PREDATORS IN THE CITY

DESIGNING URBAN OPEN SPACE TO ADAPT A STONE MARTEN POPULATION

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MSc Thesis Landscape Architecture
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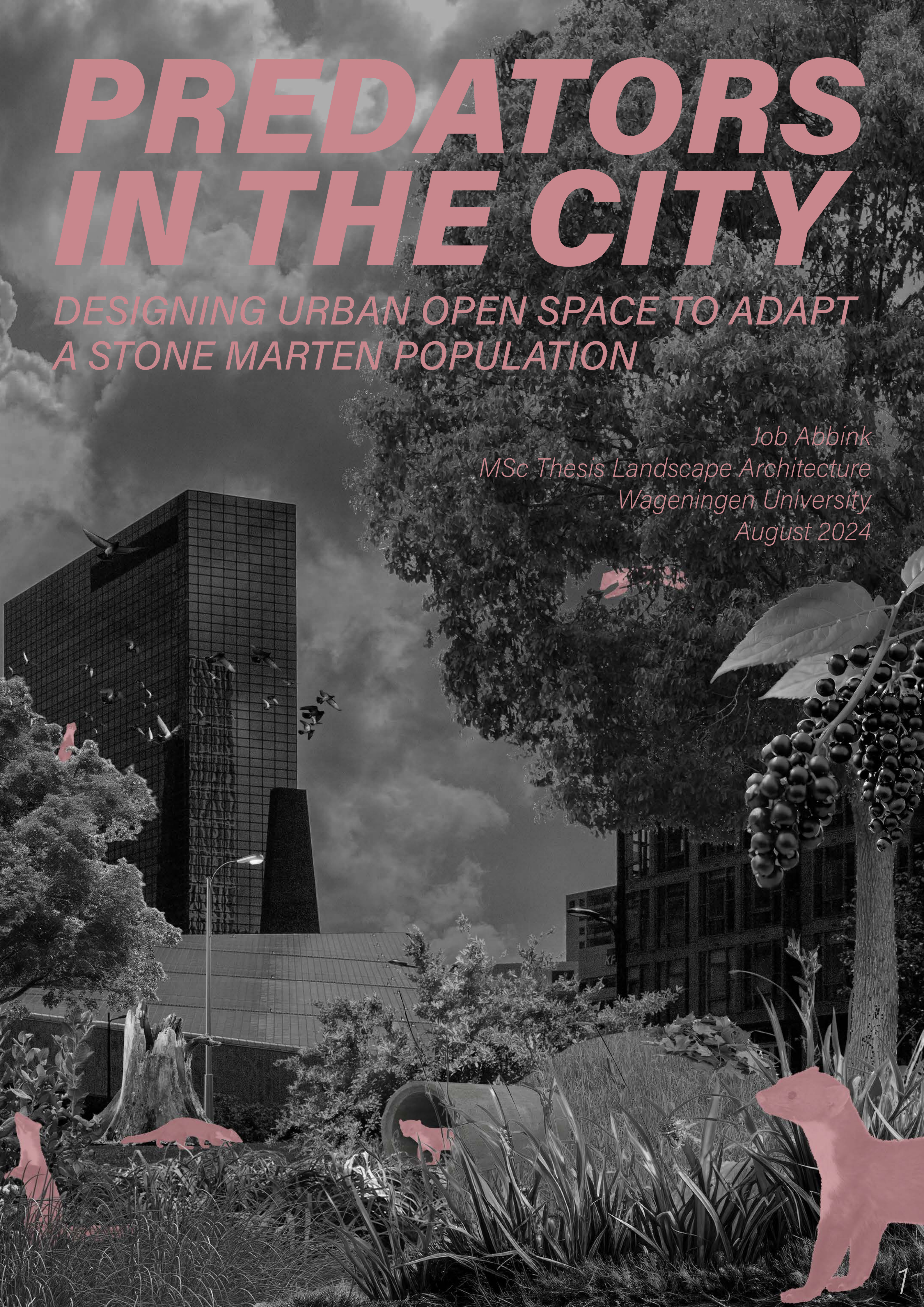

Predators in the city: Designing urban open space to adapt a stable stone marten population

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ABSTRACT

Rapid urbanization is causing a decline in biodiversity through habitat loss and fragmentation. Within urban environments a new ecosystem is created, consisting of wildlife coexisting with humans. Anthropogenic influences cause a disbalance within urban food webs, contributing to the rise of pest species. A solution to this problem can be found in its natural predators. This thesis explores the adaptation of urban open spaces for the inhabitation of such a predator: the stone marten.

The primary objective of this thesis is to develop design principles, guidelines and criteria for a marten-aided design. Apart from assessing the habitat requirements of the mammal based on its life history and seasonal needs, the biggest species-specific problem and opportunity are addressed. Respectively, the controversial relationship between humans and marten, and the possibility of induced predation pressure on one of the most widespread rodents: the brown rat. These design 'ingredients' are thereafter fitted within an open space system 'framework' aimed at distributing and stabilizing a to-be-housed marten population. Typologies of Urban Green Infrastructures and respective characteristics have been assessed to bridge the gap between behavioural/landscape ecological research and landscape design.

Through an iterative 'Research through Design' process, these design directives are applied to the chosen site of Rotterdam: The Dutch city where both solution (marten) and problem (rat) meet. City-scale design alternatives for an ecological marten network have been created and assessed though an expert panel. Explorative design alternatives on a park-scale aim at establishing marten habitats within the existing urban grid.

To support a stable stone marten population, the entirety of an individual life history needs should be met within a designated territory. Hereby limiting food availability and shelter opportunities of pests to increase predation pressure. Within urban greenery, designed areas should be separated on ecological and social significance to account for human-marten co-occurrence, achieved though low-quality habitat dividers. The available areal here is key for the successful integration of martens and other predators within the city.

This body of work seeks to assess the extent to which our built environment must be reevaluated to enhance animal liveability. Although species-specific, adapting the proposed design interventions contributes to other ecosystem services beneficial for both humans and animals.

Key words: Ecosystems in urban areas; life history; habitat requirements; landscape of fear; human-wildlife co-occurrence; open space system design; Urban Green Infrastructure

PREFACE

Dear Reader,

It is with great pleasure that I share this work with you. This thesis represents not only the culmination of my academic journey but also a significant step into my professional future. Through the lens of landscape architecture, I have explored how behavioural ecology principles can be seamlessly integrated into design practices. This endeavour has deepened my understanding of both fields and honed my skills as an independent researcher and designer.

The completion of this thesis would not have been possible without the invaluable guidance of my supervisors, whose expertise and enthusiasm have been instrumental in shaping this report. I am also profoundly grateful to my colleagues, whose support and camaraderie have been vital in navigating the challenges of this past year. Their encouragement has been a cornerstone of my progress.

Additionally, I wish to extend my heartfelt thanks to the ecologists and landscape architects who generously shared their insights with me. Their perspectives have enriched my understanding and inspired my work in ways that are both profound and enduring.

I am excited to embark on the next chapter of my career, and I hope this thesis serves as a meaningful contribution to the field of landscape architecture.

Kind regards,

Job Abbink
11 August 2024

GENERAL NOTES

Within this thesis the *Martes foina* will be referred to as 'stone marten' or simply 'marten. For addressing all marten species 'mustelids' will be used.

When referring to other marten species this will be specified. The *Rattus Norvegicus* will be referred to as 'brown rat' or simply 'rat.' When referring to other rat species this will be specified.

Observational data of set species, utilized in this study, dates from between December 11, 2021, and December 11, 2023. Population distribution data was derived from the Databank Flora en Fauna (2023).

Specialist terms in the field of behavioural ecology are explained in the glossary. There first appearance is marked with an *.

Within text, numbers or letters can be found, referring to the aforementioned design principles (***I***, ***II***, ***III***, ...) guidelines (***1***, ***2***, ***3***, ...) or design criteria (***1a***, ***2a***, ***3a***, ...) of which definitive versions are found in Appendix 1.

Non-referenced figures are made solely by the hand of the author. If adapted, this will be specified.

Throughout the thesis colours are used to accentuate different parts of the research, accent colours below highlight the colours corresponding to the different research questions.

SRQ1 ***SRQ1a*** ***SRQ1b*** ***SRQ2*** ***SRQ3***

CONTENTS

1

INTRODUCTION

1 INTRODUCTION

1.1 PROBLEM STATEMENT

Currently, 55% of the global population resides in urban areas, and this proportion is projected to increase to around 66% by 2050 (see Figure 1). This rapid urbanization leads to profound changes in landscapes (Apfelbeck et al., 2020). One prominent cause of urban development is biodiversity loss (see figure 1). Habitat loss and fragmentation are occurring on a large scale (Apfelbeck et al., 2020). Those alterations disrupt natural environments and have far-reaching effects on species communities, including changes in species composition, abundance, evenness, and richness (Faeth, Bang and Saari, 2011).

Urban environments often create stark contrasts with surrounding natural ecosystems, resulting in isolated and degraded habitats that can struggle to support diverse wildlife. As cities expand, the ecological divide between ecosystems in urban and non-urban areas becomes increasingly pronounced, highlighting the need for strategies to mitigate those impacts and promote biodiversity conservation in the face of urban growth.

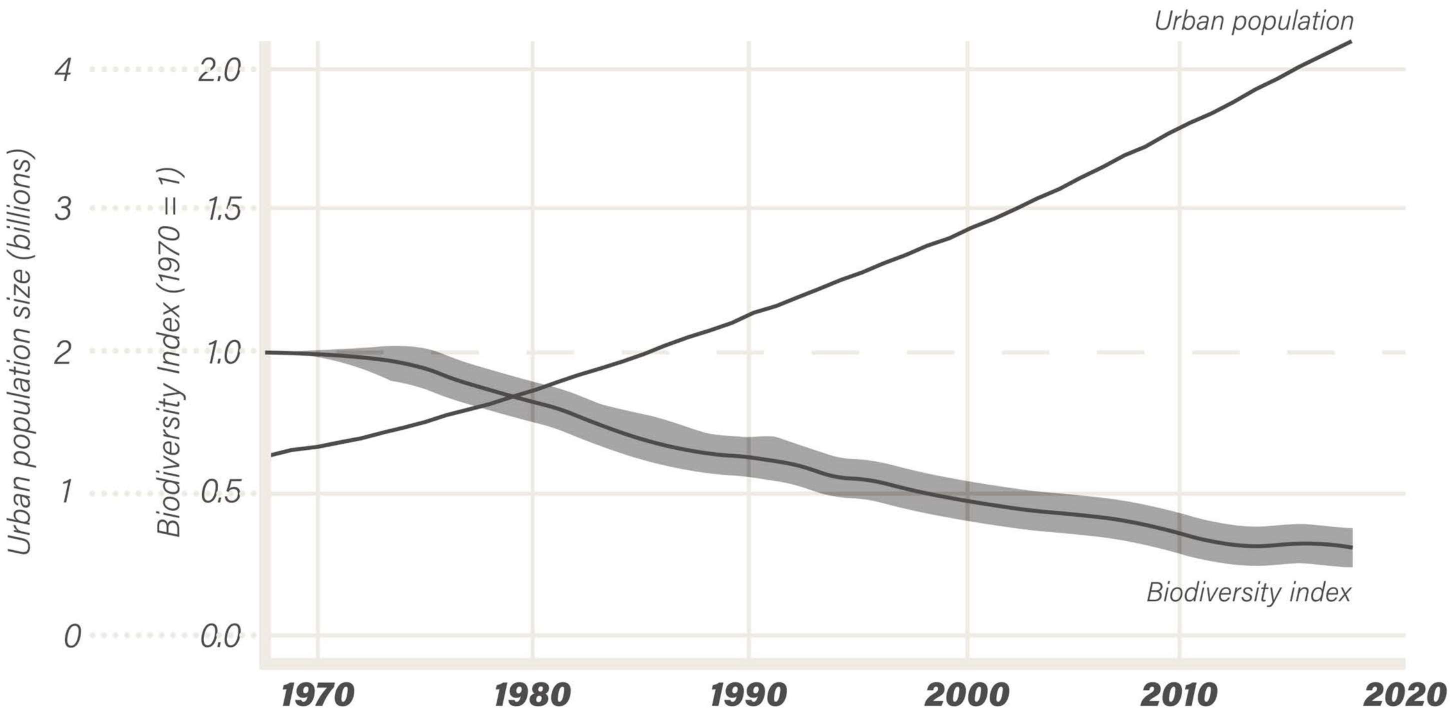


Figure 1 *Overlayed graphs on global urban population growth and biodiversity index decline. Adapted from (Our World in Data, 2022; WWF and ZSL, 2022).*

Figure 2 illustrates how humans more profoundly alter ecosystems in urban areas by means of a possible urban food web. Alteration is done by disrupting resource flows; controlling plant species diversity/ productivity; and subsidizing resources for herbivores and predators. Humans have a strong bottom-up control by, for example, public space littering, intentional animal feeding and intensive green maintenance. This has caused an abundance of synanthropes*, a term used for organisms that live close to humans and benefit from environmental modifications (Zuidema, no date). Certain animal species have thrived so much in the urban environment that they have become pests*: a common term used for organism that harm human activities, health, or the environment by causing damage, spreading diseases, or competing with other beneficial species over resources (Oerke, 2006).

Changes in animal populations at lower trophic levels have significant impacts on predator abundance and composition in urban areas (Zuidema, no date) A general loss of apex predators in urban areas has been reported, which would suggest a mesopredator release. Yet research has shown that a mesopredator outbreak does not often occur in urban environments (Zuidema, no date). In general predation pressure is lower as prey have adapted to predators by using this built environment. In addition, predators can be exterminated in the built environment as they negatively interfere with our material properties and well-being (Buijs and Jacobs, 2021). Generally speaking, an imbalance in urban ecosystems can be attributed to a lack of species from higher trophic levels. This thesis argues for the need to introduce more mesopredators in cities to help balance this ecosystem.

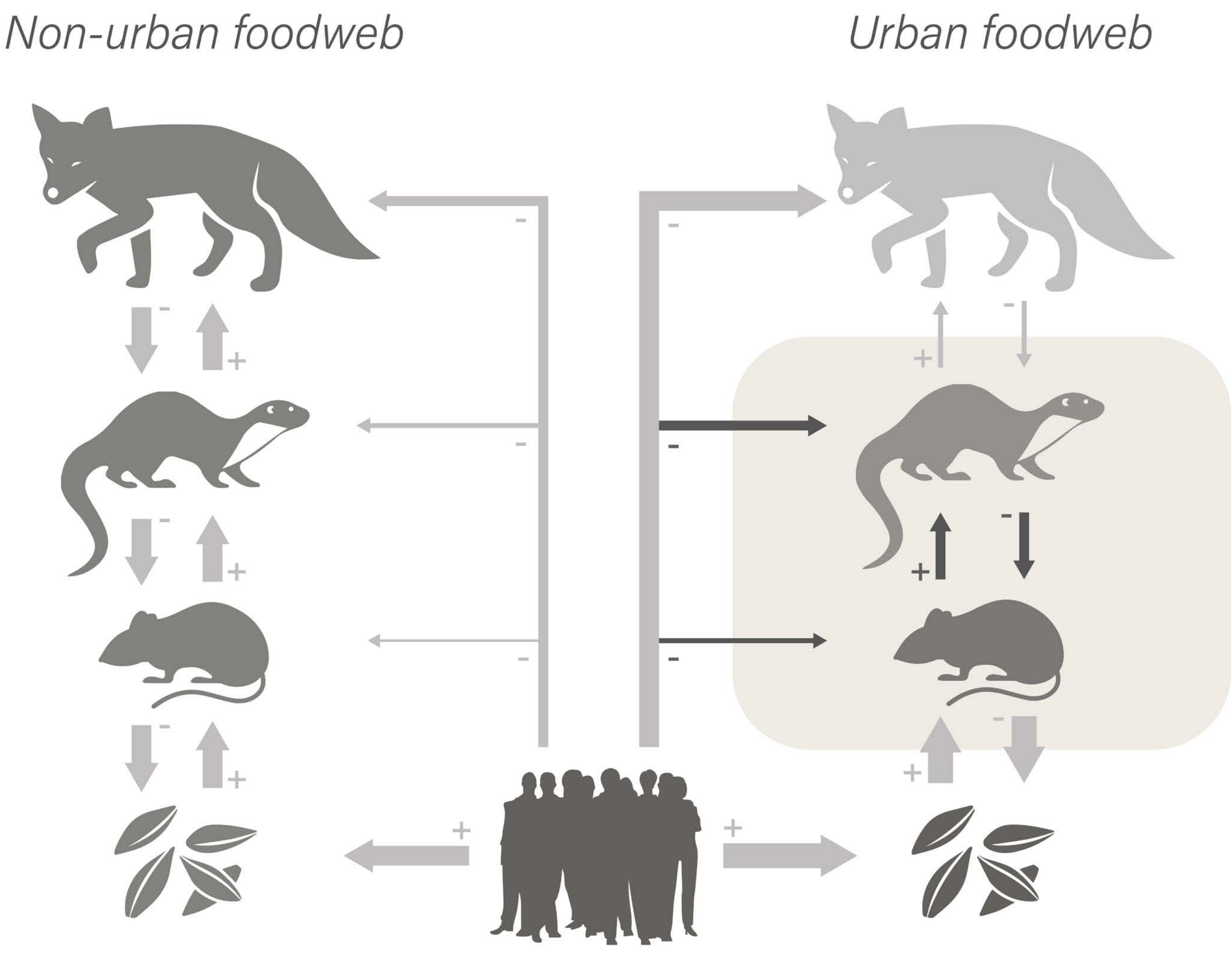


__Figure 2__ Differences between urban and non-urban foodwebs due to human influences, with predator-prey researched in this thesis highlighted. Adapted from (Warren et al., 2006).

