for biodiversity conservation. Regarding the former, utilizing the opportunities for those temporary habitats requires a different view on the business site development process. Business site development plans present 'final pictures', illustrating how business sites will look when all parcels are in full use by companies. In reality it often takes years and sometimes decades before those final pictures are realized (Accordino and Johnson 2002). Incorporating the land use dynamics of business sites in development plans would – at least temporarily – improve the habitat opportunities for pioneer species dwelling in early-successional vegetation, of which many are target species for biodiversity conservation. The findings of this study suggest that public-private partnerships are a promising direction to deal with the (protected) plant and animal species that occur at business sites, in such a way as to meet both economic and environmental interests. Among other reasons, such cooperation is based upon the spatial configuration and the dynamics of public and private land at business sites. This implies that individual conservation initiatives by companies (at the parcel level) and conservation measures taken at the level of the business site as a whole may strengthen each other. From this perspective, the 'habitat backbone' planning and design strategy (chapter 3) can be seen as a first attempt to do so.

This study illustrates that of all the options to incorporate conservation measures into business site development, those linked with early-successional vegetation on vacant parcels and flat roofs are most promising for contributing to overall biodiversity conservation (chapters 2–6). This is because this vegetation provides habitat for various (endangered) plant and animal species for which habitat availability is a key factor in their survival in urban and surrounding landscapes (e.g. Wood and Pullin 2002). To illustrate business sites' potential for conservation, for four out of eight Red List butterfly species preferring early-successional vegetation it appeared that conservation measures taken at business sites could enhance the persistence of 26% (=221 cases) of the Dutch butterfly network populations considered vulnerable (chapter 5).

Conditions for biodiversity conservation at business sites are, besides the local (site-level) scale, also affected by decisions made on a larger scale, at the landscape or even regional level. Here, planners and developers select locations where new business sites should appear or where existing business sites should be redeveloped (Digiovanna 1996). Although there are exceptions for some species (e.g. Clergeau et al. 2001), the abundance and diversity of species present in a certain urban area is usually the result of the land use at the local (site) and that on the larger (landscape, regional, national) scale levels (e.g. Mörtberg 2001; Gehrt and Chelsvig 2003). Stated differently, the contribution that habitats at business sites could make to the conservation of a species (through their metapopulation structure) depends on the size and location of the business site patch relative to the surrounding network. According to Ovaskainen and Hanski (2003) the added value of an individual patch to the metapopulation consists (among others) of i) the contribution of an individual habitat fragment to the metapopulation capacity of the network (for rare species) and ii) the contribution of an individual habitat fragment to colonization events (for common species). Business sites, often located at the city's edge, could offer habitats for rare species (e.g. pioneer butterflies or amphibians) for which populations mainly occur in the surrounding rural landscape (chapter 2, 3 and 5), and for common species that also occur in the city (see chapter 4). This implies that if biodiversity conservation is meant to be incorporated in business site planning, design and management, the effectiveness of investments in conservation measures will increase if the target species and type and amount of habitat are attuned with the regional context of ecological networks.

Will biodiversity conservation at business sites automatically lead to a better working environment for employees and neighbouring citizens? In some cases, for instance, when the business site is located adjacent to ecological corridors, incorporating conservation measures to enhance the functioning of the corridor (e.g. linear water or urban green or structures) can be easily designed such that they will add value to the quality of the living and working environment. However, I conclude based on the findings in chapter 6 that in other cases there could be a gap between the promising conservation options from a biodiversity perspective (e.g. temporary habitats on vacant business site lots) and the options preferred by most business site stakeholders (large amounts of conventional urban green). Bridging this gap requires utilization of temporary opportunities for pioneer species early in the business site development process (when few stakeholders are involved) and, later in the process, creating a better understanding among stakeholders of the significance of business sites for biodiversity conservation.

Further research

From this thesis I infer four categories of research topics recommended to improve the knowledge base for sustainable development at business sites.

1- *Broadening the species basis.* Future research on biodiversity levels at business sites should incorporate other species groups, like mammals, invertebrates and plant species, as for these species business sites may also provide habitat opportunities. Thereby research on the different habitat functions (reproduction, food, hibernation, etc.) that business sites may offer to those species could be an important extension of the current studies on biodiversity at business sites.

2- *Quantification of the temporal, spatial and other conditions under which business sites may enhance biodiversity at business sites.* How much habitat at a business site is enough to substantially support biodiversity? To what extent does the land use at the site and in its surroundings determine the level of biodiversity? Chapter 6 of this thesis discussed various business site scenarios elaborating options for biodiversity conservation. Telemetric and experimental studies based on these scenarios may support provision of quantitative figures, from which guidelines for biodiversity conservation at business sites can be derived.

3- *Extending knowledge on ecosystem services.* This thesis focused on biodiversity, both as a functional basis for ecosystem services, and as an ecosystem service in itself. Further research is needed to learn how design and management of business sites could provide different ecosystem services: what conditions are required for these ecosystem services and which ecosystem services can be combined within a business site design? Are business sites indeed capable of acting as a 'source of ecosystem services' to their surroundings?

4- Finally, this thesis described the options and opportunities for biodiversity conservation at business sites from an ecological viewpoint. *The economic and social implementation of this idea warrants more attention.* How could 'green investments' (conservation measures) be beneficial to business site stakeholders? How might we integrate the opportunities for biodiversity and other ecosystem services into the decision-making processes involved in business site planning and development? To what extent will willingness to invest vary under different land use pressures? What are the cost-benefit ratios of scenarios in which biodiversity conservation is incorporated?