1.1.a SITE & SPECIES

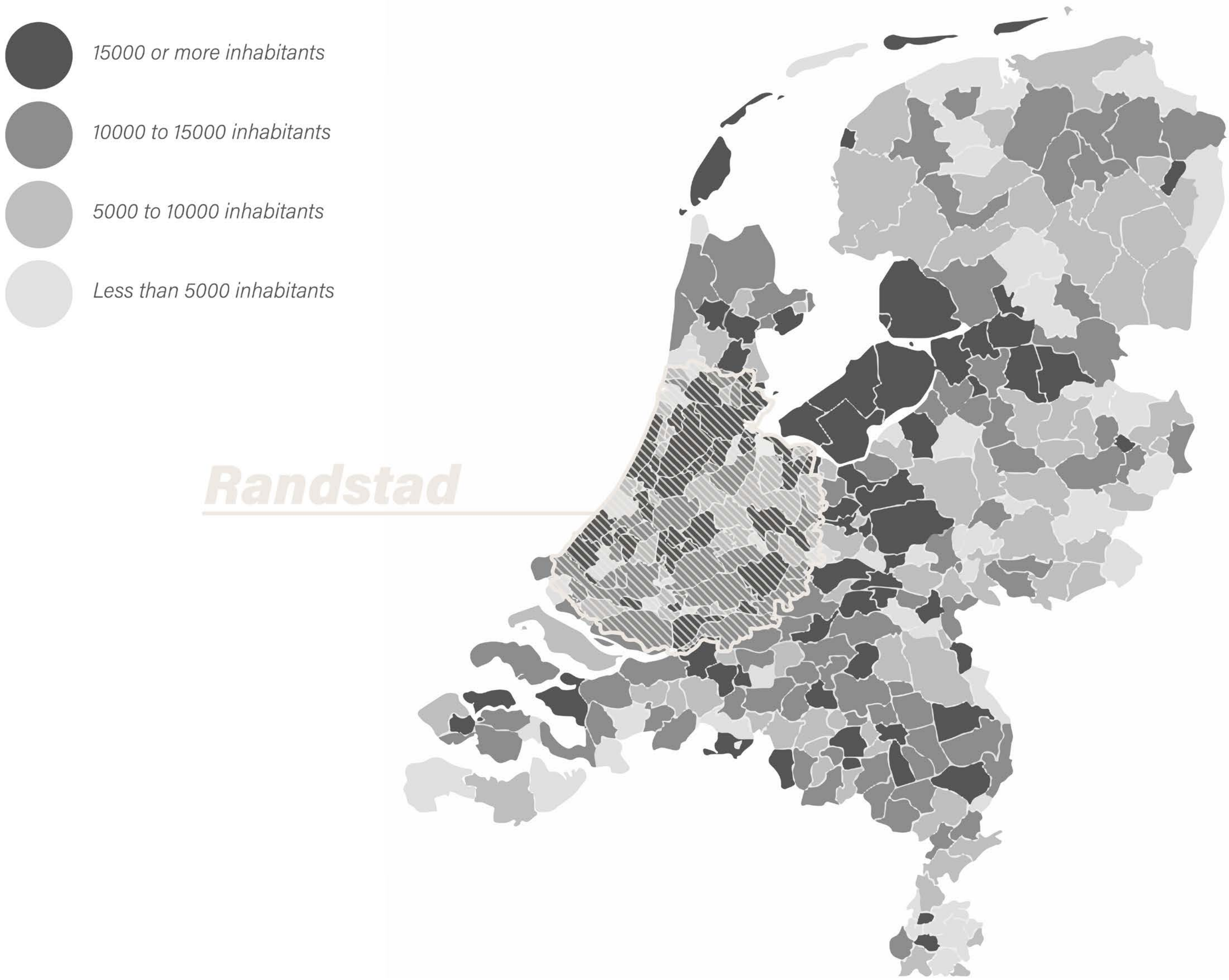
Rapid urbanization is also affecting the Netherlands. The Dutch population has surged from 5 million in 1900 to over 17 million in 2020. Consequently, existing cities have expanded significantly, and rural areas have become urbanized (Centraal Bureau voor de Statistiek, 2016). The combination of high population density and large-scale intensive agriculture has even led to greater biodiversity loss in the Netherlands compared to other parts of Europe and the world (Planbureau voor de Leefomgeving, 2013).

Figure 3 illustrates that most of those urban areas are concentrated in the 'Randstad': a metropolitan region where more than half of the country's population resides. This area has experienced the most habitat loss and fragmentation.

Nevertheless, biodiversity in Dutch cities is now higher than in rural areas, thanks to the variety and diversity of urban landscapes compared to the overexploited and monotonous rural environments (Sweco, 2021).

Urbanization in the Randstad acts as a filtering process, allowing only specific species to thrive. The reduced competition has created ideal conditions, particularly in large cities like Rotterdam, for pests (Zuidema, no date). The Rattus norvegicus, more commonly known as brown rat (figure 4, next page), is one of the most widespread and successful mammals globally. As a true synanthrope, this species has become increasingly problematic in the Randstad, here it accounts for the largest part of rodent-related nuisance (Zoogdier vereniging, no date). For this, reason the brown rat is chosen as an indicator species for rodent infestations in the Netherlands.

Figure 3 *Population density of municipalities in the Netherlands, with the Randstad highlighted. Adapted from (Centraal Bureau voor de Statistiek, 2016).*



In the Netherlands, rat nuisance reports are notably high in Rotterdam, Amsterdam, and Arnhem (figure 5). In 2018, those municipalities recorded 2,161, 2,632, and 1,654 reports of rat issues, respectively (Vegelien and Felix, 2019). Rotterdam, in particular, has experienced a marked increase in such reports over recent years (Kooyman, 2016), as depicted in Figure 6. Despite these numbers not being representative of the actual brown rat population size, They highlight the extent of nuisance and stress experienced by residents of Rotterdam.

The proliferation of brown rats in Rotterdam is largely influenced by the presence of public litter, especially in entertainment districts and areas with heavy tourist traffic. A significant factor contributing to the surge in rat populations is the intentional feeding of other animals, such as ducks. In response, a citywide feeding ban was enforced starting July 1, 2022 (Gemeente Rotterdam, no date a). Despite this measure and the continued use of chemical pest controls, the rat population has not been effectively managed, as evidenced by a rising number of complaints (Didde, 2019).

2018	2200
2019	3200
2020	4000
2021	3800
2022	4000
2023	3800

Figure 6 *Number of rat-related reports within the municipality of Rotterdam per year (Kooyman, 2016).*

Figure 4 *Brown rat (Zcebeci, 2020)*

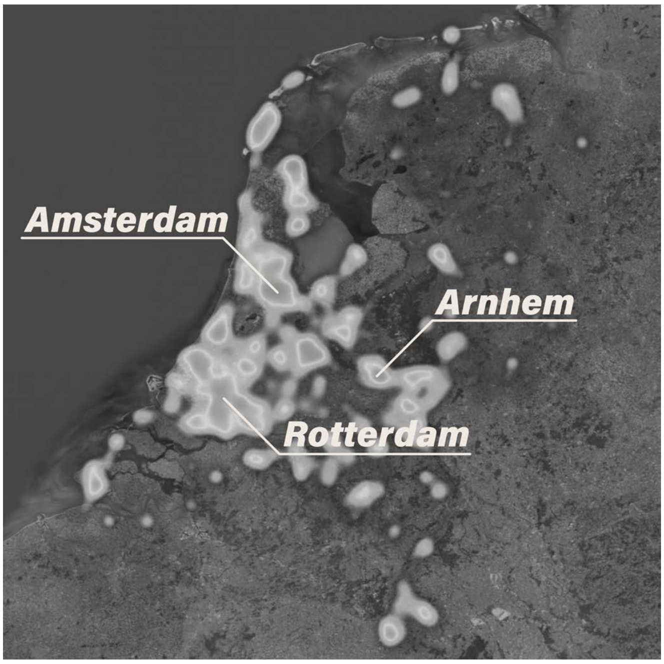


Figure 5 *Observation data of the brown rat in the Netherlands, with concentrations living in Rotterdam, Amsterdam and Arnhem. Adapted from (Waarneming.nl, 2024b).*

An underexplored solution to the rat problem may lie in their natural predators. In the Netherlands, potential predators of the brown rat include mustelids, birds of prey, foxes, wolves, and domestic animals (Zoogdier vereniging, no date). While some of these species have adapted to urban environments, certain challenges possibly hinder their effectiveness in controlling brown rat populations:

1. The animal might pose too great a danger to humans to be accommodated in the city (e.g., wolves).
2. The animal's habitat is so expansive that predation pressure may be insufficient (e.g., foxes) (Bakker, 2024).
3. The animal is too large or not agile enough, allowing rats too many escape opportunities (e.g., owls) (Colvin Bechtel et al., 1996).
4. The animal does not fit well into urban ecosystems, which can disrupt urban food webs (e.g., cats) (Bakker, 2008).
5. The animal is not adapted to urban environments (e.g., pine martens) (Zoogdiervereniging, no date).

These factors collectively constrain the ability of natural predators to control rat populations effectively in urban areas, which partly explains why rats continue to thrive in these environments (Colvin Bechtel et al., 1996).

The writer singles out an animal that might be suitable for exploring solutions to this problem: the *Martes fiona*, commonly known as stone marten (figure 7). The stone marten is a mustelid species that, unlike other species of the *Mustelidae* family, quite frequently occurs in urban areas in the Netherlands (Cöhrs et al., 2020). It has advanced from the east (figure 8) where it already has found habitats in larger cities and surrounding rural landscapes. Across green corridors stone martens have advanced to Amsterdam; yet populations in the Randstad are a relatively rarity (Maanen, 2022). Through natural population dispersal, the animal is expected to reach coastal cities in the Randstad through the dune strip where it naturally occurred in the past (Broekhuizen, Müskens and Klees, 2010). However, through random dispersal by hitching rides on cars, individuals have already managed to establish themselves in many scattered locations throughout the west of the Netherlands. One of such location reached is the city of Rotterdam (Moeliker, 2015; Dekker, 2024). Observation data of the stone marten over the last 3 years (visible in figure 8), shows that Rotterdam quite possibly has one of the, if not largest, populations of stone martens residing within the Randstad. Here, problem (pest) meets solution (predator).

Figure 7 *Stone marten (Buitenleven, no date)*

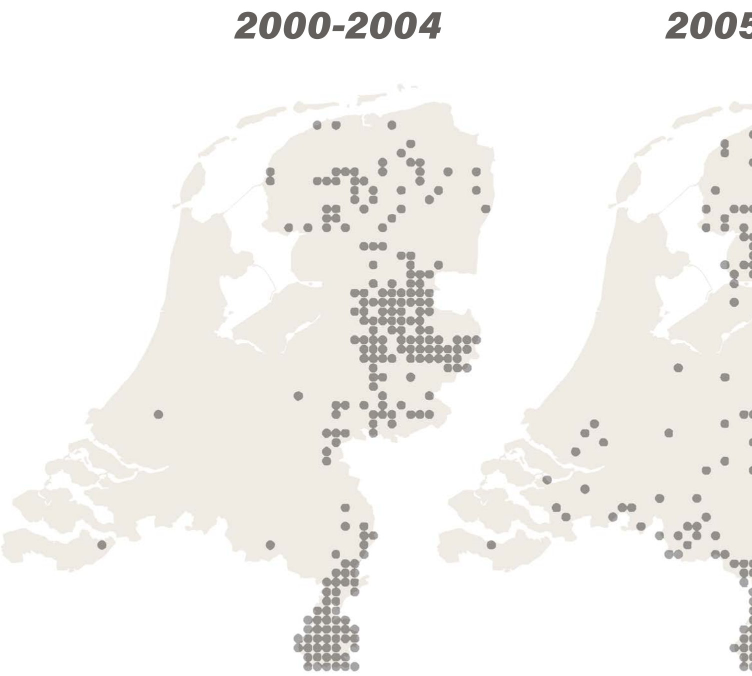


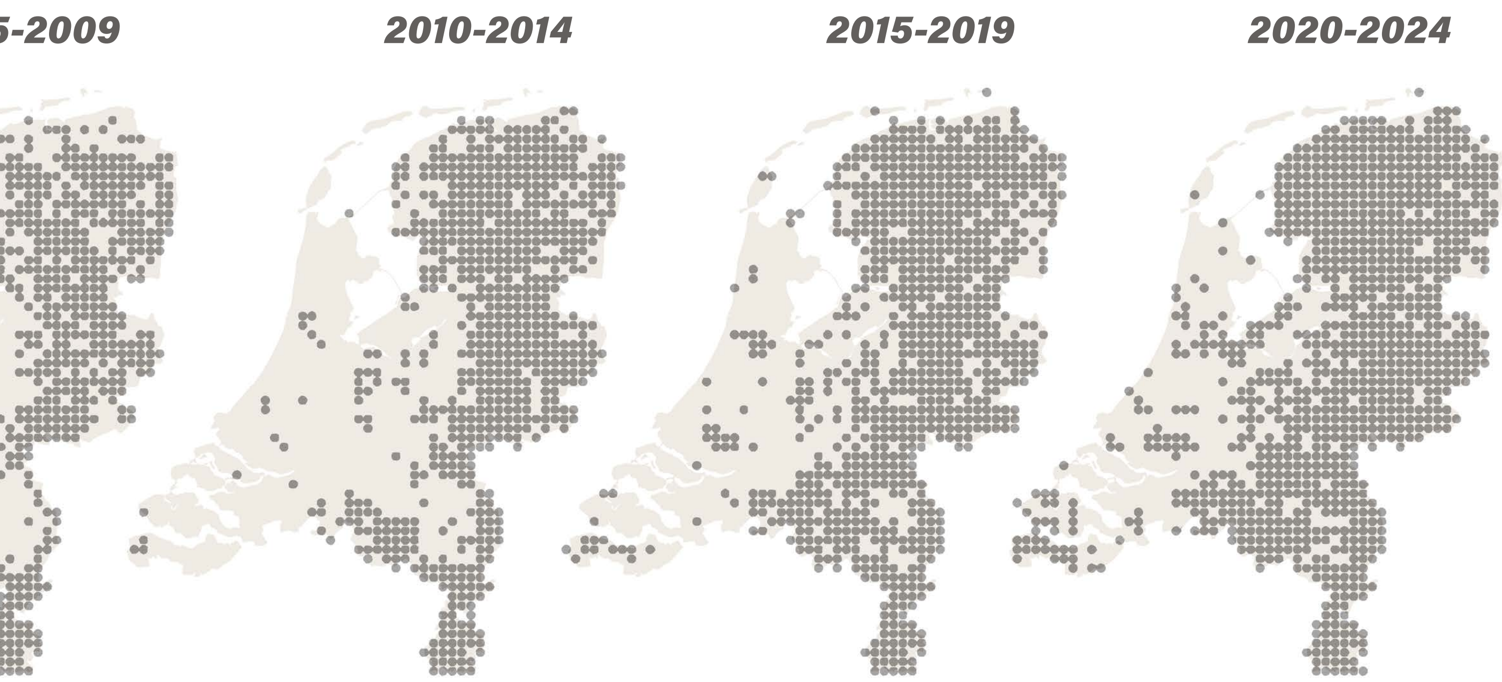
Figure 8 *Population distribution of the stone marten from 2000 to 2024. Adapted from (NDFF, 2024).*

The stone marten is an omnivorous mammal with a versatile menu of both plants and animals, one of its most frequent preys being the brown rat (Broekhuizen, Müskens and Klees, 2010; Cöhrs et al., 2020). Research has shown that the growing stone marten population in Rotterdam is already causing local reductions in brown rat populations (Bakker, 2008; De Havenloods, 2023). Effective predation is ensured due to the agile nature and compact body size, combined with an opportunistic nature makes this predator one easily adapted to these changing urban environments (Broekhuizen, Müskens and Klees, 2010).

The author perceives the stone marten as a keystone species for urban ecosystems. Just as non-urban ecosystems, certain species are critical to the survival of other species within the system (New World Encyclopedia, no date). Within this thesis, the stone marten is appointed necessairy for the sustenance of a healthy, balanced ecosystem, this statement is based on literature stating the keystone role Mustelids play by controlling prey populations (a primary example being the sea otter) (New World Encyclopedia, no date). In a larger context, the stone marten's role in generally improving urban biodiversity can therefore not be neglected.

Despite its important ecological role, the Province of Zuid-Holland, where Rotterdam is located, has placed the stone marten on the 'exemption list.' This means that the animals may be killed if they disrupt spatial development or management (Viegen, 2021). This policy threatens the further establishment of mustelids in Rotterdam. Disapproval of the stone marten is driven by human perceptions of the animal (Buitenleven, no date). The stone marten is controversial due to the nuisance it can cause, such as chewing through car cables, causing disturbances in attics or cavities, and generally contributing to noise and odour pollution (Cöhrs et al., 2020; Maanen, 2022). The issues in human-marten relations and potential improvements are discussed further in the thesis. Given that the stone marten is still relatively rare in Rotterdam, there is an opportunity to prevent it from gaining a negative reputation (Cöhrs et al., 2020).

Figure 9 (next page) illustrates the project's scales used to explore solutions for the identified problem, focusing specifically on the proposed opportunity (brown rat predation) and challenge (human acceptance).



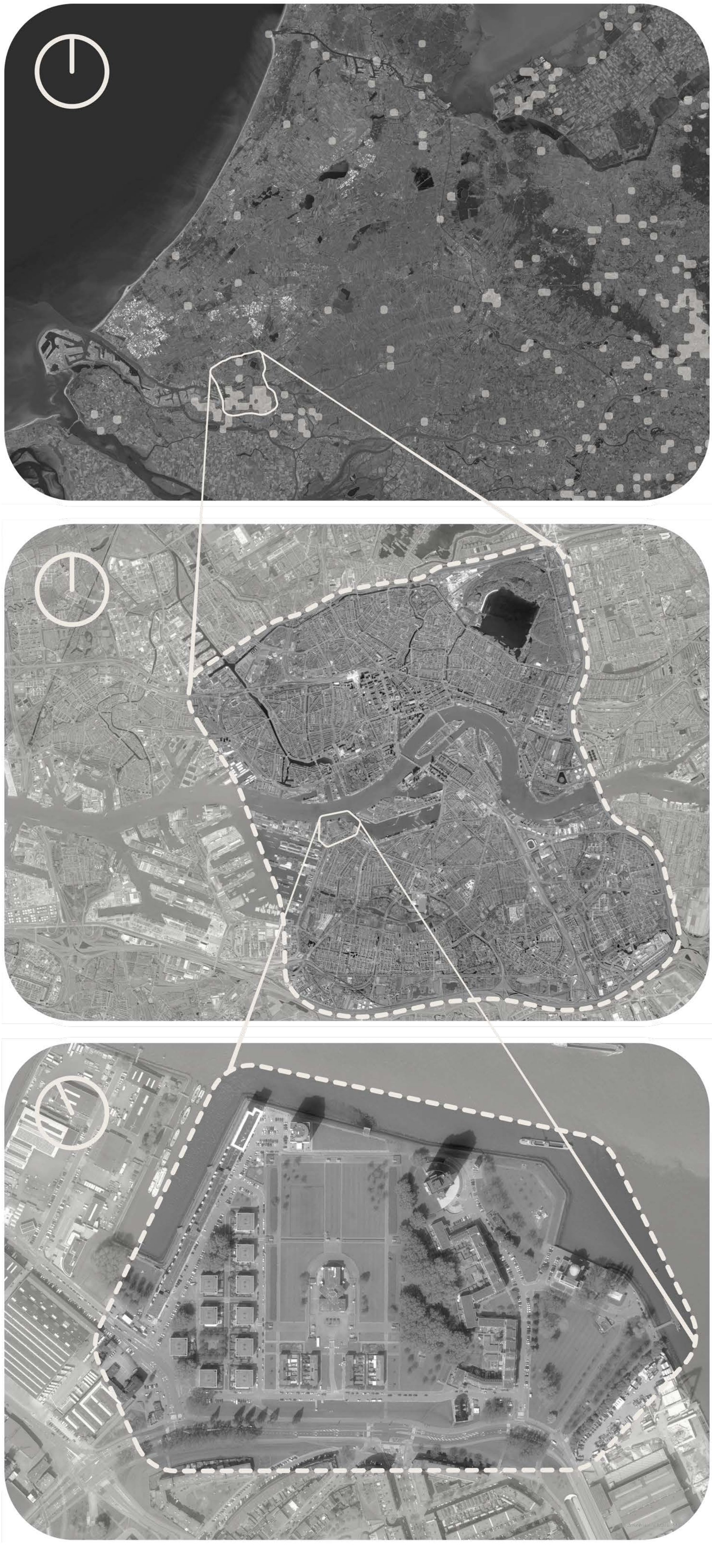


Figure 9 *Observation data of stone marten sightings within the Randstad (Waarneming.nl, 2024a) and consequently the chosen project site. Shown is the used cutout of Rotterdam and the detailed design location of the Dokhavenpark. Further reasoning for both project location is elaborated later on.*

1.2 KNOWLDEGE GAP

Within the field of landscape architecture, biodiversity is fundamentally accepted as important for the provision of many ecosystem services (Ikin et al., 2015; Deliège and Van Damme, 2019). In urban environments, designing 'Urban Green Infrastructure' (UGI) has been suggested to sustain those services and preserve biodiversity. However, the implementation of the UGI's remains challenging due to existing landscape design often overlooking biodiversity (Weisser and Hauck, 2017). Typically, urban open spaces are designed by landscape architects focussing on plants, aesthetic appeal, and functionality for human use. As a result, species' habitat provision often takes a backseat, portraying animals as obstacles if conservation necessitates changes to a project, as is illustrated by the aforementioned 'exemption list' (Russo and Cirella, 2021; Viegen, 2021).

To address this issue, Weisser and Hauck (2017) propose Animal-Aided Design (AAD) as a methodology for designing urban open spaces. Here, a species' life-cycle and corresponding habitat requirements are used to make animals, predominantly keystone species, a core component of the design process, as is shown in figure 10. Although a handful of examples exist of this design methodology, in-depth and detailed adaptation of animal-aided design methodologies is lacking (Deliège and Van Damme, 2019).

Figure 10 *Example of the animal-aided design process designing house sparrow habitat in building districts (Deliège and Van Damme, 2019).*

Although landscape design practices such as AAD can be perceived as unconventional, larger socio-cultural and ecological benefits exist because of it (Deliège and Van Damme, 2019). Landscape architects can contribute to conserving animal species richness in urban environments, which increases the visibility of wildlife in the landscape and thus improving the experiential value of the landscape. Additionally, limiting nuisance from species perceived as problematic and creating green spaces with added recreational value (Deliège and Van Damme, 2019). Such understated benefits are explored within this thesis.

Within urban environments, specifically open spaces, the possibility of humans co-occuring with predatory species is insufficiently studied (Delach, Smith and Fascione, 2012). Current research mostly focusses on the human perception of predators, questioning how humans can manage predatory populations while mitigating harmful impacts. Here, the focus is more on human wildlife co-occurrence than co-existence, (Nyhus, 2016). Whilst this thesis predominantly researches the possibilities of human-marten co-occurrence (see key concepts), certain measures taken highlight indirect mutual benefits of open space redesign.

This is because landscape architectural projects suffer from the problem where the focus is on designing for nature instead of designing with nature, which is even more so the case in urban areas where nature is even viewed as a tool to design for humans (Russo and Cirella, 2021). On the other side of the spectrum, conservationists are often in favour of protected areas, also in cities, with little access for humans and no human design (Weisser and Hauck, 2017).

There is a considerable amount of research centred on the use of predators as natural pest-control (Luff, 1983). In recent years, natural pest control has been accepted as an important ecosystem service, which causes us to move from chemical pest control to integrated pest management (Daily, 2012). Yet, most studies focus on agricultural landscapes, as ecosystem service loss can cause crop production instability. Within the field of landscape architecture, the possibility of design to re-establish or re-balance predator-prey relationships is not often covered, yet these and similar problems can be resolved by effectively designing urban open space.

For this thesis, species and site specificity are at play. Research on the behavioural ecology of stone martens, including populations living in the Netherlands, has been done elaborately (Nelck and Van Pelt, 1996; Müskens and Broekhuizen, 2005; Herr, Schley and Roper, 2009). This research already clarifies that stone martens are well adapted to urban conditions and urbanization has surprisingly little impact on their socio-spatial organization. There is a lack of scientific literature on stone marten populations and individuals in Rotterdam. However, substantial grey literature exists, particularly concerning the human-marten relationship (Bakker, 2008; Moeliker, 2015; De Havenloods, 2023). Overall, there is a significant gap in scientific research on potential landscape architectural strategies to mitigate the nuisance caused by stone martens.

In general, a notable divide is observed between the fields of behavioural ecology and landscape architecture. This thesis will aim at bridging this gap

1.3 THESIS STATEMENT

1.3.a RESEARCH OBJECTIVE

In this thesis, it is investigated how landscape architecture can contribute to stone marten populations in urban open spaces through the adaptation of urban green infrastructures.

In general this body of work will make readers understand the importance of designing urban open spaces, using green infrastructure, to account for animal liveability, improving biodiversity and creating a healthier ecosystem. By using the stone marten as an example, species-specific benefits that a stone marten population can bring to urban areas are highlighted. The goal is to enable designers and planners to incorporate animal-aided spatial interventions when (re)designing urban open spaces, in this case ensuring better support for stone martens in the future.

The term 'safely' within the main research question refers to the term 'stable' used in the second sub-research question. Stability is of great importance as enormous population growth could cause stone martens to become a new pest. In addition, it can lead to excessive predation, which can dilute possible prey populations too much (Nyhus, 2016). Although this thesis primarily focusses on improving the liveability of urban open spaces for stone martens, the second research question aims at creating guiding measures for the adaptation of an open space system that limits exponential population growth. This system both aims at creating a balanced predator-prey relationships and (mostly) separate human- and marten-occupied spaces to provide human-marten co-occurrence. To be elaborated in text.

1.3.b RESEARCH QUESTIONS

MRQ

How could landscape architects (re)design urban open spaces in order to safely adopt a stone marten population?

SRQ1

What are habitat requirements needed to facilitate a stone marten population in urban areas?

SRQ1a

How can habitat provisions for stone martens improve their predation pressure on brown rats in urban areas?

SRQ1b

How can habitat provisions for stone martens be adapted to facilitate their co-occurrence with humans in urban areas?

SRQ2

How can open space system design be adapted to create an ecological network for a stable stone marten population in urban areas?

SRQ3

How can Urban Green Infrastructures be used or modified to support a stone marten population?

1.4 KEY CONCEPTS

ECOSYSTEMS IN URBAN AREAS

This thesis will research how landscape architecture could be used to aim at creating a more balanced ecosystem in urban areas. An ecosystem in urban areas is an ecosystem situated in an environment in which people live at high densities, and where built structures and infrastructure cover much of the land surface (Russo and Cirella, 2021). The large interplay and often co-dependency between humans and animals within urban areas makes it different from other ecosystems (Russo and Cirella, 2021). In addition, animals in urban areas have been subjected to rapid natural selection, while species in other ecosystems have more time to adapt. Although interspecies relationships are important for creating a balanced ecosystem, this thesis mostly focusses on the marten-rat relationship.

LIFE HISTORY

Life history refers to how a species develops, survives, and reproduces throughout its existence, involving trade-offs in living patterns to ensure successful survival in its environment. It encompasses age-, stage- and sex-specific patterns and events within the life cycle. Understanding a species' life history is essential for effective conservation efforts (Bednekoff, 2019). Key life events, used within this thesis, that define the stone marten's life cycle include (but are not limited to): mate-guarding (males), mating, pregnancy (females), nesting (females), rearing, maturing (pup), dispersal (pup), territory establishment (juvenile), territory reduction (senior) and death (Broekhuizen, Müskens and Klees, 2010). Mentioned events are vital criteria for stone martens to determine suitable habitats.

HABITAT REQUIREMENTS

A habitat is a space that meets all the environmental conditions for an organism to survive. The most basic components a habitat for most mammals must provide (as used within this thesis) are space, shelter, cover and food (Stanley, no date).

Although its habitat needs are largely dependent on an individual's life history stage, these habitat requirements remain constant throughout the animal's whole life cycle. These habitat requirements possibly vary with daytime (such as the nocturnal foraging activity) and seasonal changes (such as the fruit-based diet during summer/autumn).

HUMAN-WILDLIFE CO-OCCURRENCE

Marten-related conflicts arise due to insufficient habitat in urban open spaces, forcing martens to coinhabit spaces with humans. With human-wildlife coexistence*, both parties share the same space without posing significant threats to each other's wellbeing (Nyhus, 2016). Spatial separation between human and marten-occupied areas is desired to better enhance their relationship and resolve direct conflicts. Addressing this involves understanding the underlying issues and finding acceptable solutions for spatial co-occurrence (Delach, Smith and Fascione, 2012). Therefore this thesis aims at adapting the concept of human-marten co-occurrence* (Nyhus, 2016). Co-dependancy is aimed to reduce, still indirect mutual benefits exist through the provision of other important ecosystem services (Apfelbeck et al., 2020).

LANDSCAPE OF FEAR

Habitat requirements of stone martens and brown rats overlap extensively through intraspecific competition* over shared resources martens can often outcompete rats. For this competition to occur, one or more resources should be limited in supply, according to the respective population sizes (Mainwaring and Hartley, 2019). Apart from direct predation and reduction of resource availability, a 'landscape of fear' is created. This theory defines the spatial variation in prey perception of predation risk (the likelihood of a prey animal being killed by a predator). A divide between perceived and actual risk is created to further reduce brown rat population size (Bleicher, 2017).

OPEN SPACE SYSTEM DESIGN

In ecology, which studies the interactions between organisms and their environment, landscape ecology examines how landscape patterns impact processes across various temporal and spatial scales (Turner, 1989). This thesis focuses on the interaction between martens and urban landscapes, specifically within urban open spaces (UOS). The term "open space," as used by landscape architects, refers to land areas that are mostly unbuilt (Forman and Godron, 1981). In this thesis, urban open spaces are defined as unbuilt, publicly accessible areas within populated settlements. Open space system design will be adapted by dividing spaces based on their forms and functions. Spatial concepts will translate principles of landscape ecology into practical design guidelines, as is often done by landscape architects and spatial planners (Penteado, 2023). A mosaic of spatial elements Is used based on literature by Foreman (1995).

URBAN GREEN INFRASTRUCTURE

UOS predominantly include greenery, which mainly consist of Urban Green Infrastructures and various manmade grey infrastructures (Jansson et al., 2020). Urban Green Infrastructure, or UGI, is a collective term for diverse types of green structures. Norton et al (2015) refers to UGI's as: *natural features, spaces, and systems, both public and private, that provide various environmental, social, and economic benefits".* Although private UGI's will not be used, this definition is adopted. The primary aim of UGI is often to enhance the quality of life for urban residents through various ecosystem services (Jones et al., 2022). This thesis primarily focuses ecological benefits for stone martens. Given the significant variation in UGI typologies across different sources, multiple will be integrated (Braquinho et al., 2015; Ecological Institute, 2020; Jones et al., 2022).

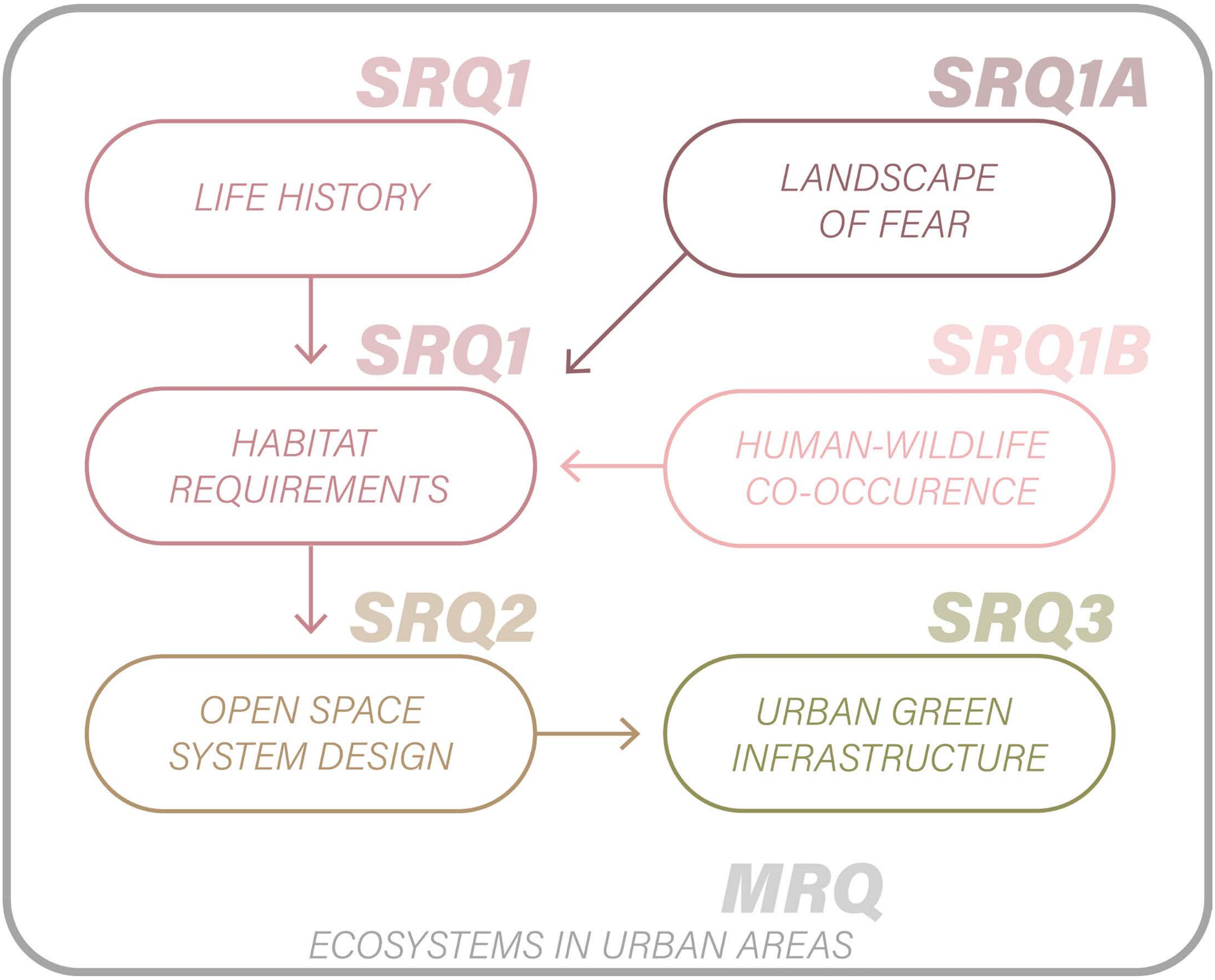


Figure 11 *Conceptual framework of key concepts and adjacent research questions.*

1.5 METHODOLOGICAL FRAMEWORK

This research has adopted a Research through Design approach (RtD). RtD bridges a gap between the endeavors of research and design, which are often seen as separate from each other (Lenzholzer, Duchhart and Koh, 2013). This is often done by undergoing an iterative process where design alternatives and design interventions are assessed and adapted based on gathered knowledge. This thesis adapts a constructivist view on the RtD-approach, as defined by (Lenzholzer, Duchhart and Koh (2013). This view suggests new qualitative constructs to be embedded within the built environment. These often respond to changes in ecological behaviour, urban tissue and the social environment, all of which appear to a certain degree within this body of work. By solving (socio-) ecological issues, through actively employing designing within the research process, the constructivist view was integrated. At the basis of this thesis' RtD design process stands Research for Design (RfD), aimed at informing design to improve its quality and reliability (Lenzholzer, Duchhart and Koh, 2013). The sub-research questions aimed at producing a set of design principles, guidelines and criteria, as defined by Brink et al. (2017):

1. Design principles are strategic ways of guiding designers in their search for solutions by designing. These strategies are neither specific nor totally universal.
2. Design guidelines provide adjacent knowledge in the form of recommendations, creating possible solution that address design principles. This helps to improve the design process.
3. Design criteria are specific goals set for the design to be achieved in order to be successful. In other words, to effectively adapt design guidelines and thereby solve design principles.

Given the variability and ambiguity in the definitions of these concepts across different sources, a representative example from this thesis is presented:

1. Principle: "Create an ecological network in urban open space to facilitate a stably growing stone marten population [***IV***]."
2. Guideline: "Create habitat patches that meet female martens requirements [***8***]."
3. Criteria: "Patches should preferably be 15 ha for females and 30 ha for males [***8b***].

The basic structure of how information has been gathered, analysed, and evaluated through a design/ research practice is described in figure 12 on page 23 The necessary materials for this methodology are listed in figure 13 on page 25. A concise overview of this process will now be provided.