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Summary

Summary

‘Business sites’ is a (Dutch) planning term for ‘areas designated by local, regional and in some cases national authorities to accommodate multiple companies that produce, transfer or store goods’. These areas can be further classified as high-quality business sites, mixed business sites, logistic areas, heavy industrial areas and seaport areas. Other countries refer to these sites as business districts, business parks, industrial sites, industrial districts or industrial estates. In the Netherlands most business sites are relatively small (average size of 27 ha). They are typically densely distributed, with about eight business sites per municipality. As little attention has been paid to the appearance and life span of these sites, some 30% of the 3,600 Dutch business sites is outdated from an economic viewpoint.

Although the concept of the mono-functional business site has hardly changed over time, the world has evolved. Various economic, social and environmental trends have together increased the complexity in which business site planning, development and management take place nowadays. Among them, the growing attention for sustainable development appears an important trend. Sustainable economic development strategies promote mutually beneficial environmental, social and economic progress. These strategies (e.g. ‘careful industrial land use’ and ‘industrial ecology’) address many environmental and social aspects that traditionally have not been included in business site development and management. The strategies focus on diminishing the negative environmental impacts of the business site. However, sustainable development is also about creating added value, not only preventing damage to the environment. It may include the management of land to improve provision of ecosystem services to humans. In cities, urban ecosystems support citizens’ quality of life by providing services as air filtering, micro-climate regulation, noise reduction and enhancing biodiversity. Business sites have so far not been considered as accommodating ecosystems and thus providing ecosystem services.

This thesis explores options and opportunities in the planning, design and management of business sites to accommodate ecosystems as a source of ecosystem services to their surroundings. It thereby focuses on the potential of business sites ‘to support biodiversity’, an important ecosystem service related to the quality of human life. It explores (primarily from an ecological viewpoint) the current and potential contributions that business sites could make to biodiversity conservation, both at the site level and at the landscape level. It subsequently ranks (from a multifunctional viewpoint) the best options for conservation as preferred by stakeholders.

Five research questions were defined to fulfil this aim:

1 *How can the biodiversity at current business sites be characterized compared to other urban land use types?*

This question aimed to obtain insights into the current state of affairs concerning the biodiversity occurring at business sites, using breeding bird populations to represent biodiversity. Dutch bird census data for business sites was compared with data from residential areas and urban green spaces. In general, a significantly lower abundance and species richness of breeding birds was found at these economic sites, as observed at survey plots in the Netherlands. However, the bird guild level presented a more differentiated picture regarding the role of business sites as habitats for breeding birds. The business sites in our sample appeared to be especially preferred by birds linked with early successional (e.g. sparse or low) vegetation. In contrast, birds that prefer climax vegetation (e.g. aged forests) were almost absent at these sites, reflecting the fact that the trees at the business sites were not old enough to accommodate tree-hole nesting birds. The resulting bird assemblage differentiates business sites from other urban land use types, both built and not built. Business sites especially contribute to the city's bird diversity by providing habitats for breeding birds that prefer dynamic habitats with low, early successional vegetation. Especially for coastal species and the Common Linnet, *Cardualis cannabina*, a Red List species, business sites appear to be favourite urban habitats.

This explorative study demonstrates that breeding bird assemblages at business sites differ distinctly from those in residential areas and urban green spaces. The study contributes to the existing literature by providing insights into the suitability of existing business sites as places for biodiversity conservation, in particular, for breeding birds, as illustrated by the Dutch situation. As such, it provides an indication of the added value of business site habitat for urban bird communities.

2 *How can endangered species currently occurring at business sites be conserved despite the dynamic and economically-oriented land use of these sites?*

The strategy developed for this study combines the dynamics of business site habitat with the stability of protected habitat on public lands, with emphasis on early successional habitat. I showed how with this specific planning and design strategy (the 'habitat backbone') the long-term survival of an endangered species in these areas can be ensured. This strategy is based upon the spatial and temporal dynamics in both the species metapopulation and its habitat pattern in port areas, and it includes the creation of permanent habitat strategically located on (semi)public lands with an overall carrying capacity sufficient to support persistent populations. Additional habitat in the port area, on private parcels, will have a more temporal character but nonetheless increases the overall (meta)population size. The dynamics in this part of the network are stabilized by the habitat backbone. Metapopulations characteristically demonstrate turnover, with local populations going extinct and becoming re-established, resulting in a distribution pattern that shifts over time. Thus, the metapopulation concept can be used to design a strategy which links the local population(s) at the business sites with those in the surrounding region. Through such linkages, the risks of local extinctions are spread i) by making use of the opportunities that the relative stability of public land offers to act as refugium and ii) because public and private lands are spatially interconnected, so that from this refugium habitat dispersers can quickly (re)colonize habitats on private land.

Concerning the institutional aspects, I found that implementing the habitat backbone strategy in the case of the natterjack toad (*Bufo calamita*) in the Port of Antwerp is possible only if landowners, local governments and environmental NGOs cooperate.

3 *Could peri-urban business sites strengthen inner-city nature and thus support the quality of life of citizens?*

Most business sites can be found at the city's edge. Here, due to their size and land use, business sites may contain relatively large areas with pioneer and brushwood vegetation, which is scarce elsewhere in cities. This raises the idea that business sites may harbour source populations for the occurrence of plants and animals species further towards the central part of cities. This idea was explored with butterflies as species group, and with spatial scenarios based upon a practical case. I conclude that peri-urban nature areas (e.g. at business sites), if large enough (25-50 ha), can have a positive influence on the presence of butterflies in inner-city neighbourhoods. With a large number of migrating individuals, positively related to the size and management of peri-urban habitat patches, and careful design of the source area and its boundary with the residential area the impact on the density of residential populations will be relatively large. For butterfly species considered good dispersers, some scenarios showed the density of the residential butterflies increased by 50% where there was a peri-urban population that acts as source. In the case of the settlement of Hoogvliet, the future situation will contain less urban green space than at present, which means a lower carrying capacity for butterflies. The contribution of peri-urban migrants to small populations of butterflies within the residential area will therefore increase in importance, as it supports the probability that -- despite the reduction of urban green -- citizens will continue to experience butterflies in their living environment. These results also suggest that the connectivity between inner-city and peri-urban habitat patches, via linear corridors like green road verges, enhances the contribution of peri-urban migrants to inner-city populations. This emphasizes the potential importance of urban green structures in connecting peri-urban and inner-urban network patches for butterflies and similar species.