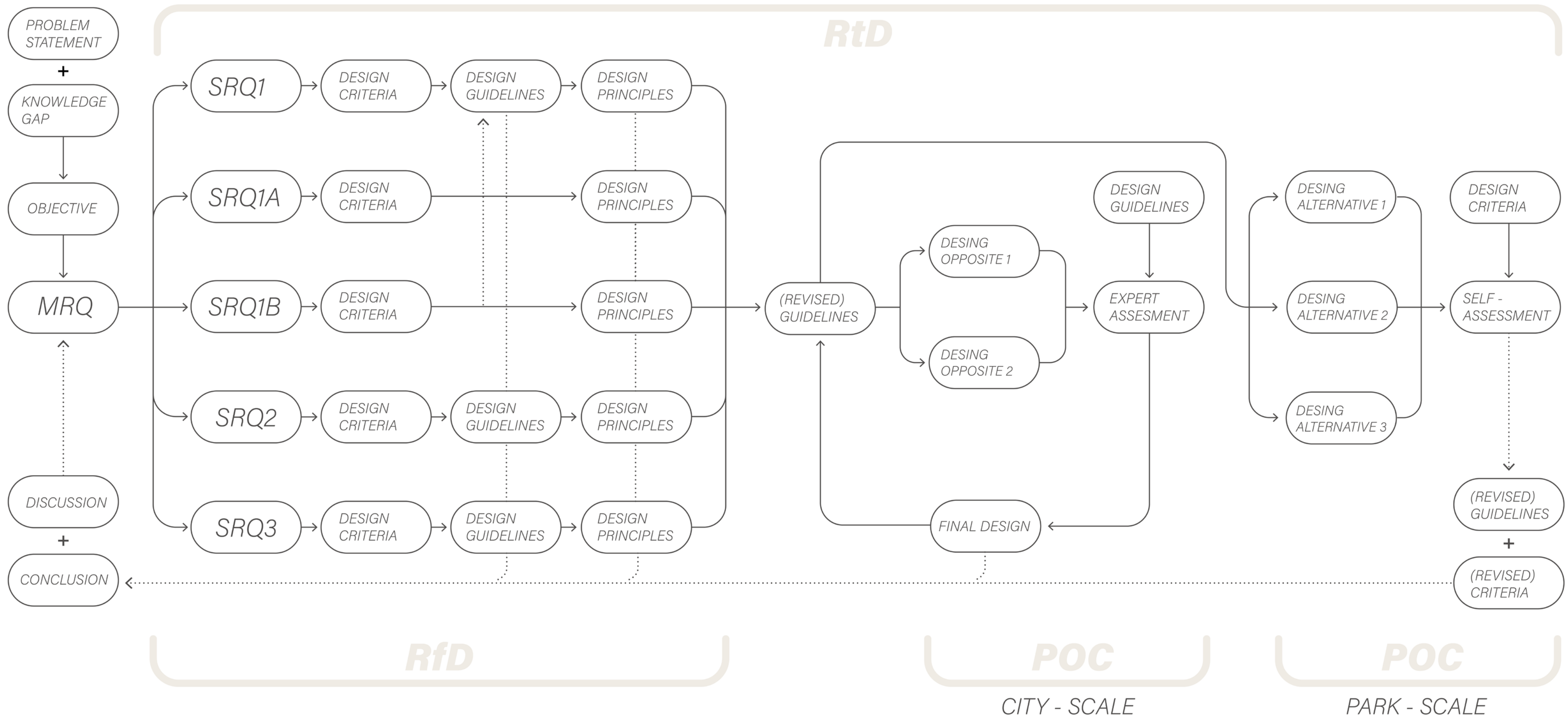


Figure 12 Methodological framework of the design process

RESEARCH FOCUS

SRQ1 delineates the habitat requirements of stone martens as design guidelines with necessairy criteria. This was done by reviewing books on the life-cycle of the species, and gathering research reports on the behavioural ecology of the animal.

SRQ1A defines how design guidelines can be adapted to improve predation on rats by martens. This was done by formulating adjacent design criteria based on scientific literature. Observational data of both species' populations was gathered from within the Netherlands as much as possible.

SRQ1B similarly produces design criteria to guide the design guidelines of SRQ1 towards providing human-marten co-occurrence. This question has partially delved into grey literature to assess the current human-marten relation within the Netherlands, where possible even Rotterdam, and how the human perception can be improved.

SRQ2 creates a framework in which the ingredients of abovementioned question can be fitted. Literature by Dramstad et al., 1996) will delineate spatial concepts and according criteria for population distribution are catered towards a stable stone marten population. Scientific literature on the socio-spatial organisation of the marten has been valuable for answering that question. In this way design criteria from SRQ1B/2 aimed at limiting exponential population growth, e.g. stabilizing a marten population.

SRQ3 relates the design outputs of previous questions to different UGI characteristics. This broadly defined concept is based in both scientific and non-scientific literature. Self-assessment of the suitability of different UGI typologies has offered more practical tools for the integration the research's finding within landscape architecture. It is important that they provoke a translation of 'what is' to 'what could be' (Smith et al., 2016).

In general, design guidelines and principles of the research questions are partially used to answer the main-research question. In this way, a blueprint for marten-friendly (re)design of urban green space is provided.

DESIGN FOCUS

The project area's design was used as a proof of concept (POC). A POC is a demonstration showing that a concept, idea, or theory is feasible and can be practically implemented (Jobin, Le Masson and Hooge, 2020). In this thesis, it helped to confirm the feasibility of proposed design principles, guidelines and criteria for general implementation. This was done by addressing two scales.

The city-scale level explored the possible configuration of an ecological marten network within Rotterdam's urban open spaces. An overview of the population distribution was combined with a thematic analysis of the city. Design guidelines (and criteria) applicable to this scale have been used to create two design opposites. The first alternative strictly followed design criteria whereas the second alternative adheres more to design guidelines. Both alternatives link to existing well-known green structure visions of Rotterdam to provide guidance and improve validity. To assess the design opposites, the parties involved with corresponding visions were consulted for a qualitative and quantitative assessment. Four experts were used, divided into two group sessions, and their input was used to revise design guidelines and create a final design.

Revised guidelines and criteria were used to explore a possible design for stone marten habitat patches and dispersal corridors on a smaller scale. The Dokhavenpark was chosen for the park-scale design as it is an important site within the final city-scale design. An exploded layered analysis of the site composition, concerning spatial information both directly and indirectly related to the research, was gathered. Recognizing specific site characteristics has contributed to adopting and improving guidelines (Oshan et al., 2022). This analysis served as an inspiration for the development of three varying design alternatives that propose possible future trajectories for this specific site. As they present the large variety in design possibilities derived from this research, no final design was created. In contrast, the respective alternatives were self-assessed based on design criteria.

After revising the established criteria, a comprehensive conclusion and discussion for this thesis's research have been formulated. This was based on design principles, guidelines, criteria and main outtakes of the design practice and their assessment.

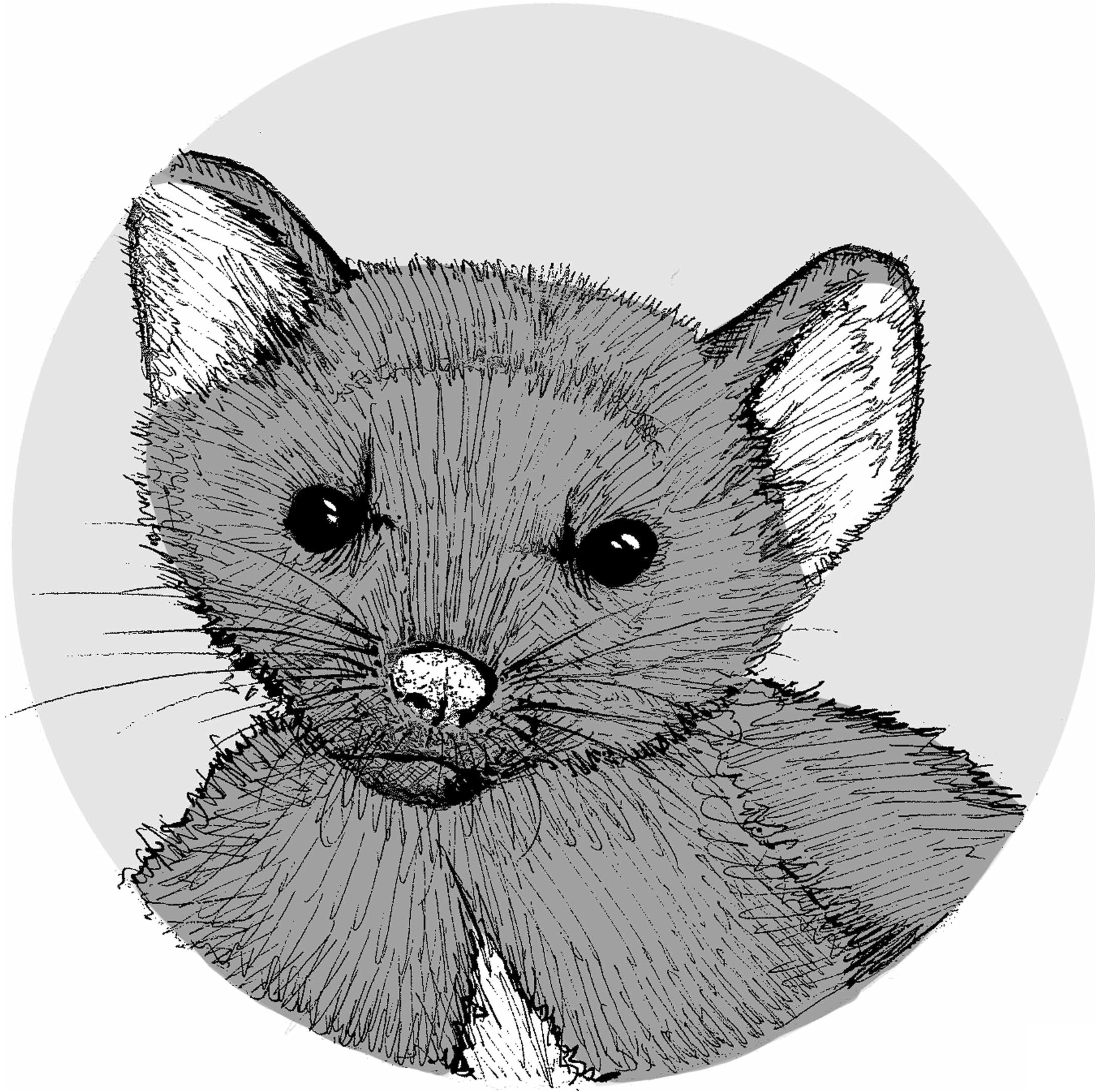
MRQ	SRQ / PoC	(Key) concepts	Methods	Materials	Outputs
How could landscape architects (re)design urban open spaces in order to safely adopt a stone marten population?	SRQ1: What are habitat requirements needed to facilitate a stone marten population in urban areas?	Ecosystems in urban areas Habitat requirements Life history	Research through design Research for Design Literature review	Books, scientific journals and research reports	Design principles Design Guidelines Design criteria
	SRQ1A: How can habitat provisions for stone martens improve their predation pressure on brown rats in urban areas?	landscape of fear			
	SRQ1B: How can habitat provisions for stone martens be adapted to facilitate their co-occurrence with humans in urban areas?	Human-marten co-occurence		Grey literature	
	SRQ2: How can open space system design be adapted to create an ecological network for a stable stone marten population in urban areas?	Open space system design			Design Guidelines
	SRQ3: How can Urban Green Infrastructures be used or modified to support a stone marten population?	Urban Green Infrastructure		Grey literature	Design Guidelines
	Proof of concept design principles, guidelines and criteria on city scale-level	"Ecological network"	Landscape analysis	Spatial data GIS and municipality Green structure visions	Thematic analysis maps
			Testing design opposites	Expert assessment	City-scale design opposites Final design Visualisation
	Proof of concept design principles, guidelines and criteria on park scale-level	"habitat patch" & "dispersal corridor"	Site analysis	Spatial data GIS and municipality Grey literature Fieldwork	Exploded analysis maps
			Testing design alternatives	Self-assessment	Park-scale design alternatives Cross-sections

Figure 13 Summary of methods, materials and outputs.

HABITAT

2

REQUIREMENTS



2.1 SRQ1 - LIFE HISTORY

INTRODUCTION

The stone marten is a small mammal in the Mustelidae family, other species in this family occurring in the Netherlands include the weasel, stoat, American polecat, mink, Eurasian badger and Eurasian otter. Most similar species to the stone marten in Europe is the pine marten (figure 14, p.29). As names suggest the biggest behavioural difference is the stone marten's preference for stony biotopes and the pine marten's preference for forests. Both species are very agile and can easily traverse through such landscapes (figure X) (Broekhuizen, Müskens and Klees, 2010).

The stone marten is approximately the size of a domestic cat, with males being longer and heavier than females (figure 14). The coat is primarily ashen to grey-brown, featuring a white throat patch that extends to the front legs. Its presence is often signalled by droppings containing remnants of hair, feathers, bone fragments, and kernels. Its paws contain smell glands which the animal also uses to mark its territory. In contrast to the stone marten, the pine marten is generally more slender, possesses yellow-brown fur, larger ears, black nose and a black undercoat (Broekhuizen, Müskens and Klees, 2010).

Figure 14 *Species portrait stone marten*

Figure 15 *Mating martens (Waarnemingen.nl, 2024a).*

2.1.a. MATING

Mating for stone martens takes place in summer between mid-June and mid-August. Just before the mating season starts in June, testis development in males' peaks (Herr, 2008). This is why at the start of June males already tend to be more aggressive to same-sex individuals. After the mating season, during autumn, some males were found to still have well developed testicles and free sperm present even though most males more logically had this hormone composition just before the mating season. This could be explained by juveniles partly inhabiting their father's habitat, here the father could be suppressing the sexual activity of the juvenile (Broekhuizen, Müskens and Klees, 2010). *Borders between male territories will be created to help decrease the need for territorial aggression [**1**]. This can be done by using borders that are either permanent or temporarily strong within the period of high testis development [**1a**].*

Similar to other mammals, such as seen by urban-living red foxes, stone martens use the built environment to border off their territory (Herr, 2008; Kimmig, 2021). Infrastructural barriers such as streets and waterways can form a divide between two male marten territories. *For this reason, design can use existing infrastructural barriers to divide male marten territories [**1b**]. As will be elaborated in chapter 3, edge habitat can strengthen this territorial divide through induced marten stress factors [**1c**].*

During the mating season, males tend to conquer females by screeching, hissing and fighting off other males (Zoogdiervereniging, no date). The male's stench is quite strong during this period, making it unnecessary to design something that encourages male-female encounters. *Still, induced habitat connectivity due to the provision of corridors will promote such interactions, especially for less densely populated areas [**3**].*

Females are fertile for about ten days in which they could mate with multiple males, yet typically females tend to want to mate for just one, two or at most three days. This is partly the reason why stone marten females tend to mate with just one male. The other reason is the fact that males tend to stay in close proximity to their partner, even sharing the same den (Broekhuizen, Müskens and Klees, 2010). *By designing male territories to totally encapsulate that of female martens territorial behaviour between males will decrease [* ***4*** *].*

In general, females are impregnated every summer, but in the Netherlands there have been reports of urban living stone marten females frequently skipping reproduction. This has been attributed to higher marten population densities (Herr, Schley and Roper, 2009). Within heading 'territory', it will be elaborated how the right male-female ratio could decrease this effect in urban areas. *Apart from intersexual territorial overlap provision, designing high intensity used areas of males and females close to each other hypothesizes that the likelihood that all females will be mated increases [* ***4a*** *].*

Each stone marten habitat requirement within this chapter is represented through a landscape diagram showing the spatial implication of adjacent guideline and criteria. The respective design criteria within these figure are referred to in-text.

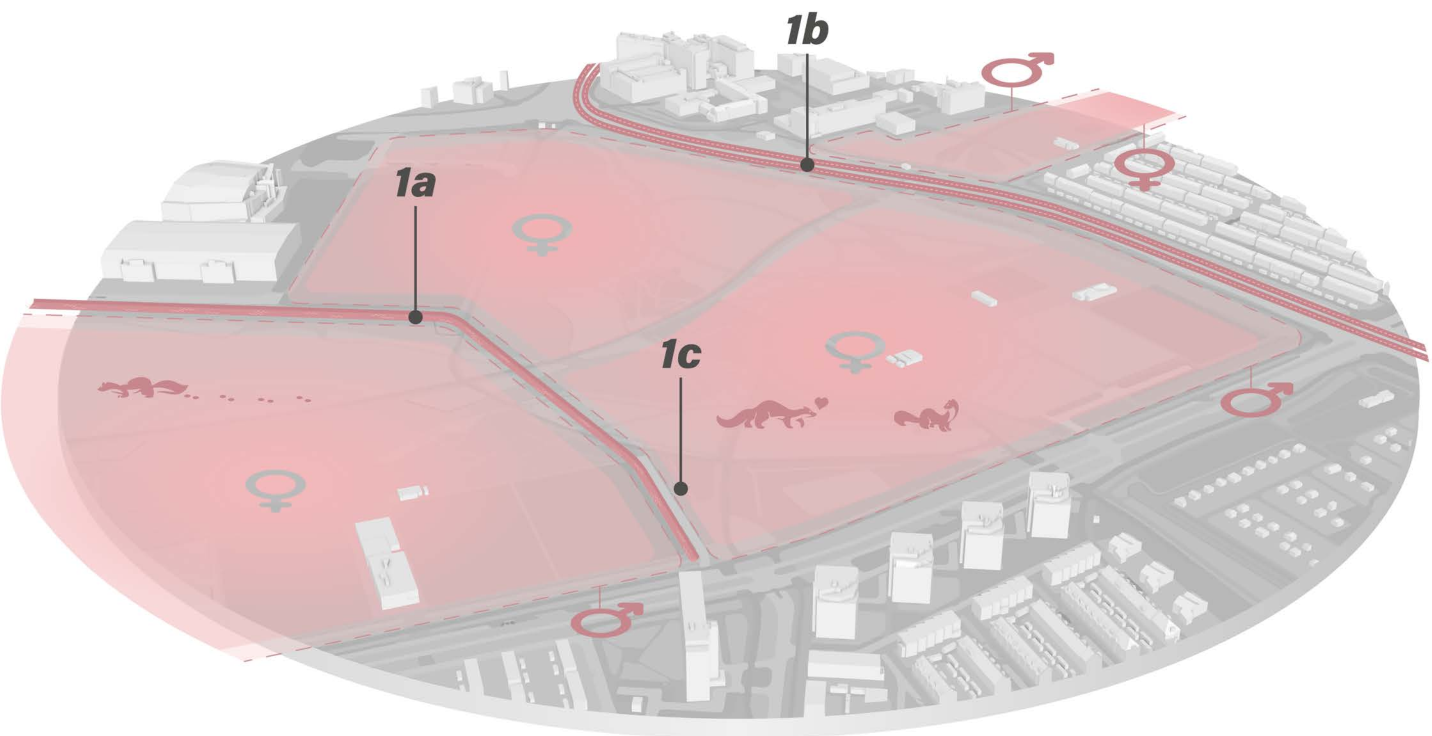


Figure 16 *Diagram for guideline 1 (mating) and corresponding design criteria.*

Figure 17 *Nesting marten pups (ANRH, 2010).*

2.1.b. NESTING & REARING

The reproductive cycle of stone martens is characterised by delayed implantation causing the gestation period to be 8,5 to 9 months (Herr, 2008). The pups are born between early March and mid-April. The average litter size is about 2 to 3 pups, with a range from one to five pups (Broekhuizen, Müskens and Klees, 2010). At the end of the pregnancy the female makes itself a nest* in a quiet and secluded place, using material already available or gathering loose nesting material. By pulling material towards her, a raised edge is created around the nest, providing the pups with extra shelter (Broekhuizen, Müskens and Klees, 2010). *Due to the long gestation period, multiple permanent nests will be created within a female's habitat [* ***2*** *]. Based on the observation data of denning activity by Herr et al. (2010) concerning a stone marten population in Nijmegen, Netherlands, it is estimated that having at least five suitable nesting sites within a female's habitat will provide sufficient nesting options [* ***2a*** *]. These nesting options should have sufficient loose material within vicinity of the nest [* ***2b*** *]. The nest must also be located in a quiet, secluded spot [* ***2c*** *].*

Similar to other carnivores, stone martens prefer nesting/denning locations to have a latrine: a designated places close to the nest/den where animals habitually defecate and urinate. Amongst mustelids, latrine sites are often designated for territorial scent-marking (possibly increasingly important for nesting martens) and hygienic purposes (Buesching and Jordan, 2022). *For these reasons nests will be designed to have a latrine within close proximity [* ***2d*** *].*

After eight weeks the nest is no longer maintained (Broekhuizen, Müskens and Klees, 2010). The pups* consume solid food after seven weeks but will not leave the den until they are nine weeks old. The area around the nest is used by the mother to deposit prey, slowly teaching her pups to walk and protect their prey (Zoogdiervereniging, no date; Broekhuizen, Müskens and Klees, 2010). *For this reason, the nest location should be spacious, providing plenty of space for the female martens to rear their pups through hunting [2e]. In similar vein, it is important that easily obtainable food resources are available in the direct vicinity of the nest for pups to learn how to forage [* ***2f*** *].*

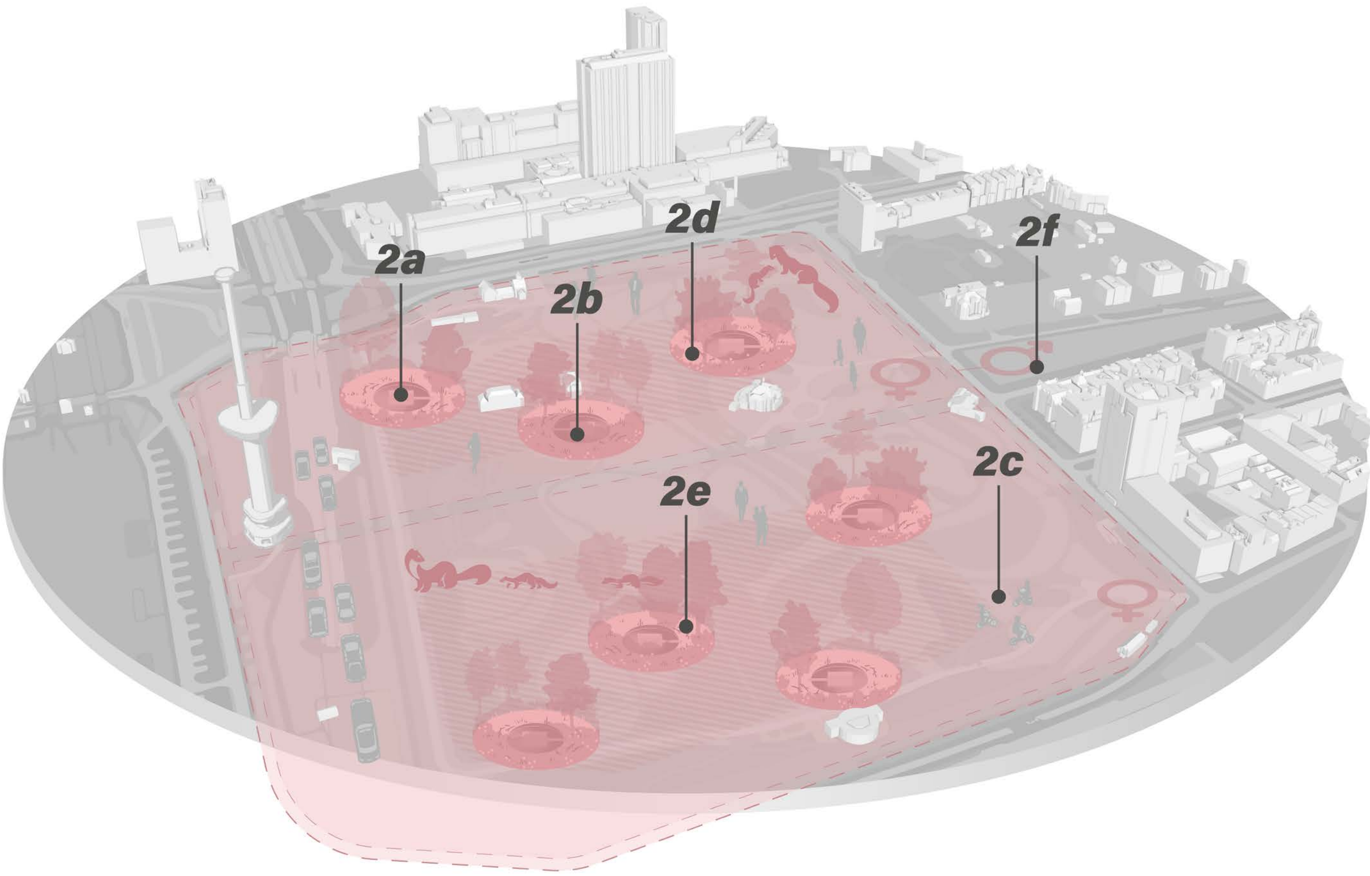


Figure 18 *Diagram for guideline 2 (nesting & rearing) and corresponding design criteria.*

Figure 19 *Juvenile in search of territory (Wildwood, 2015).*

2.1.c. PUP DISPERSAL

Dispersal of the pups away from their birthplace happens from August onward, when they go looking for their own habitat (Herr, 2008; Broekhuizen, Müskens and Klees, 2010). For stone martens, a female biased natal dispersal is often observed. This means that, after birth, female pups are more frequently and quickly dismissed by the mother than male pups as these female martens pose sexual competition for the mother. This often causes female pups to be dispersed further away from the nest more so than male pups (Larroque et al., 2016).

FITTING MODEL

Pups can find their own habitat in two ways. The first method is according to a so-called 'fitting' model. If a male parent's territory is large enough it can be shared with one of the male pups. Through rearranging, both individuals can still live independently from each other, but not pose mutual threats. The pup then uses the part of the territory the parent uses the least (Broekhuizen, Müskens and Klees, 2010). For exponentially increasing the stone marten population within an urban area the 'fitting model' is favoured, as it densifies individual male habitats and increases succession within a certain area. *Increased habitat quality of UOS is expected to provide more shelter opportunity [* ***5*** *] [* ***6*** *] and food availability [* ***7*** *] than a male marten uses on average in respect to the territorial areal designed for, temporarily fitting will possibly occur more frequently. Restricted population densification is further researched in SRQ2 as, on the other hand, the fitting model increases the chance of overpopulation (also see discussion).*

FIGURE-IT-OUT-YOURSELF MODEL

The second method for habitat finding is according to a so-called 'figure-it-out-yourself' model. Here, the pup has to flee the nest after approximately three months, as it would otherwise pose a threat to the parent's resources. The animals are banned from the parent's habitat; if lucky they find a suitable habitat in close proximity, and if not the juveniles* sometimes have to cover exceptionally long distances (Broekhuizen, Müskens and Klees, 2010). *For optimal pup dispersal a network of corridors will be created that connect possible habitats [**3**]. In this way juveniles can safely cross large distances without creating conflict.*

*Within annual period of dispersal, it is important that set corridors have sufficient habitat qualities to facilitate marten juveniles throughout their journey [**3a**]. According to Klees (2024) it is important that (especially narrow) corridors have multiple traversal possibilities [**3b**] at different heights for safe and sheltered movement and multiple vegetational layers provide ample denning possibilities. Additionally, fruiting plants can line the corridors [**3c**] to consistently provide easy food resources for these lesser experienced hunters.*

When traversing, stone martens choose spaces based on a combination of shelter opportunity and openness, the latter is to remain vigilant for potential dangers while moving. *Corridors will therefore be lined with patchy edge vegetation [**3d**].*

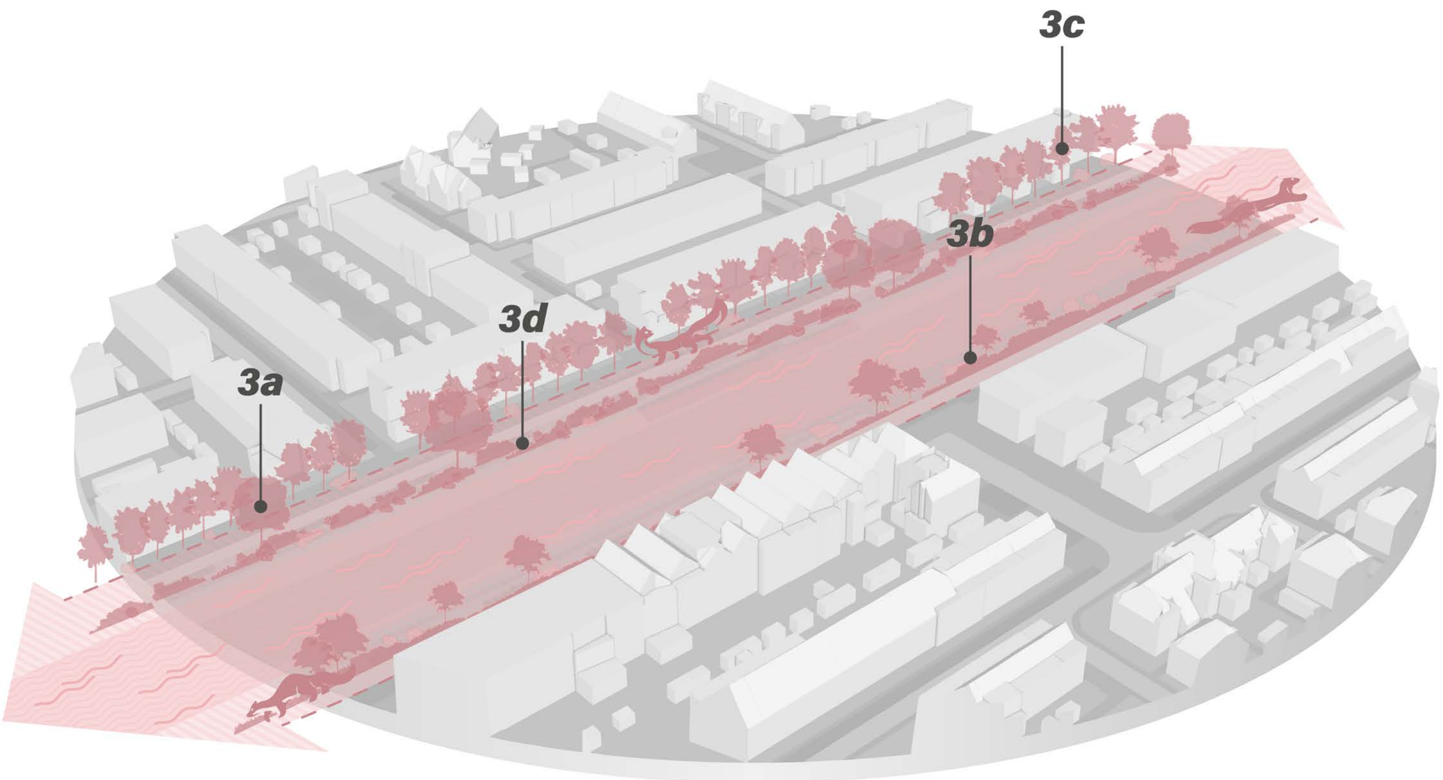


Figure 20 *Diagram for guideline 3 (pup dispersal) and corresponding design criteria.*

Figure 21 *Marten defending its shelter (Kloppenburg, 2021).*

2.1.d. TERRITORY

SOCIO-SPATIAL ORGANIZATION

The socio-spatial organization* of stone martens, just as other mustelids, has same-sex individuals defending their territory against one another while male and female territories overlap extensively. This is also known as intrasexual territoriality (Herr, Schley and Roper, 2009). There is no cooperation in the territorial defence between males and females here. A male territory tends to be larger than a female territory as male territories usually overlap with multiple female territories. As Herr (2008) has observed in his research, it is even the case that a male territory can totally encapsulate that of a female. To minimize confrontation, open space will be designed for this territorial division. *This means that a male stone marten's territory will be created to totally encapsulate female territories [* ***4*** *]. On a more specific note, overlap between the highly-used habitat area (otherwise known as core areas) of both sexes is desirable [* ***4a*** *].*

As mentioned, male territoriality is mostly concerned with securing exclusive access to females, this is called 'mate-guarding' (Bisonette and Broekhuizen, 1995; Müskens and Broekhuizen, 2005). Females are mostly concerned with the need for securing access to sufficient food resources for themselves and their pups (Herr, 2008; Herr et al., 2010). In general, the availability of suitable nesting location is leading cause for female territoriality. *Within female core areas, abundant food resources will be created to provide for adults and pups of both sexes [* ***4b*** *]. Suitable nesting locations will be ample within the male-female core areas [* ***2h*** *].*

TERRITORIAL DENSITY

Stone martens are considered 'urban adapters'. This means that they are able to take advantage of urban conditions, even though they are not totally secluded from rural areas. To adapt to the urban environment such species have an increased population density, reduced habitat size and reduced territorial behaviour (Herr, Schley and Roper, 2009). A study on Arctic foxes by (Pletenev et al., 2021) has shown that if the environment provided sufficient habitat requirements, habitat size of foxes was found to be even smaller than measured in existing research.

For urban living stone martens a change in habitat type has generally had surprisingly little impact on their socio-spatial organization. Stone marten populations in urban areas often do not have a higher degree of aggregation (as do other urban carnivores) and the existence of social groups in urban areas has not yet been documented (Herr, 2008). For this reason the potential of overpopulation and creating a new pest species is hypothesized to be manageable (see discussion)

Still, research by Müskens and Broekhuizen (2005) (figure 22) shows an example of individuals inhabiting smaller territories than observed in research. Despite species differences, it is expected that the population density of urban martens may increase in a similar manner (Pletenev et al., 2021). As a result, the territorial distribution, as outlined in these and other design guidelines, may be inconsistent with how the population will actually spread. A certain flexibility in the adaptation of spatial matters is therefore accepted. But on the contrary, limits to the maximalisation of habitat qualities are still desired to decrease the chance of overpopulation.

Figure 22 *MCP data of radio-tracked stone martens in Borgharen (Müskens and Broekhuizen, 2005). MCP is a spatial analysis method creating occupational areas based on spatial points. Female territories 8.5, 9.9 and 20.5 ha of 100% MCP. 2: Male territory 95.5 ha of 95% MCP. 3/4: 95%, 75% and 50% MCP male/female territories.*

HABITAT USAGE

As stone martens get older the fringes of their habitat are more strictly established, exploring other marten's habitat is unnecessairy as they have had time to optimize their current areal. This also makes it possible for older martens to occupy a smaller areal with still sufficient habitat requirements available. During autumn and winter the habitat size of urban martens is also smaller, in comparison to summer and spring, this is believed to be so because part of the area temporarily becomes less attractive (Broekhuizen, Müskens and Klees, 2010). *Both situations make it favourable to provide seasonal food resources close to marten dens/shelters [* ***7d*** *].*

Younger stone martens do occasionally leave their habitat, mostly to investigate the presence of another individual in a neighbouring habitat. When a neighbour is gone, the habitat of an individual can shift. As stone martens can only defend a certain areal the lesser valued part of its own habitat will be neglected.

This process makes that a stone marten population will naturally spread out equally over a certain environment, as long as sufficient habitat requirements are present (Broekhuizen, Müskens and Klees, 2010). *It is thus important for habitat requirements to be equally spread over open space so that a natural balance within the population could be achieved [* ***4c*** *]*

Establishing such a territory is a self-solving matter, partly due to their nocturnal lifestyle and partly due to their excellent scent marking. Stone martens intentionally leave behind faeces and urine to mark their territory, but unintentionally leave behind scented traces via the smell glands within the marten's paws. In this way the stone marten avoids confrontation with conspecifics and other animal species, which the animal usually prefers (Broekhuizen, Müskens and Klees, 2010). *Although spatial differentiation of habitat is beneficial [* ***4d*** *], still a natural habitat distribution will inevitably emerge.*

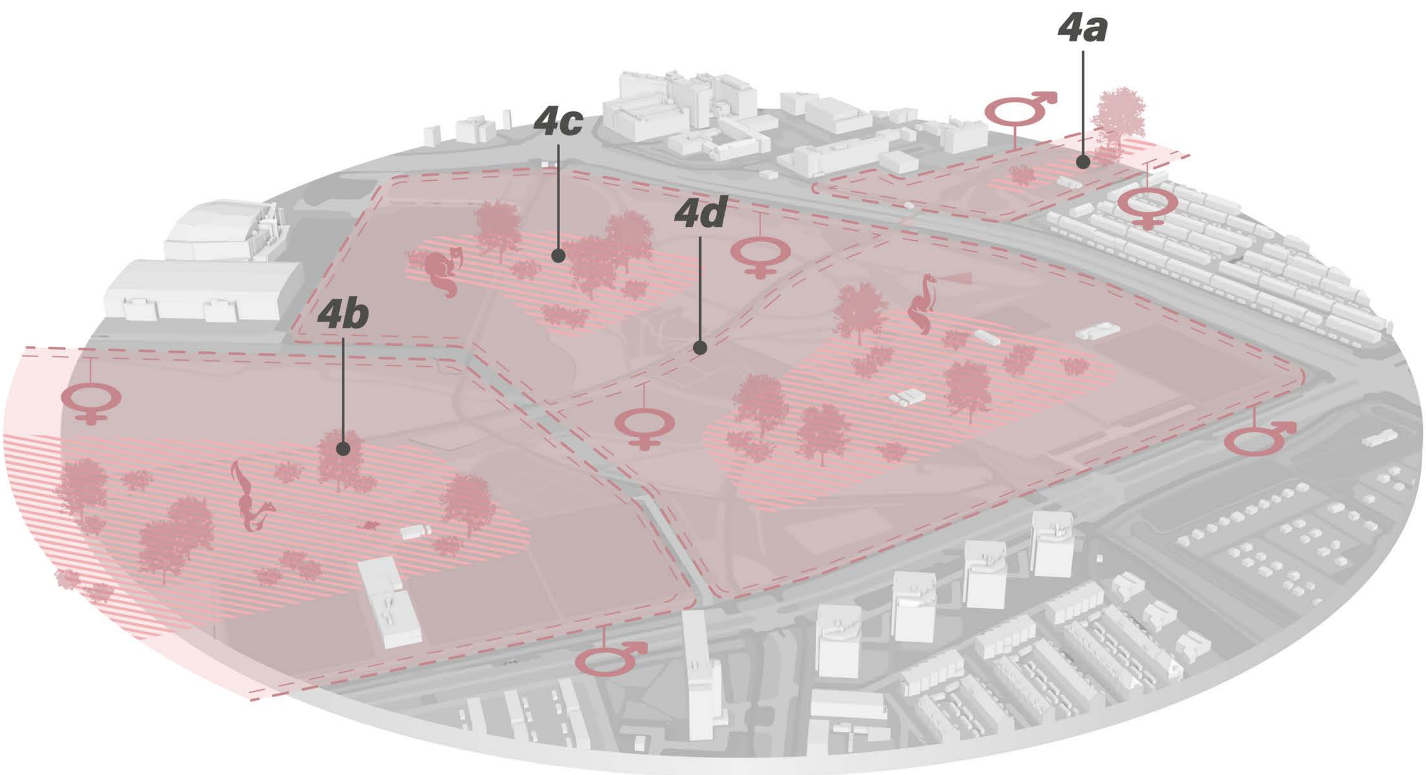


Figure 23 *Diagram for guideline 4 (territory) and corresponding design criteria.*