4 *To what extent may business sites (because of their location, size and use) potentially be capable of supporting biodiversity occurring in the surrounding landscape?*

In this study, conducted in the Netherlands, we selected eight endangered butterfly species inhabiting low-productive, early-successional vegetation, because vacant lots, lawns and green roofs at business sites offer potential habitat for these butterflies. Combining national data on butterfly populations and on business site distribution, we explored the extent to which additional butterfly habitat at business sites could enhance the sustainability of vulnerable butterfly populations nearby. We thereby defined 'butterfly network areas', as contiguous areas where the species were observed. In addition, we identified priority sites where habitat improvements would be most effective for butterfly conservation. We found i) 187 butterfly network areas situated within dispersal distance of business sites large enough to offer potential habitat for local populations and ii) 87 network areas where adjacent business sites offered potential habitat for 10 local populations, together sufficient for an independent, sustainable metapopulation. A subset of 93 business sites (2.5% of all Dutch sites) fit into this latter category, with in some cases multiple business sites in the vicinity of the same butterfly population. For four butterfly species (*A. agestis*, *H. semele*, *I. lathonia* and *O. faunus*), additional habitat developed at nearby business sites could support a substantial proportion (19–33%) of vulnerable populations on a national scale. In conclusion, although more detailed study is necessary before our findings can be applied in practice, the present study nonetheless suggests considerable potential for business sites to contribute to biodiversity conservation in the surrounding landscape.

5 *What are the design and management options for biodiversity conservation at business sites, and which of these options are preferred by the business site stakeholders?*

Biodiversity conservation at business sites can be shaped in different ways, each with its own (socio)economic and environmental characteristics. What are the main options for biodiversity conservation in terms of business site design and management? How may stakeholders rank these options, given their preferences for the various characteristics? Does this ranking provide clues for the implementation of biodiversity conservation at business sites? Findings from this thesis illustrate how a multi-criteria analysis (MCA) framework for sustainable business sites might be used to analyse how biodiversity can be enhanced at a business site. First, different options for biodiversity conservation at business sites (green roofs, ecological management of conventional green, supporting early-successional vegetation on vacant parcels, design of ecological corridors and stepping stones) were elaborated in spatial scenarios of the business site, with one extra scenario illustrating the traditional situation (small amounts of urban green, managed with little attention for biodiversity conservation). Then, the scenarios were assessed according to a range of socioeconomic and environmental criteria (e.g. the costs and financial benefits of conservation measures). Finally, using the MCA framework the scenarios were ranked based on stakeholders' preferences among the criteria. This ranking appeared rather robust, as uncertainty analyses with effect and weight scores gave in most cases no differences in original ranking order. Scenarios in which a large amount of urban green was included in the design appeared to be favourite among all stakeholders -- employees, neighbours and environmental NGOs as well as companies and local governments. Furthermore, our results suggest that implementing measures to enhance biodiversity may be acceptable only if combined with other green functions (predominantly 'recreation' and 'health and well-being') and if suited to the functional appearance of the business site environment ('external appearance' and 'tidiness'). The study broadens the current concept of sustainable business site development by focusing on strategies to enhance biodiversity and landscape values at business sites.

From a methodological point of view, the thesis illustrates how different approaches, concepts (e.g. metapopulation theory) and techniques (e.g. scenario studies), not regularly applied in the field of science of urban ecology, can be applied in urban environments. It also elaborates the idea that city landscapes, and business sites in particular, may offer opportunities for temporary habitat patches with early-successional vegetation.

The papers in this thesis indicate that business sites may contain biodiversity abundance beyond the levels one would generally expect based on earlier studies. By analysing business site cases distributed over the Netherlands (including one in Belgium), and incorporating data on species density and diversity (of breeding birds and amphibians), this thesis presents a more complete and nuanced picture of current biodiversity levels at business sites than reported earlier in existing literature. Limited data availability on the biodiversity levels at business sites, however, still restricts the extent to which explanatory factors (with respect to species abundance and diversity) can be identified.

Next, this thesis explored ideas that go beyond current practice, such as what can be done at business sites to support biodiversity occurring in the vicinity of the site. It thereby contributes to the existing literature, as this idea was explored for the first time. I conclude that this thesis illustrates – with 'biodiversity' as the ecosystem service of interest -- that by altering business site design and management these economic areas could function as a source to enhance local, landscape and regional sustainability. Thereby supporting biodiversity may also deliver benefits for people and the economy, besides the benefits for plants and animals.

Business sites, often located at the city's edge, can offer habitats for rare species (e.g. pioneer butterflies and amphibians), which mainly occur in the surrounding rural landscape (chapter 2, 3 and 5), and for common species that also occur in the city (see chapter 4). This implies that if biodiversity conservation is incorporated in business site planning, design and management, the effectiveness of investments in conservation measures will increase if the target species and type and amount of habitat are attuned with the regional context of ecological networks.

With regard to the implications of the findings of this thesis for policy and practice, this thesis shows that especially derelict land on vacant lots and green or gravel roofs on business site buildings may offer opportunities for biodiversity conservation (e.g. for endangered butterflies). Besides, I suggest that public-private partnerships are a promising direction to deal with the (protected) plant and animal species that occur at business sites, in such a way as to meet both economic and environmental interests. Among other reasons, such cooperation is based upon the spatial configuration and the dynamics of public and private land at business sites, resulting in individual conservation initiatives by companies (at the parcel level) and conservation measures taken at the business site level, as these can strengthen each other. From this perspective, the 'habitat backbone' planning and design strategy (chapter 3) can be seen as a first attempt in this direction.