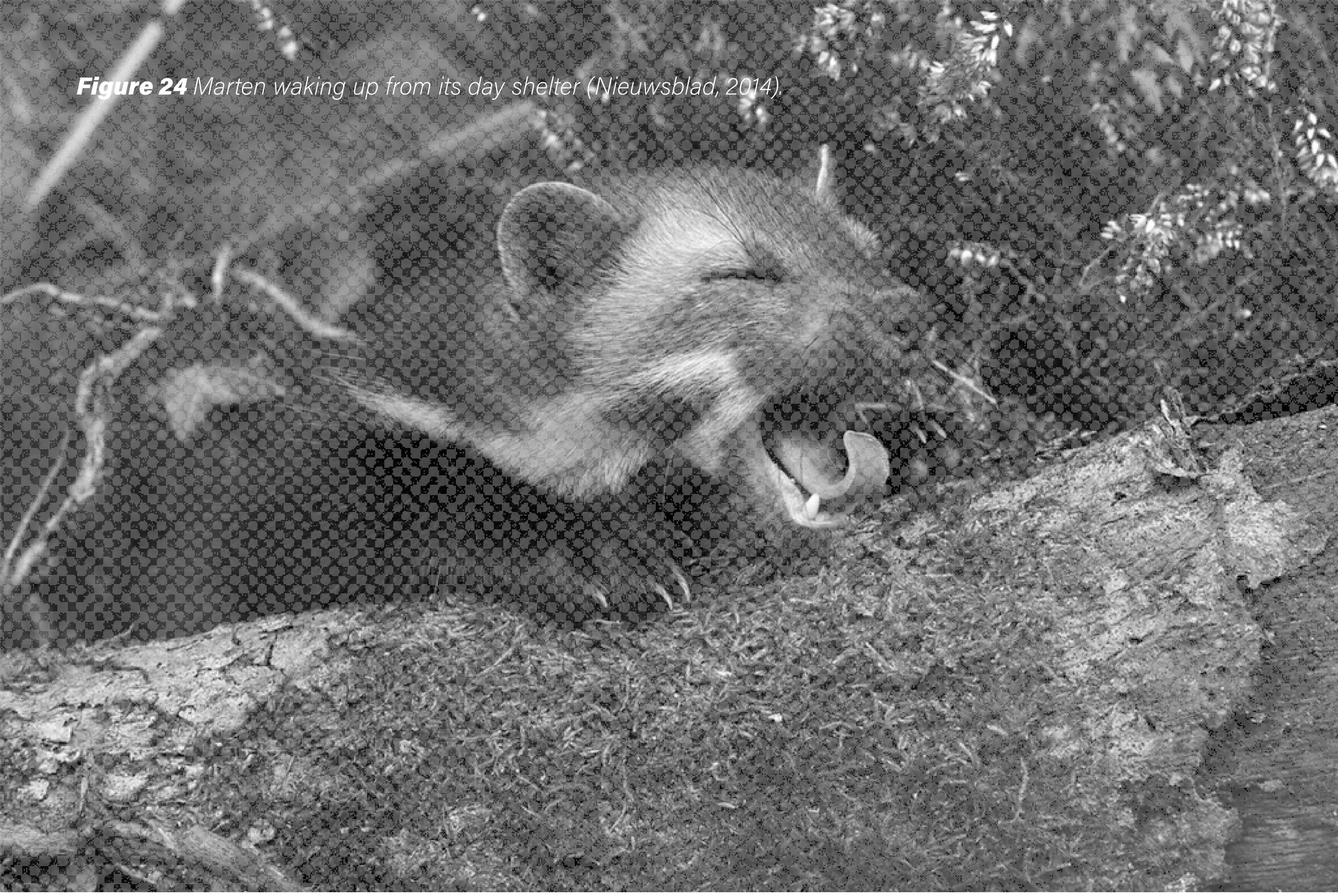


Figure 24 *Marten waking up from its day shelter (Nieuwsblad, 2014).*

2.1.e. SHELTER

Stone martens sleep during the day. For this, they need a safe and dark shelter* (Herr, 2008). Although they prefer stony biotopes, hence the name 'stone marten', within urban areas they also reside in green space. There shelter location choice is dependent on seasonal temperatures. During winter, built areas provide more permanent insulated denning *(and nesting) places whereas summer boasts more flexible cooler denning places in green space (Berge, Berlengee and Gouwy, 2021).

PERMANENT DAY SHELTERS

One individual's habitat can contain dozens of suitable shelters, but most animals occupy between five and twenty shelters at a time (Zoogdiervereniging, no date). *By providing 10 permanent day shelters within an individual's habitat it is thought that plenty of denning opportunity during colder months could be created, even accounting for potential habitat densification [* ***5*** *]. Within a female habitat five of these shelters should be made ideally usable as den [* ***5a*** *].*

Stone martens can find their day shelter at high altitudes as they are excellent climbers. Due to their size, they can fit through gaps of five centimetres in diameter, which is why they often reside in buildings (Zoogdiervereniging, no date). Harder to reach places are preferred in urban areas as they make it difficult for other mammals, like cats, to disturb them (Broekhuizen, Müskens and Klees, 2010). *Marten shelters will be placed at high altitudes or designed to have a five-centimetre -wide entrance [* ***5b*** *]. With this measurement smaller mammals such as squirrels can also use these denning places while access is denied to predators the size of a cat or larger (Berge, Berlengee and Gouwy, 2021).*

Since stone martens are not diggers, they will at most accumulate surrounding materials to form a suitable hiding place, if none is available. Research has shown that stone martens almost always choose shelters that are covered, as to be sheltered form possible predation . This is important to create a safe place to sleep. *For this reason the stone marten shelters should be designed to have overhead coverage [* ***5c*** *].*

Fieldwork has shown that stone martens might prefer shelters that are similar to the nesting place in which they grew up (Broekhuizen, Müskens and Klees, 2010). *This is why dens and nests used within UOS design should be similar in typology to increase the chance of inhabitation [* ***5d*** *].*

FLEXIBLE DAY SHELTERS

More shrubbery and trees within UOS can provide opportunity for flexible day shelters during summer. Vegetation is frequently used for both resting and safe traversal. Between shelters the marten constantly shifts (Broekhuizen, Müskens and Klees, 2010). Not all of the martens shelters are frequently used, this depends on their suitability and location. In this way if a shelter has become inhospitable an individual has multiple other places to find refuge (Müskens and La Haye, 2022). *By adding more vegetation to UOS plenty of flexible shelter opportunities for stone martens will arise. A certain degree of naturalness can also create resting places in other natural landscape elements (such as tree stumps and leaf piles). [* ***6*** *].*

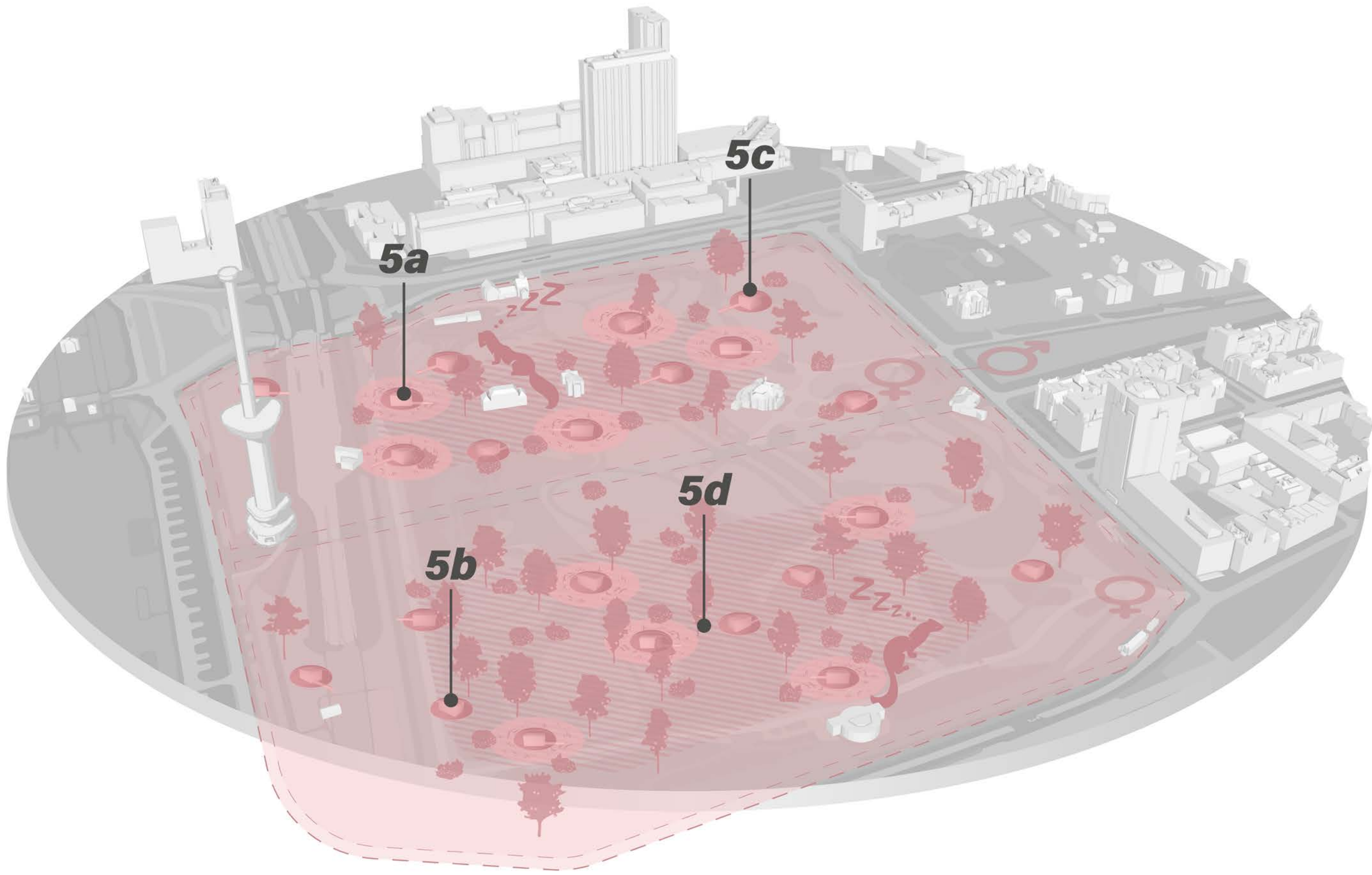


Figure 25 *Diagram for guideline 5 (shelter) and corresponding design criteria.*

MARTERHOOP

Based on the combined design criteria for nesting and permanent denning locations a nest/den design is made called 'marterhoop.' The design combines the thesis' research with the 'marten box' model of the Zoogdiervereniging and Westra (2020). Design inspiration is taken from Berge, Berlengee and Gouwy (2021).

The 'marterhopen,' or marter heaps, are marten boxes, positioned within a heap of soil (outside layer), unpermeable material (middle layer) and deadwood (inside layer). The layers keep the marten shelters warm and dry all-year round. The marten box is divided between sleeping/ nesting compartment and latrine*.

By consistently using the marterhoop throughout this thesis familiarity with permanent shelters is aimed for [***5d***]. Difference between nest and den is solely led by it's placement within the landscape. Marthopen suitable as nests have an area of undisturbed space around it for rearing [***2e***], easily obtainable food sources should be provided [***2f***] and their positioning is more quiet and secluded than necessairy for solely denning [***2c***].

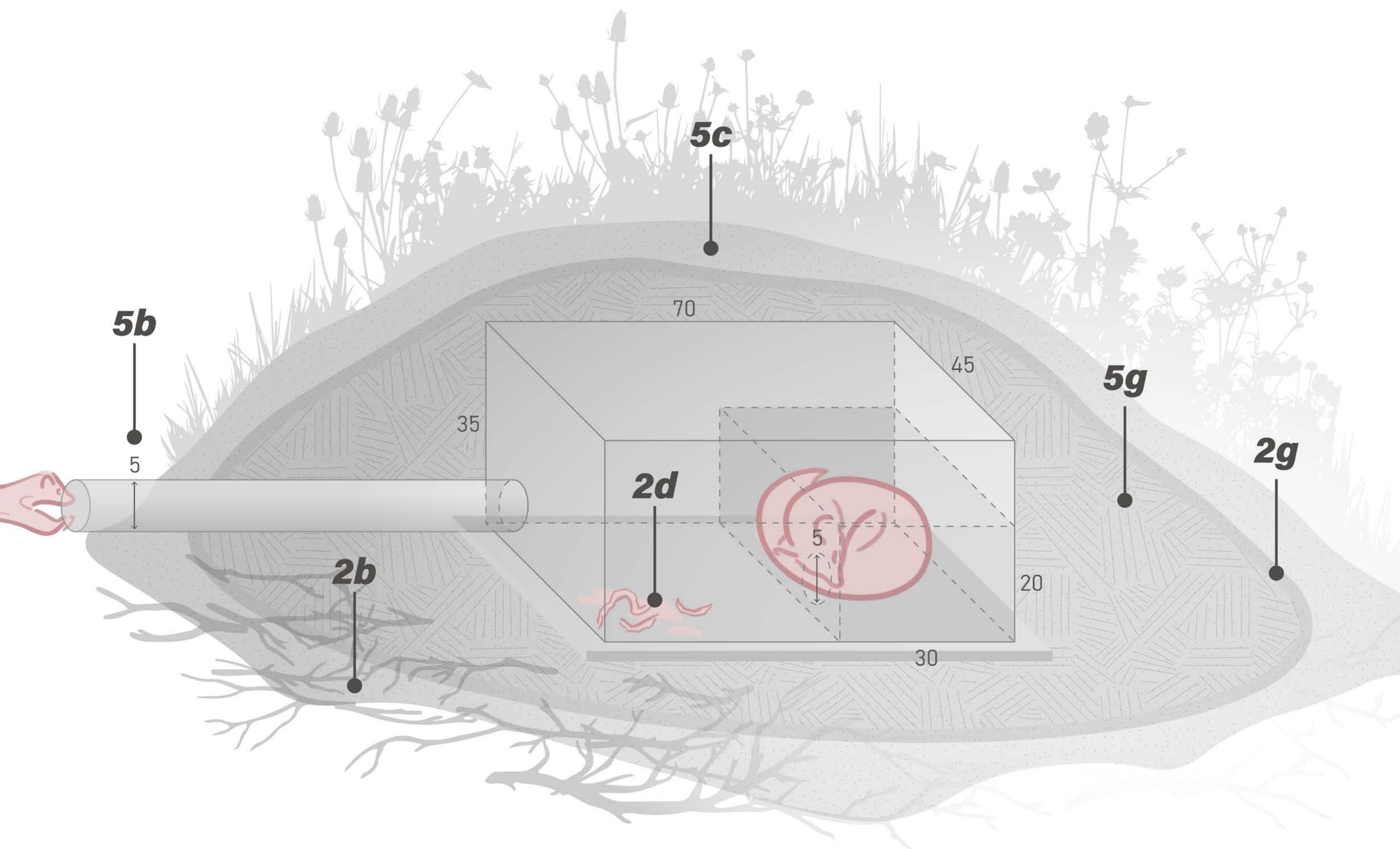


Figure 26 *Permanent marten nest/den design 'marterhoop.'*

Figure 27 *Marten traversing through a tree (Natuurpunt, no date).*

2.1.f. MOVEMENT

Stone martens are considered to be both crepuscular and nocturnal animals. Their activity pattern is tightly linked to the sunrise and sunset, mostly leaving after sunset and getting back to their nest just before sunrise. During long winter nights though the marten leaves its den earlier and returns to its den later. This is because in winter foraging is alternated with resting periods whilst in summer martens mostly forage all night long. The stone marten will find a night shelter to quickly rest, not necessarily having similar strict requirements as its day shelter (Herr, 2008). *These flexible night shelters and safe traversal possibilities during foraging activity can be found in vegetation, consisting of natural landscape elements such as visualized in figure 29 (p. 44) [**6**]. Within season of increased foraging activity vegetation should therefore bloom [**6a**]. Organic debris will retain traversal shelter during other seasons [**6b**].*

A stone marten, in general, needs about eight to ten hours a day to forage, during which they can travel large distances (Broekhuizen, Müskens and Klees, 2010). The distance stone martens cover per night differs per sex. Research has stated that in urban areas males move on average 5,3 km per night whereas females move only 1,5 km (Genovesi and Boitani, 1997). Yet, in theory, the animal can travel up to ten or fifteen kilometres per night (Broekhuizen, Müskens and Klees, 2010). Urban living martens tend to stay inside or closer to their den in comparison to rural living martens due to better food provision (Herr, 2008). During cold or stormy weather, stone martens will not leave their shelter for days at a time if their food supply allows it (Zoogdiervereniging, no date). *Part of its foraging sites can therefore easily be made available, apart from decreasing foraging distances it is important that natural landscape element connect shelter places and foraging sites [**6c**].*

Rain does not pose an obstacle for the stone marten, but the animal does like to be mostly covered when moving through open space (Zoogdiervereniging, no date). The animal does this to be shielded from rain, but also from visibility. Natural landscape elements should thus *provide overhead coverage [* ***6d*** *].*

Stone martens are excellent climbers, being able to climb the facades of most buildings. Additionally, they are excellent jumpers, being able to bridge gaps one and a half meters wide. This skill makes it possible for martens to move themselves at high altitudes. *Adding natural landscape elements that are varying in height makes it possible for martens to safely move at greater heights [* ***6e*** *]. Elevated landscape structures should be connected for traversal continuity, a maximam gap per natural landscape element of 1,5 meters is therefore needed [* ***6f*** *].*

Even though stone martens can swim, they try to avoid this (Zoogdiervereniging, no date).