Furthermore, I conclude based on the findings of chapter 6 that in some cases a gap may arise between the options for conservation that are promising from a biodiversity perspective (e.g. temporary habitats on vacant business site lots) and the options preferred by most business site stakeholders (large amounts of conventional urban green).

From this thesis I infer four categories of future research topics for improving the knowledge base for sustainable development on business sites: i) broadening the species basis, ii) quantification of the temporal, spatial and other conditions under which business sites may enhance biodiversity at business sites, iii) extending knowledge on ecosystem services and iv) exploring the economic and social implementation of the idea of biodiversity conservation at business sites.

Samenvatting

Samenvatting

‘Bedrijventerreinen’ is een (Nederlandse) planningsterm voor ‘gebieden toegewezen door lokale, regionale en in sommige gevallen nationale overheden voor bedrijven die goederen produceren, distribueren of opslaan’. Deze terreinen kunnen verder worden ingedeeld in hoogwaardige bedrijventerreinen, gemengde bedrijventerreinen, distributieterreinen, zware industrieterreinen en zeehavens. Andere landen verwijzen naar deze terreinen als ‘business districts’, ‘business parks’, ‘industrial sites’, ‘industrial districts’ of ‘industrial estates’. In Nederland zijn bedrijventerreinen relatief klein (gemiddeld 27 ha), en komen in hoge dichtheden voor (gemiddeld 8 bedrijventerreinen per gemeente). Omdat er jarenlang weinig aandacht is geschonken aan het uiterlijk en de levensduur van de terreinen, is - volgens economische normen - inmiddels zo’n 30% van de 3.600 Nederlandse bedrijventerreinen verouderd.

Alhoewel het concept van het monofunctionele bedrijventerrein de afgelopen decennia weinig veranderd is, heeft de wereld de nodige veranderingen ondergaan. Door een samenspel van verschillende economische, sociale en milieukundige trends is de complexiteit waarin dezer dagen de planning, ontwikkeling en beheer van bedrijventerreinen plaatsvindt, toegenomen. Een belangrijke trend daarbij is de groeiende aandacht voor duurzame ontwikkeling. Duurzame economische ontwikkelingsstrategieën gaan uit van een wederzijds voordelige milieukundige, sociale en economische voortgang. Deze strategieën (zoals bijvoorbeeld ‘zorgvuldig industrieel landgebruik’ of ‘industriële ecologie’) behandelen veel milieukundige en sociale aspecten die in de traditionele bedrijventerreinontwikkeling en –beheer niet worden meegenomen. De strategieën richten zich daarbij op het verminderen van de negatieve gevolgen van het bedrijventerrein op het milieu. Echter, duurzame ontwikkeling gaat ook over het creëren van meerwaarde, niet alleen het voorkomen van milieuschade. Het kan ook inhouden dat een gebied dusdanig wordt ingericht en beheerd dat in ‘*ecosystem services*’ (diensten van het ecosysteem) voor de mens wordt voorzien. Voor het stedelijk gebied betekent dit dat stadsgroen en stadswater (onderdelen van het urbane ecosysteem) kunnen bijdragen aan een betere leefbaarheid voor bewoners doordat ze diensten leveren. Enkele voorbeelden van urbane ‘*ecosystem services*’ zijn luchtzuivering (stadsgroen filtert fijnstof en andere verontreiniging uit de lucht), verminderen van hoge temperaturen (vegetatie en water zorgt voor verkoeling van de stad in de zomer) en het bieden van habitat voor biodiversiteit (waardoor bijv. stadsbewoners in hun directe woonomgeving kunnen genieten van plant- en dierleven). Bedrijventerreinen zijn tot dusver niet bedacht als onderdeel van het stedelijke ecosysteem en als leveranciers van ‘*ecosystem services*’ voor hun omgeving.

Deze dissertatie verkent de mogelijkheden en kansen in de planning, ontwerp en beheer van bedrijventerreinen voor het accommoderen van ecosystemen, zodat deze als bron van '*ecosystem services*' voor hun omgeving kunnen dienen. De dissertatie richt zich daarbij op de potentie van bedrijventerreinen in het 'ondersteunen van biodiversiteit', een belangrijke 'service' gerelateerd aan de kwaliteit van het menselijk leven. In dit proefschrift verken ik (voornamelijk vanuit een ecologische invalshoek) de huidige en toekomstige bijdragen die bedrijventerreinen kunnen leveren aan biodiversiteitbehoud, zowel op terreinniveau als op landschapsniveau. Daarnaast rangschik ik (vanuit een multifunctionele invalshoek) de beste mogelijkheden voor biodiversiteitbehoud op bedrijventerreinen, zoals gewaardeerd door belanghebbenden van deze terreinen.

Vijf onderzoeksvragen zijn er gedefinieerd om dit doel te bereiken:

1. *Hoe kan de biodiversiteit van huidige bedrijventerreinen worden gekarakteriseerd, in vergelijking met andere stedelijke landgebruikvormen?*