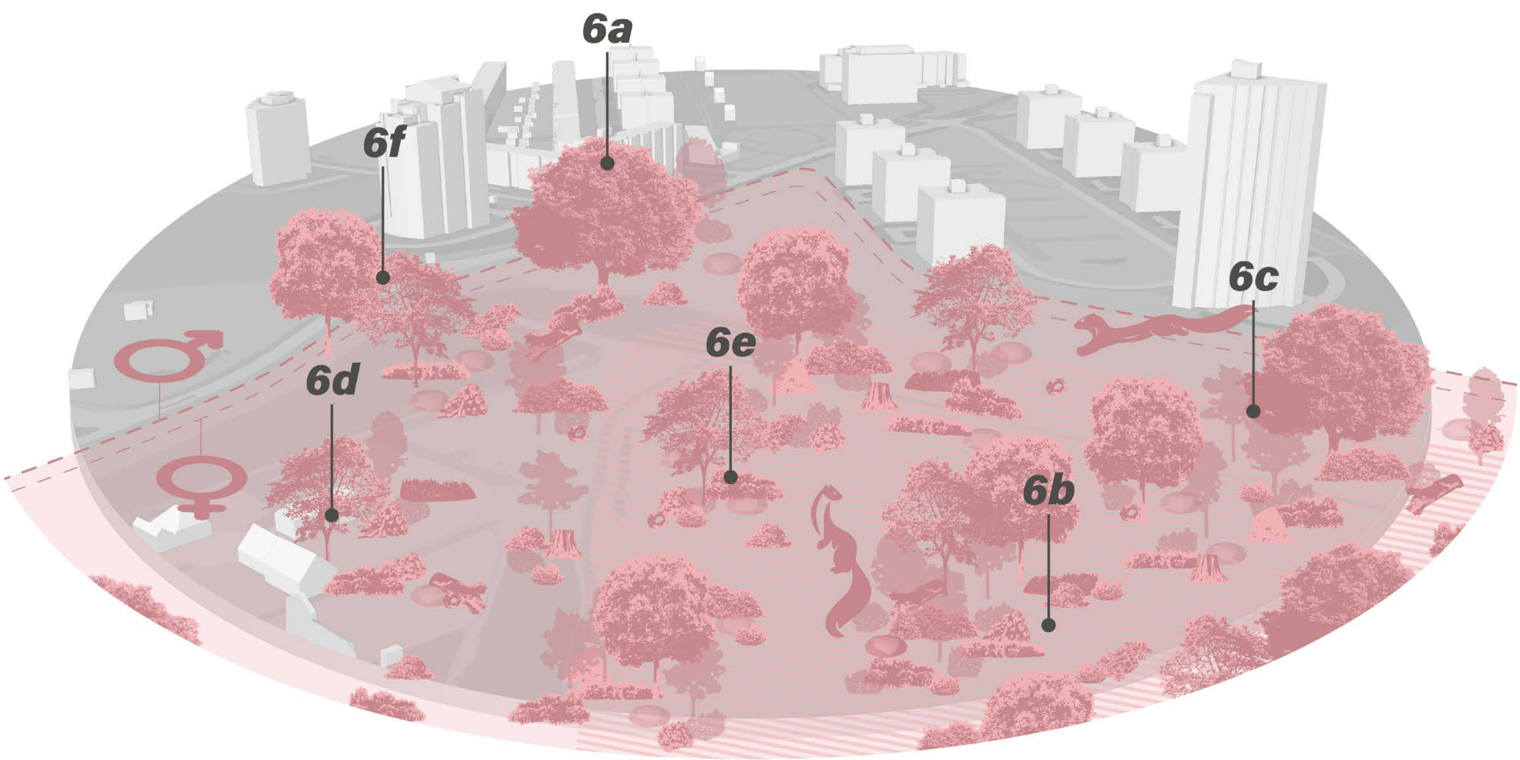


Figure 28 *Diagram for guideline 6 (traversal) and corresponding design criteria.*

Natural landscape elements

'Natural landscape elements' is used in this thesis as a collective name for elements/structures unbuilt by humans. They possibly comprise of dead organic debris from vegetation or organic material available within urban open space.

Within this visualizer you can see how such elements can be used to traverse or rest. This selection aligns with the design criteria previously mentioned.

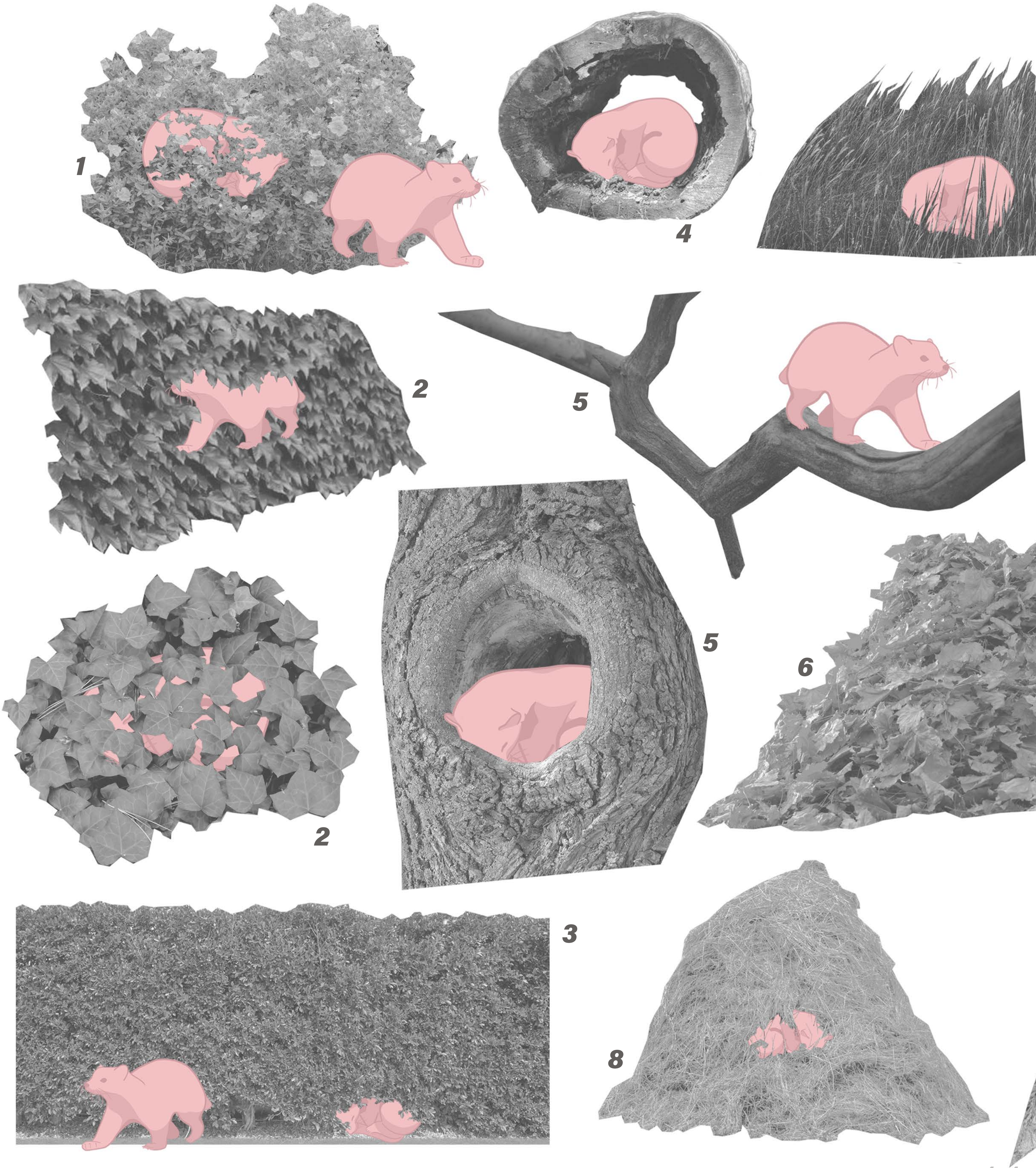


Figure 29 *Collection of natural landscape elements used for traversing and resting. Examples include shrubs (1), ivy (2), hedges (3), dead wood (4), trees (5), Leave piles (6), ditches (7), hay stacks (8), bird nests (9) and high grasses (10).*

Figure 30 Marten consuming an egg (Natuurpunt, no date).

2.1.g. FORAGING

Stone martens are omnivorous and opportunistic feeders, the latter meaning that the animal forages the food sources that are easiest to obtain. This further solidifies their high adaptability to the different environments that the animal inhabits (Herr, Schley and Roper, 2009). The two biggest food groups are fruits (as is previously mentioned) and small mammals, as can be seen in figure 31 (Broekhuizen, Müskens and Klees, 2010).

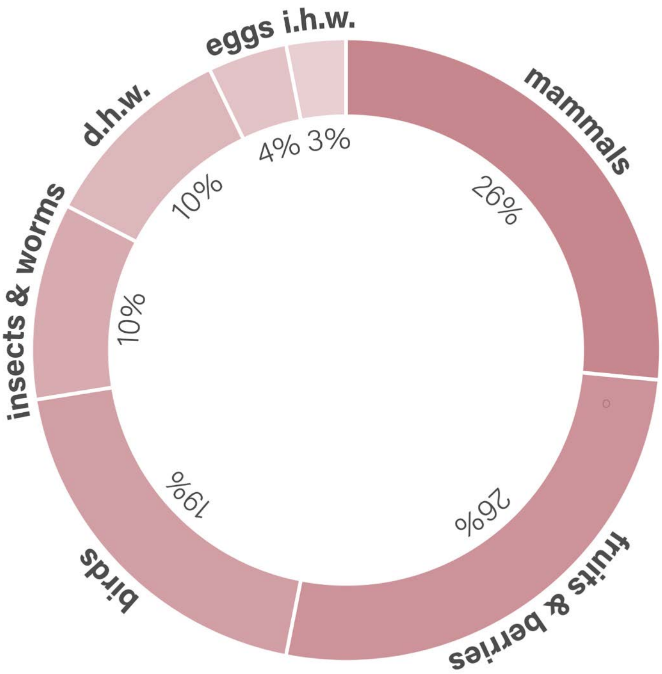


Figure 31 *Food consumption marten based on research by (Nelck and Van Pelt, 1996). (in)digestible human waste is represtented as i.h.w. and d.h.w. respectively*

HERBIVOUROUS DIET

Stone marten's consumption of plant-based foods is limited to fruits, of which mostly berries. Berries are mostly consumed during the summer and autumn seasons. Other fruits, like apples and pears, become more prominent in their diet during autumn. In late autumn and winter, stone martens still take advantage of fallen, or even rotten fruit. A prerequisite for all plant-based food is that it has to be ripe. Research on martens in the Netherlands has revealed a particular fondness of certain plant species that are toxic to humans and rats, the latter being elaborated in heading 2.2 (Nelck and Van Pelt, 1996). Possible fruiting plants usable for this thesis are detailed in figure 33 (p.49). *Within every marten territory berry bush and fruit tree species will be added [**7**] that provide ripe/rotten fruit during summer and autumn [**7a**]. For pups and juveniles alike plant-based resources are of utmost importance as it is difficult for them to catch living prey (Broekhuizen, Müskens and Klees, 2010). This makes it important to surround dens with easily reachable berries and fruits [**3c**].*

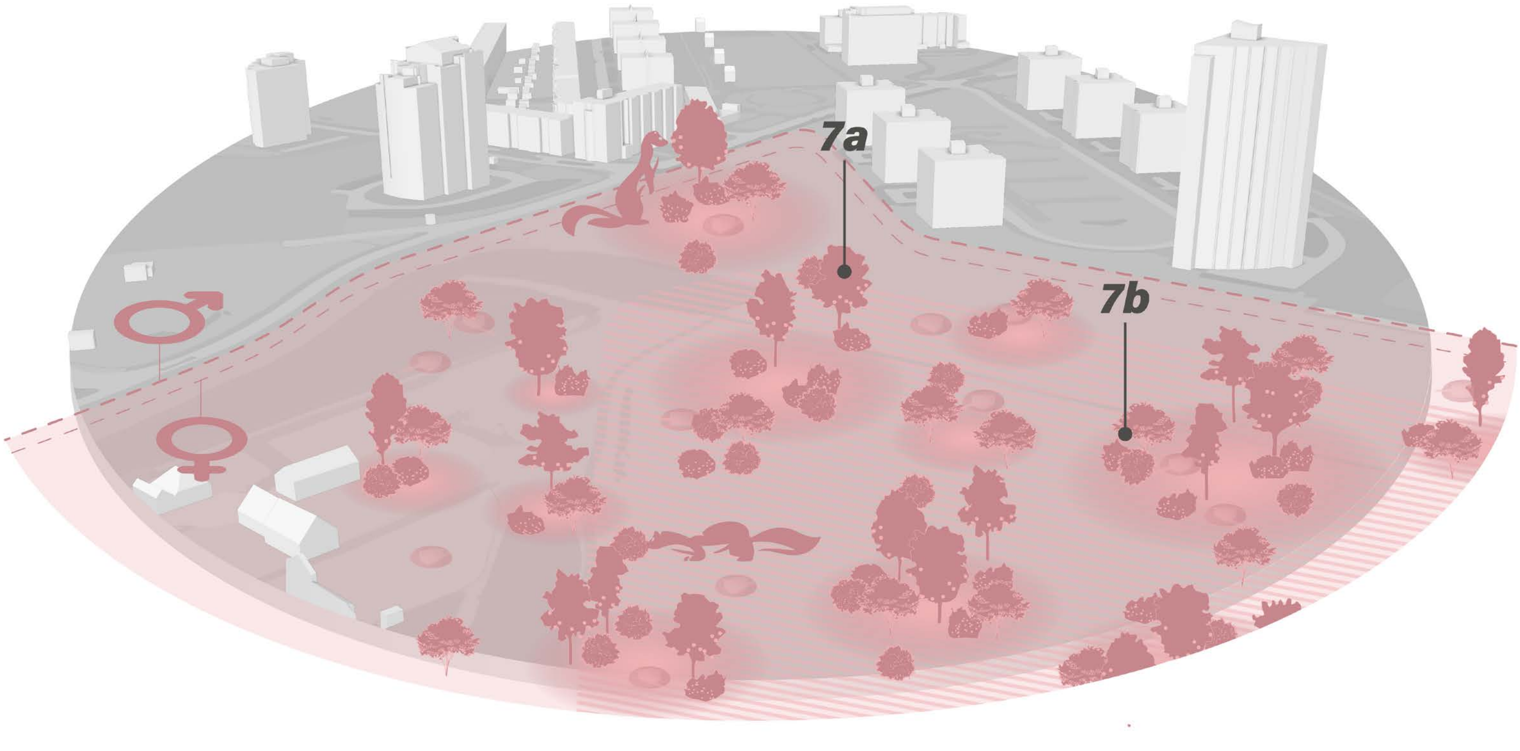


Figure 32 *Diagram for guideline 7 (foraging) and corresponding design criteria.*

CARNIVOUROUS DIET

Mammals make up an equally large portion of the marten's diet, especially in winter and spring when fruits have limited availability. Yet, birds and mice are eaten whole-year-round (Herr, 2008). As stone martens are mesopredators, there is a limit to prey size in regards to large birds and mammals. The size limit for birds lies somewhere around pigeons (a common marten prey in urban areas) and chickens; for mammals, this limit is around hares and rats. Still, there are exception to these limits. Insects can make up a relatively large portion of the marten's diet in summer, amphibians and reptiles are rarely consumed by stone martens. It is striking that they also take on more difficult preys such as moles and young hedgehogs (Broekhuizen, Müskens and Klees, 2010).

Even though most synanthropes thrive on the abundance of human waste, the marten merely consumes it as a supplement to their usual food intake (Bateman and Fleming, 2012) Martens mostly rely on free-ranging animals and free-growing plants. Both food groups are very seasonal and location-based (Broekhuizen, Müskens and Klees, 2010). *As this thesis' scope is limited to brown rat predation, direct design measure for other interspecies predator-prey relations are not researched. A preference for wild-ranging animals does imply that improving urban green spaces will naturally increase the presence of potential prey in the area [**6**] (Bakker, 2008).*

The food the animal has gathered is consumed in a quiet place, similar to other urban living animals. For this reason small food supplies can be found around marten shelters (Zoogdiervereniging, no date). *Possible food supply locations will arise due to the addition of natural landscape elements, which will be added to open space as mentioned in previous paragraphs [**6**].*

Fruiting plant selection

For this thesis design, the writer has chosen a range of fruiting plants to incorporate into the design (figure 33, next page). The selection process considers not only species that produce fruit aligning with the marten's dietary needs [***7a***] but also ensures that the plants are native to the site to provide familiarity local martens (Klees, 2024). Other selection criteria are related to SRQ1A and will be detailed in that chapter. Accompanying plant list is found in appendix 2.