Deze vraag had als doel inzicht te verwerven in de huidige stand van zaken betreffende biodiversiteit op bedrijventerreinen. Broedvogels werden daarbij gekozen als vertegenwoordigers van die biodiversiteit. Om de broedvogels van bedrijventerreinen te kunnen karakteriseren vergeleek ik Nederlandse verspreidings-data van broedvogels waargenomen op bedrijventerreinen met vergelijkbare data van woonwijken en stedelijk groen. Over het algemeen werden op de onderzochte bedrijventerreinen significant lagere broedvogeldichtheden en -soorten gevonden. Echter, op 'vogelgroep-niveau' (vb. bosvogels, weidevogels) liet de analyse een genuanceerder beeld zien voor wat betreft de rol van bedrijventerreinen voor broedvogels. De bedrijventerreinen in de steekproef bleken vooral de voorkeur te hebben van broedvogels van vegetaties in de eerste successiestadia (zoals bijvoorbeeld op braakliggende percelen). Het onderzoek liet verder zien dat in contrast hiermee broedvogels die een voorkeur hebben voor zogeheten climaxvegetaties (oude bossen) vrijwel geheel afwezig waren. Hiermee werd geïllustreerd dat bomen op bedrijventerreinen vaak niet oud zijn, en daarmee dus niet voldoende diameter hebben om vogelsoorten die in boomholten broeden (bijv. spechten) onderdak te bieden. De broedvogelgemeenschap op bedrijventerreinen verschilt daarmee van andere stedelijke landgebruiktypen, zowel bebouwd (woonwijken) als onbebouwd (stadsgroen). Bedrijventerreinen dragen bij aan de stedelijke biodiversiteit doordat ze habitat bieden voor soorten van pioniers- en ruigtevegetaties, situaties die niet vaak elders in de stad te vinden zijn. Speciaal voor kustvogels en de Kneu (*Carduelis cannabina*), een Rode Lijstsoort, blijken bedrijventerreinen een favoriet habitat.

Deze verkennende studie heeft ten opzicht van de bestaande literatuur extra inzichten opgeleverd over de geschiktheid van bestaande bedrijventerreinen als locaties voor biodiversiteitbehoud, geïllustreerd voor de Nederlandse situatie. Daarbij geeft de studie een indicatie van de meerwaarde van bedrijventerreinhabitat voor stadsvogelgemeenschappen.

2. *Hoe kunnen bedreigde soorten die momenteel op bedrijventerreinen voorkomen, beschermd worden ondanks het dynamisch en economisch gebruik van deze terreinen?*

Soms komen op bedrijventerreinen beschermde planten en dieren voor, soorten die veelal worden aangetrokken door het dynamisch landgebruik en de tijdelijke habitat die daardoor ontstaan. Door hun beschermde status wordt de aanwezigheid van deze soorten vaak als een probleem gezien door bedrijven die zich op het bedrijventerrein willen vestigen of willen uitbreiden. Bij het doorlopen van wettelijk verplichte natuurbeschermingsprocedures kan namelijk vertraging optreden voor de bouw van bedrijfspanden en infrastructuur. De strategie die in deze studie werd ontwikkeld, combineert de dynamiek van tijdelijke habitat op de bedrijventerreinpercelen met de relatieve stabiliteit van beschermd habitat dat aanwezig kan zijn op de openbare ruimte (het '*casco*') van het bedrijventerrein. Ik laat met deze specifieke planning- en ontwerpstrategie (de '*habitat backbone*') zien hoe de overleving van bedreigde soorten op deze terreinen op lange termijn verzekerd kan worden. De strategie is uitgewerkt voor zeehavens als bedrijventerreintype, en gebaseerd op de ruimtelijke en temporele dynamiek in zowel de metapopulatie van soorten alsmede het aanbod aan habitat op deze terreinen. Het omvat het ontwikkelen van permanent habitat, strategisch gelegen in de openbare ruimte op het bedrijventerrein, en met voldoende capaciteit om levensvatbare populaties van de betreffende soort te ondersteunen. Dit permanente habitat wordt vanwege zijn functie en ligging de '*habitat backbone*' genoemd. Additioneel habitat, gelegen op aan de '*habitat backbone*' grenzende bedrijfspercelen, heeft een meer tijdelijk karakter. Desalniettemin draagt dit additioneel habitat bij aan het vergroten van de habitatnetwerk voor de gehele metapopulatie (waardoor de kans kleiner is dat de soort in het betreffende gebied uitsterft). De dynamiek in het aanbod van additioneel habitat op de bedrijfspercelen (soms aanwezig, dan weer een tijd niet) wordt daarbij gestabiliseerd door de permanente aanwezigheid van de '*habitat backbone*'. Metapopulaties (netwerken van samenhangende lokale populaties) kenmerken zich door een verloop in lokale populaties die uitsterven en weer gekoloniseerd worden. Voor soorten die in metapopulaties leven houdt dit in dat hun verspreidingspatroon in de loop van de tijd verandert. In de dynamische bedrijventerreinomgeving kan het metapopulatie-concept daarom gebruikt worden om een strategie te ontwerpen waarin lokale populaties op bedrijventerreinen met elkaar en met populaties in het omringend gebied verbonden worden. Door deze samenhang wordt het risico van uitsterven van lokale populaties gespreid. De '*habitat backbone*' strategie maakt daarbij gebruik van de kansen die de relatieve stabiliteit van de openbare ruimte biedt als '*refugium*' én het idee dat bedrijfspercelen en de openbare ruimte met elkaar verbonden zijn, zodat vanuit de '*habitat backbone*' eventueel beschikbaar habitat op bedrijfspercelen snel ge(re)koloniseerd kan worden.

Het toepassen van de '*habitat backbone*' strategie in het geval van de rugstreeppad (*Bufo calamita*) in de Antwerpse haven heeft me geleerd dat deze strategie alleen succesvol kan zijn als terrein-eigenaren, lokale overheden en natuur- en milieuorganisaties samenwerken.

3 *Kunnen bedrijventerreinen in de stadsrand de binnenstedelijke natuur versterken en daarmee de leefbaarheid van bewoners vergroten?*

De meeste bedrijventerreinen zijn in de stadsrand gelegen. Vanwege hun omvang en landgebruik bevatten bedrijventerreinen hier vaak zogeheten pioniers- en ruigte-vegetaties. Deze vegetaties met specifieke plant- en diersoorten zijn schaars in andere delen van de stad. Op grond van dit gegeven ontstond het idee dat bedrijventerreinen gelegen in de stadsrand bronpopulaties kunnen herbergen van waaruit planten en dieren binnenstedelijke gebieden verderop in de stad (vb. woonwijken) kunnen koloniseren. Stadsbewoners kunnen daarmee meer van natuur genieten. Dit idee werd verkend in een modelstudie met dagvlinders als voorbeeld, en met enkele ruimtelijke scenario's gebaseerd op een praktijkcasus. Op basis van de resultaten concludeer ik dat habitat in de stadsrand (bijvoorbeeld op bedrijventerreinen), mits groot genoeg (25-50 ha), een positieve invloed kunnen hebben op het voorkomen van dagvlinders in binnenstedelijke woonwijken. Met een groot aantal migrerende vlinders, samenvallend met de omvang en het beheer van de habitat in de stadsrand, en een zorgvuldig ontwerp van het brongebied (vb. bedrijventerrein) en aangrenzende woonwijken zal de impact op het voorkomen van vlinders in de woonwijken relatief groot zijn. Voor vlindersoorten die zich gemakkelijk door het landschap verspreiden (goede '*dispersers*') laten sommige scenario's zien dat de vlinderdichtheid in woonwijken met 50% toenam als er een bronpopulatie in de stadsrand was.

In de praktijkcasus Hoogvliet (woonkern tegen de Rotterdamse haven) zal in de toekomst als gevolg van stedelijke herstructurering minder stadsgroen in de woonwijken aanwezig zijn, wat inhoudt dat er ook minder habitat voor vlinders zal zijn. In de aangrenzende Rotterdamse haven (Pernis e.o.) of het nabijgelegen Poortugaal is echter ruimte voor extra bronpopulaties. Deze modelstudie liet zien dat het ontwikkelen van vlinderhabitat in deze gebieden kan bijdragen aan het algeheel voorkomen van vlinders in de woonkern Hoogvliet. Hierdoor kunnen bewoners ook in de toekomst van dagvlinders blijven genieten, dit ondanks er dan minder groen in de woonkern aanwezig zal zijn. De resultaten van de modelstudie suggereren verder dat de connectiviteit tussen de habitat in de stadsrand en de binnenstedelijke gebieden, via lijnvormige landschapselementen als wegbermen, de bijdrage versterkt van stadsrandmigranten aan de binnenstedelijke vlinderpopulaties. Dit benadrukt het potentiële belang van stedelijke groenstructuren in het verbinden van habitat-netwerken tussen de stadsrand en binnenstad voor vlinders en vergelijkbare soorten.

4 *In hoeverre kunnen bedrijventerreinen (vanwege hun locatie, omvang en gebruik) in potentie bijdragen aan het behoud van biodiversiteit in het omringend landschap?*

In deze studie, uitgevoerd voor de Nederlandse situatie, zijn acht bedreigde dagvlindersoorten geselecteerd die een habitatvoorkeur hebben voor voedselarme pionierssituaties. Dit omdat de braakliggende terreinen, gazons en groene daken op bedrijventerreinen een potentieel habitat voor deze soorten bieden. Door landelijke data over het voorkomen van dagvlinders en bedrijventerreinen met elkaar te combineren, heb ik verkend in welke mate additioneel vlinderhabitat op bedrijventerreinen de levensvatbaarheid van nabijgelegen, kwetsbare vlinderpopulaties zou kunnen versterken. Daarbij zijn 'vlindernetwerkgebieden' gedefinieerd als aaneengesloten gebieden waar de betreffende soort in het recente verleden werd waargenomen. Daarnaast zijn in deze studie locaties geïdentificeerd waar het ontwikkelen van habitat het meest effectief zou zijn, vanuit het oogpunt van vlinderbescherming. Uiteindelijk zijn voor de acht soorten tezamen 187 vlindernetwerkgebieden gevonden waar nabijgelegen bedrijventerreinen voldoende habitat (1-2.5 ha) kan bieden voor tenminste één lokale populatie van de betreffende soort én 87 vlindernetwerkgebieden waar op nabijgelegen bedrijventerreinen zelfs voldoende ruimte is voor habitat (10-25 ha) genoeg voor 10 lokale populaties. Omdat in het laatste geval dit genoeg habitat is voor een levensvatbare metapopulatie, kan het ontwikkelen van vlinderhabitat op die bedrijventerreinlocaties het voortbestaan van nabijgelegen kwetsbare vlinderpopulaties in één keer veilig stellen. Het gaat daarbij om 93 bedrijventerreinen (2.5% van alle Nederlandse terreinen), waarvan in een aantal gevallen er meerdere bedrijventerreinen zijn die nabij hetzelfde vlindernetwerkgebied gelegen zijn. Voor vier van de acht soorten, het bruin blauwtje (*Aricia agestis*), de heivlinder (*Hipparchia semele*), de kleine parelmoervlinder (*Issoria lathonia*) en het groot dikkopje (*Ochlodes faunus*), kan het ontwikkelen van additioneel vlinderhabitat op nabijgelegen bedrijventerreinen een substantieel deel (19-33%) van de kwetsbare populaties in Nederland versterken. Concluderend, ondanks dat meer gedetailleerde onderzoek nodig is voordat deze resultaten in de praktijk kunnen worden toegepast, suggereert deze studie een flink potentie voor bedrijventerreinen in het bijdragen aan biodiversiteitbehoud in het omringende landschap.

5 *Wat zijn de ontwerp- en beheermogelijkheden voor biodiversiteitbehoud op bedrijventerreinen, en welke van die mogelijkheden hebben de voorkeur van bedrijventerrein-stakeholders?*

Biodiversiteitbehoud op bedrijventerrein kan op verschillende manieren worden vormgegeven, iedere mogelijkheid heeft daarbij zijn eigen sociaal-economische en milieukundige eigenschappen. Wat zijn de belangrijke opties voor biodiversiteitbehoud op bedrijventerreinen in termen van ontwerp en beheer? Hoe zullen stakeholders deze opties rangschikken, gegeven hun voorkeur voor bepaalde aspecten (vb. kosten of recreatiewaarde)? Geeft een rangschikking inzicht in hoe biodiversiteitbehoud op bedrijventerreinen het best in praktijk kan worden gebracht?

De resultaten uit deze studie laten zien hoe 'een multi-criteria analyse (MCA) raamwerk voor duurzame bedrijventerreinen' gebruikt kan worden om te onderzoeken hoe biodiversiteit op bedrijventerreinen versterkt kan worden. Eerst zijn verschillende opties voor biodiversiteitbehoud op bedrijventerreinen (groene daken, ecologisch beheer van bestaand groen, benutten braakliggende terreinen, ontwerp van ecologische verbindingszones en stapstenen op het bedrijventerrein) uitgewerkt in ruimtelijke scenario's, met daarbij één extra scenario dat het traditionele bedrijventerrein vertegenwoordigt (weinig groen, beheerd met weinig aandacht voor biodiversiteitbehoud). Vervolgens zijn de scenario's getoetst op diverse sociaal-economische en milieukundige criteria. Uiteindelijk werden met behulp van het MCA raamwerk de scenario's gerangschikt, daarbij meegenomen de voorkeur van stakeholders voor de verschillende criteria. De rangschikking bleek tamelijk robuust, omdat een onzekerheidsanalyse met 'effect en gewichten scores' in de meeste gevallen geen verandering in de rangschikking opleverde.

Bedrijventerreinscenario's waarbij een grote hoeveelheid groen in het ontwerp was meegenomen, bleken favoriet onder alle stakeholders: werknemers, omwonenden en natuur- en milieuorganisaties alsmede ook ondernemers en lokale overheden. Tevens lieten de resultaten zien dat het toepassen van maatregelen voor biodiversiteitbehoud op bedrijventerreinen het meeste draagvlak hebben in die gevallen waarin de maatregelen ook andere groene functies (voornamelijk recreatie en gezondheid) versterken en indien ze passen binnen de functionele uitstraling van het bedrijventerrein ('goed onderhouden'). Deze studie verbreedt het huidige concept van duurzame bedrijventerreinontwikkeling door zich te richten op strategieën om biodiversiteit en landschappelijke waarden op bedrijventerreinen te versterken.

Vanuit een methodologische invalshoek laat deze dissertatie zien hoe verschillende benaderingen, concepten (bijv. de metapopulatie-theorie) en technieken (bijv. scenariostudies), nog niet vaak toegepast in het wetenschappelijk vakgebied van de urbane ecologie, kunnen worden toegepast in de stedelijke omgeving. Het werkt daarbij ook het idee uit dat stadslandschappen, en bedrijventerreinen in het bijzonder, kansen bieden voor tijdelijke natuur. Voor dit type natuur, dat vaak bijzondere soorten aantrekt, is momenteel nauwelijks aandacht in beleid en beheer.

De artikelen in deze dissertatie geven aan dat op de huidige bedrijventerreinen meer biodiversiteit aanwezig is dan dat men in eerste instantie zou verwachten. Door bedrijventerreinen verspreid over Nederland (en één in België) te onderzoeken, en daarbij gegevens over dichtheden en diversiteit van soorten (betreffende broedvogels en amfibieën) mee te nemen, geeft deze dissertatie een completer en genuanceerder beeld van de biodiversiteit op bedrijventerreinen dan tot dusver beschreven in de literatuur. De geringe beschikbaarheid van empirische data over plant- en dierleven op bedrijventerreinen beperkt echter nog steeds de mate waarin verklarende variabelen (met betrekking tot soortdichtheden en –diversiteit) benoemd kunnen worden.

Voorts verkent deze dissertatie ideeën die verdergaan dan de bestaande praktijk, zoals bijvoorbeeld het idee van wat er op bedrijventerreinen kan worden gedaan om de omliggende biodiversiteit te versterken. De dissertatie draagt daarmee bij aan de bestaande literatuur aangezien dergelijke benaderingen niet eerder zijn verkend. Ik concludeer dat deze dissertatie laat zien – met ‘biodiversiteit’ als de geselecteerde ‘*ecosystem service*’ – dat door het ontwerp en beheer van bedrijventerreinen aan te passen deze economische terreinen als bron kunnen dienen voor lokale, landschappelijke en regionale duurzaamheid. Daarbij levert het versterken van biodiversiteit voordelen op voor mens en economie, naast die voor plant en dier.

Bedrijventerreinen, veelal aan de stadsrand gelegen, kunnen habitat bieden voor zeldzame soorten (zoals dagvlinders en amfibieën van pionierhabitat), die voornamelijk in het omringend rurale gebied voorkomen (hoofdstuk 2, 3 en 5), en voor algemeen voorkomende soorten die ook in de stad voorkomen (hoofdstuk 4). Dit impliceert dat indien biodiversiteitbehoud onderdeel gaat uitmaken van bedrijventerreinplanning, -ontwerp en – beheer, de effectiviteit qua investeringen zal toenemen indien de keuze voor soorten en bijbehorende maatregelen wordt afgestemd op de regionale context met daarin de omliggende ecologische netwerken.

Deze dissertatie laat, wat betreft de implicaties voor beleid en praktijk, zien dat met name braakliggende terreinen en groene of grinddaken op bedrijfspanden kansen bieden voor biodiversiteitbehoud (bijv. voor bedreigde dagvlinder- of vogelsoorten). Daarnaast suggereer ik dat publiek-private samenwerking een veelbelovende oplossingsrichting kan zijn voor het omgaan met (beschermde) plant- en diersoorten die op bedrijventerreinen voorkomen, op een dusdanige manier dat economische en ecologische belangen worden gediend. Dit komt onder meer doordat een dergelijke samenwerking is gebaseerd op de ruimtelijke configuratie en dynamiek van zowel de bedrijfspercelen als de openbare ruimte op bedrijventerreinen. Hierdoor kunnen individuele natuurbeschermingsinitiatieven door bedrijven (op perceelsniveau) en maatregelen voor biodiversiteitbehoud op het bedrijventerreinniveau elkaar versterken. Vanuit dat perspectief kan de planning- en ontwerpstrategie ‘*the habitat backbone*’ (hoofdstuk 3) worden gezien als een eerste poging in deze richting.

Verder concludeer ik, op basis van de resultaten van hoofdstuk 6, dat er in sommige gevallen een gat dreigt te ontstaan tussen die natuurbeschermingsopties die veelbelovend zijn vanuit een biodiversiteitsperspectief (bijv. tijdelijke habitats op braakliggende percelen) en de opties die het meest door de stakeholders van bedrijventerreinen gewaardeerd worden (grote hoeveelheden van conventioneel groen).

Tenslotte zie ik, op grond van deze dissertatie, vier categorieën voor toekomstig onderzoek aan een duurzame ontwikkeling van bedrijventerreinen: i) het verbreden van de soortbasis (bijv. met flora), ii) het kwantificeren van temporele, ruimtelijke en andere condities waaronder bedrijventerreinen biodiversiteit kunnen versterken, iii) het uitbreiden van de kennis van '*ecosystem services*' en iv) het verkennen van de economische en sociale uitvoering van het idee voor biodiversiteitbehoud op bedrijventerreinen.

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Curriculum vitae

De auteur van dit proefschrift, Robbert Petrus Hendrik Snep, werd op 21 april 1974 geboren in Eindhoven. Na een jaar op de kleuterschool in de Akkerstraat doorliep hij met goed gevolg de basisschool Nutsschool Floralaan, waarna hij naar het atheneum op het Eindhovense Lorentz Lyceum ging. Daar deed hij in 1993 eindexamen, om vervolgens Biologie te gaan studeren aan de Fontys Hogeschool te Tilburg. Als afstudeerstage koos hij in 1997 niet geheel verrassend voor een onderzoek aan amfibieën (o.m. nachtelijk zenderwerk aan de boomkikker, *Hyla arborea*) bij het toenmalige Instituut voor Bos- en Natuuronderzoek (IBN-DLO) te Wageningen. Na zijn afstuderen stroomde hij door in een Biologie-opleiding aan de Wageningen Universiteit. Al na een halfjaar verliet hij deze opleiding voor een onderzoeksbaan bij hetzelfde IBN-DLO. Na twee jaar bij dit instituut en zijn opvolger Alterra gewerkt te hebben, besloot hij alsnog de universitaire doorstroomstudie af te ronden (naast zijn baan). In 2002 behaalde hij zijn ingenieurstitel, met als studierichting landschaps-ecologie, en een afstudeeronderzoek naar dierpopulaties in steden.

Vanaf eind jaren tachtig van de vorige eeuw verricht Robbert inventarisaties naar de verspreiding van amfibieën en reptielen, in het bijzonder binnen de regio Zuidoost-Brabant. Hij was in de periode 1990-1996 actief als deel-coördinator van het Eindhovense poelenoverleg, en één van de oprichters van de stichting Stadsnatuur Eindhoven. Vanaf 2000 verdiept hij zich ook onderzoeksmatig in de urbane ecologie. Na een bezoek aan een ‘urban ecology’ bijeenkomst met internationale onderzoekers in Melbourne in 2003, besloot hij om i.s.m. prof. Jari Niemelä (Helsinki) en prof. Jürgen Breuste (Salzburg) het European Network for Urban Landscape Ecology (ENULE) op te richten. Bij deze internationale netwerkorganisatie voor stadsecologisch onderzoek zijn inmiddels ruim 60 Europese onderzoekers aangesloten. Vanuit ENULE organiseerde hij in 2007 een succesvol Urban Ecology symposium, workshop en excursie op het IALE World Congress in Ede, met deelnemers uit de gehele wereld. Robbert is verder ‘associate editor’ bij de journals Urban Ecosystems en Biotope City, geeft regelmatig gastcolleges en excursies ‘stedelijke ecologie’, is recentelijk gevraagd voor de Technische Adviescommissie voor de Amsterdamse Hoofdgroenstructuur, en is actief als beheerder van het Nederlandse discussieplatform Stedelijke Ecologie.

Vanuit het Alterra-team Stadsregionale Ontwikkeling onderzoekt hij, samen met collega’s uit diverse disciplines, de mogelijkheden om middels groen en water de leefbaarheid van de stedelijke omgeving te verbeteren. Zijn promotie-onderzoek naar biodiversiteitbehoud op bedrijventerreinen past dan ook binnen een bredere visie voor een duurzamere stad, met speciale interesse voor innovatieve ‘rood-groen combinaties’ en het onder de aandacht brengen bij bewoners, beleidsmakers en bedrijven van het belang van natuur in de stedelijke context.

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Place: Wageningen Date: 6 February 2009

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SENSE PhD courses:

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- Cambridge Advanced English

Research and Management Skills:

- Writing PhD research proposal
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- AK Stadtökologie Jahrestagung 2004, 21 October 2004, Berlin, Germany
- 45th European Regional Science Conference, 23 – 27 August 2005, Amsterdam, The Netherlands
- 1st European Congress on Conservation Biology, 22 -26 August 2006, Eger, Hungary
- IALE 2007 World Congress, 9 – 12 July 2007 , Ede, The Netherlands

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