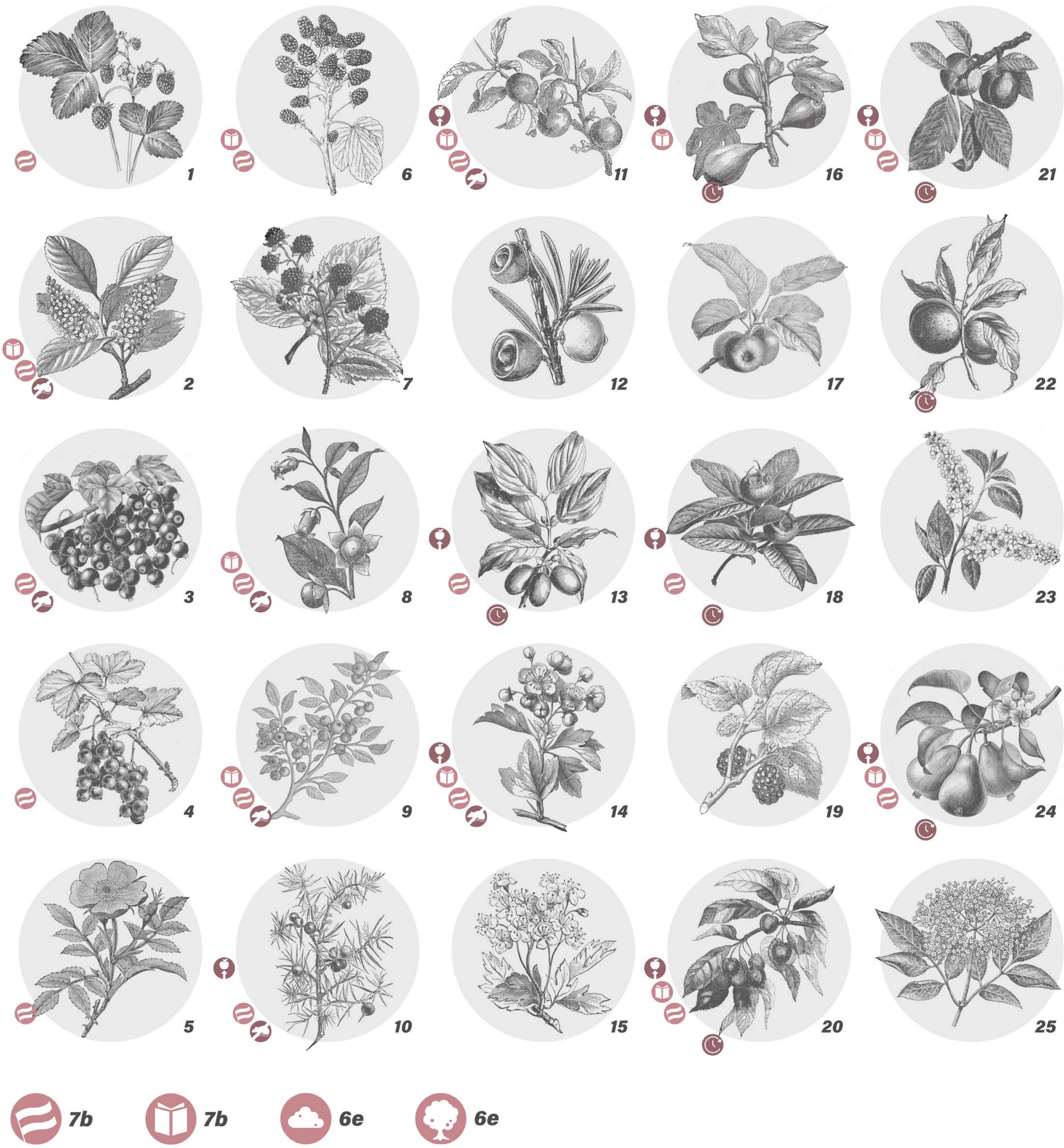


Figure 33 *Fruiting plant selection to be used in the thesis, legend according to applicable criteria.*

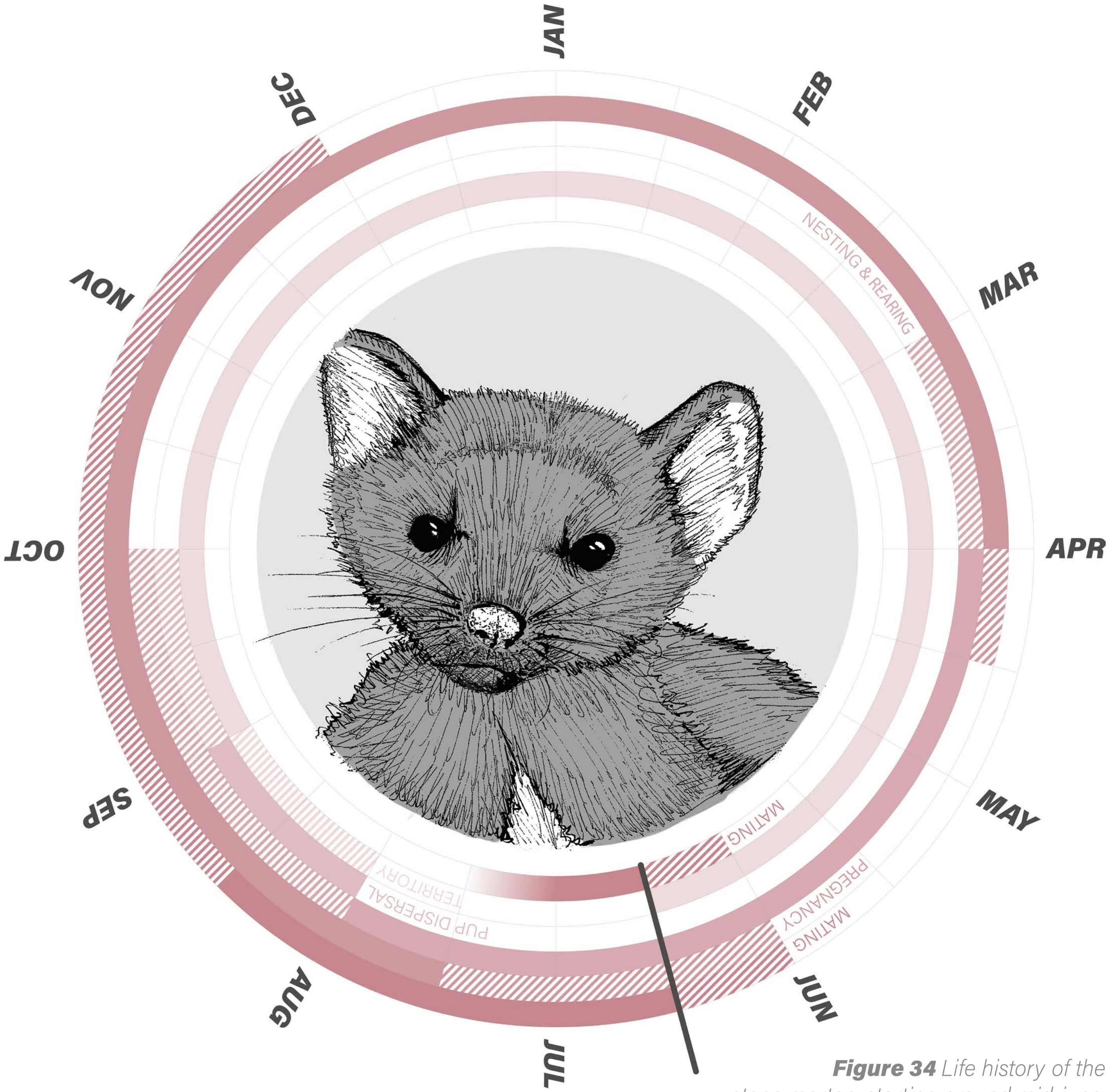


***Figure 34** Life history of the stone marten, starting around mid-june.*

CONCLUSION

In figure 34 the important life-cycle events of the stone marten are made visible. Due to a long gestation period, large parental investment and large margins within other events, temporary design solution to habitat provisions are not expected to be efficient. Year-round highly-qualitative nesting locations are especially important for female habitat provisions and consequently male inhabitation. In relation to other habitat requirements, seasonal changes in habitat requirements (seen in figure 35, p.51) are non-problematic to the opportunistic stone marten. As long as á food source or shelter opportunity is available.

When looking at the design guidelines and criteria in appendix 1 lot of overlap in habitat requirements can be seen. Simple design solutions can be able to cover multiple life necessities. For example, simply planting shrubbery can offer: temporary shelter, traversal routes, hiding places, fruit resources, territorial division, nesting material, or potential prey. In general, a lot of habitat requirements are indirectly linked to the 6th design guideline, which is therefore especially important.

A fundamental design principle for providing life necessities and general habitat requirements for stone martens is that within a designated female territory, a space must be created to accommodate all of the animal's life history needs [**I**]. This approach is necessary due to the solitary nature of stone martens, which requires distinct areas for various activities per individual. In other words, the design must support spaces for mating (1), growing (2), settling (3), staying (4), resting (5), moving (6), and foraging (7). These descriptions, will , respectively, be used to describe the 7 guidelines. These 7 design guidelines relate to these habitat requirements that can be distinguished:

Mating [***1***]
The design should facilitate mate-guarding and promote female encounters.

Nesting & rearing [***2***]
Design should provide isolated, insulated spaces for female martens to nest and pups to grow up.

Pup dispersal [***3***]
Design should aid the safe dispersal of juveniles towards a future habitat by creation of a corridor network with easily-available habitat requirements

Territory [***4***]
Design should account for the rigid socio-spatial organization by using ample space and widely providing nesting places within intersexual territories.

Shelter [***5***]
Design provides permanent day shelters during all seasons, and creates flexible day shelters during summer plus flexible night shelter during winter through the provision of natural landscape elements.

Movement [***6***]
Design aids the safe movement of martens within their habitat through the provision of a multitude of green traversal routes that connect resting and foraging places.

Foraging [***7***]
Design should provide carefully selected fruiting plants that fit within the seasonal needs of a marten's herbivorous diet.

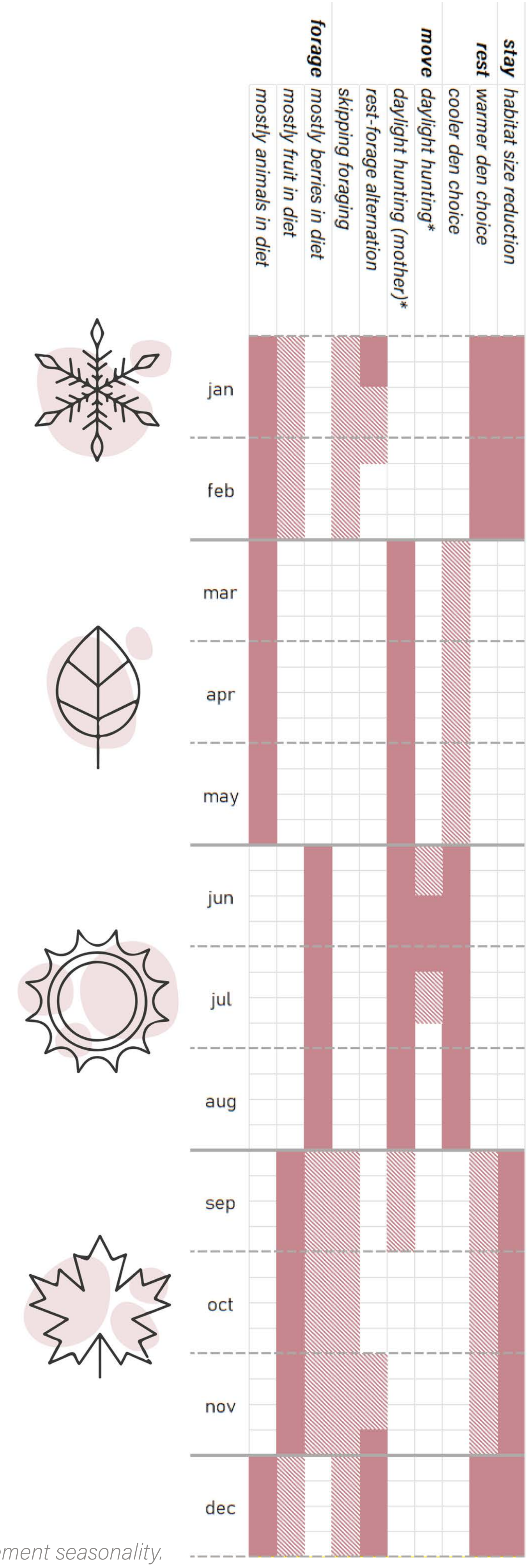


Figure 35 *Marten habitat requirement seasonality.*

2.2 SRQ1.a - BROWN RAT PREDATION

INTRODUCTION

The brown rat is, such as most pest species, an r-selected pest species*. Such species conform to having rapid (sexual) development, small body size and a high production rate of offspring. Variable environments, like built areas, best suit such species (Hulme-Beaman et al., 2016). Such species populations know both periods of large population growth and catastrophic mortality rates. Due to relatively small parental investment, among other things, the later challenge can be overseen, as visible in figure 36/37, page 53 (Kelly McLain, 1991).

Stone martens are generally a K-selected species*. K-traited species rely more on environmental constancy, selected to mostly have a larger body size, parental investment and slow rate of maturation. These factors lead to variable yet substantial population expansion in species such as brown rats, while stone marten populations, for example, experience a more gradual but steady growth (Kelly McLain, 1991). These traits make the stone marten less likely to become a pest (see discussion).

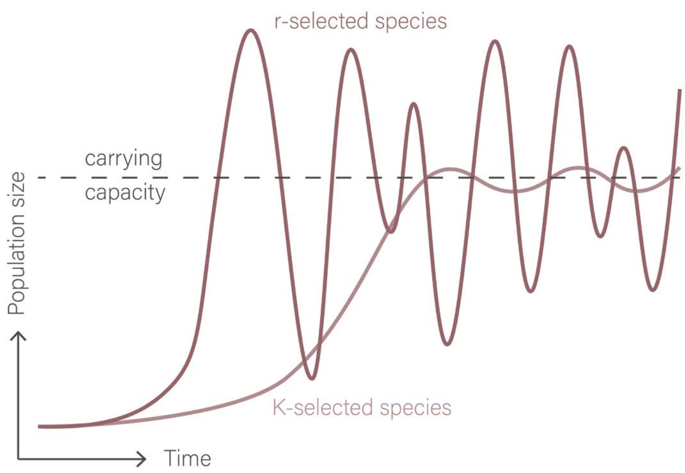


Figure 36 *Differences r/k-selection through time*

For this reason it is important to decrease the capacity limit of the area in which the rat is unwanted (Kelly McLain, 1991). Research has shown that this can be achieved by changing the amount of food and shelter that brown rats can find (Van Adrichem et al., 2013). By reducing/deteriorating nesting opportunities and decreasing the food availability/reachability within the design the population size will decrease. This is because due to a high reproduction rate, solely increasing the direct predation rate will not minimize brown rat populations in urban areas. By extensively overlapping brown rat and stone marten habitat within the design, the effective predation pressure on brown rats increases.

$$\frac{dN}{dt} = rN\left(1 - \frac{N}{K}\right)$$

Figure 37 *Simplified Verhulst model of population dynamics. Population size N, time t, maximum growth rate r and capacity limit K.*

Figure 38 *Rats eating human waste (Sommariva, 2020)*

2.2.a FOOD AVAILABILITY

The brown rat is a generalist species, inhabiting different environments and having a varied diet makes it difficult to decrease the brown rat's food availability (Van Adrichem et al., 2013). As synanthropic species the brown rat is often found in vicinity of human activity as the occurrence of human waste seems to be an important factor in its habitat (Bateman and Fleming, 2012; Van Adrichem et al., 2013). This is most easily sourced within buildings or waste disposal dumps. Such big food supplies make it easier for the brown rat to select its own menu of protein-rich and starchy foods (Zoogdier vereniging, no date; Verkem, Maeseneer and Vandendriesche, 2003) *By decreasing the accessibility of buildings for brown rats their food availability is significantly limited (elaborated in 'shelter opportunity') [* ***6e*** *]. By additionally minimizing safe access to waste disposal dumps the rat's menu becomes even more difficult to obtain. This can be done by establishing either stone marten shelters or foraging sites (within marten territories) around them [* ***4e*** *]. This creates a 'landscape of fear.'*

Contiguous vegetation makes it easier for rats to safely forage through the environment. Literature by Davis, Emlen and Stokes (1948) argues that brown rats make use of regular foraging paths, not utilising their whole areal to move from their harbourage area to their food sources. *If possible, design could aim at inducing the 'Landscape of Fear' by overlapping marten movement through more patch-like natural landscape elements with brown rat foraging sites/paths [* ***6f*** *.] Drastically decreasing the protein availability can even enforce cannibalism between rats, further reducing the population size (Zoogdier vereniging, no date).*

Even though both stone marten and brown rats fulfil different roles within urban food webs, there is large overlap within their diet. Both species consume, for example, fruit, larvae, bird eggs and young mammals (Zoogdier vereniging, no date; Traweger et al., 2006). Additionally both animals' foraging happens during the night. Through interspecific competition over food resources, the stone marten will (most of the time) outcompete the brown rat. Not to mention the fact that such resources can be used by martens as trapping mechanisms (Zuidema, no date). *In general, it can be noted that an increase in rat/marten food resources within the design will not provide ample food for rats as long as these resources are used by marten or other possible predators/competitors (for elaboration, see discussion).*

PLANT SELECTION

Related to the vegetal diet of the stone marten, certain measures can be taken within the selection of fruiting plants that do not create of a shared food resource for both predator and prey. Even though brown rats are excellent climbers, they seldomly climb trees (Traweger et al., 2006). *By solely using plant species that provide high-hanging fruits within the design, food availability for martens improves whilst that of the rat remains the same [* ***7c*** *]. It is further recommended to choose fruit tree varieties that hold their fruit and seed longer [* ***7d*** *]. Such species growing in the Netherlands include multiple cherry (Prunus) and apple (Malus) tree varieties (Broekhuizen, Müskens and Klees, 2010; Papakosta et al., 2014).*

Shrubs are an important landscape element for martens to rest and move about, additionally certain shrub species grow berries which are frequently consumed by stone martens (Nelck and Van Pelt, 1996; Broekhuizen, Müskens and Klees, 2010). Low-growing berry bushes can provide an easy food source for rats, but a select few shrub species are toxic to rats while being favoured by martens. *These will be used in the design [* ***7e*** *]. Most of these species are part of the nightshade family (Solanaceae). Examples of such species growing in the Netherlands are the European yew (Taxus baccata), black nightshade (Solanum nigrum) and European blueberry (Vaccinium myrtillus).*

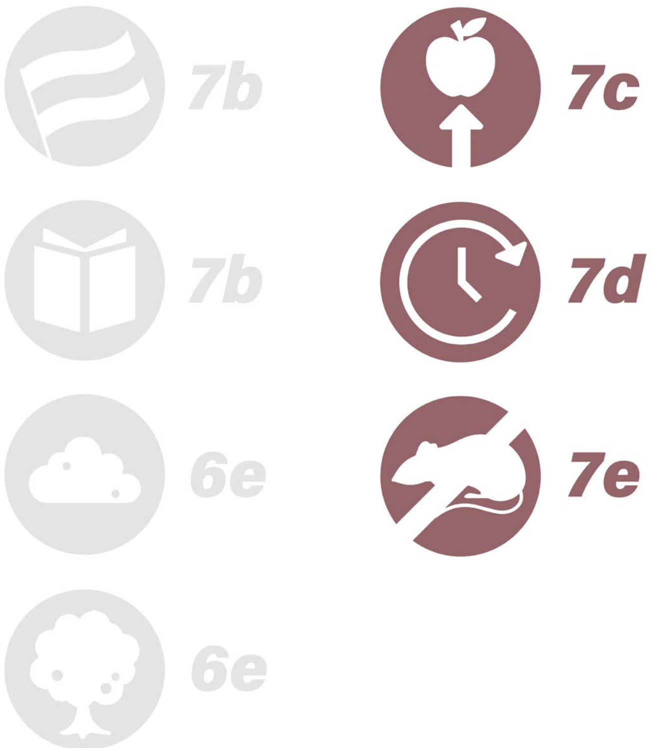


Figure 39 *Corresponding design criteria plant selection on brown rat predation, used in figure 33.*

The list of plant species suitable for this thesis' design, to be found in figure 33 (p. 49), is partially selected on the abovementioned design criteria. In figure 39 above you can see which symbol correspond to which design criteria. In general, it is believed that by worsening the food availability rats spend more time foraging, which makes them even more vulnerable to predation by martens.

Figure 40 Brown rat peaking out ot its den (Gunter, 2024)

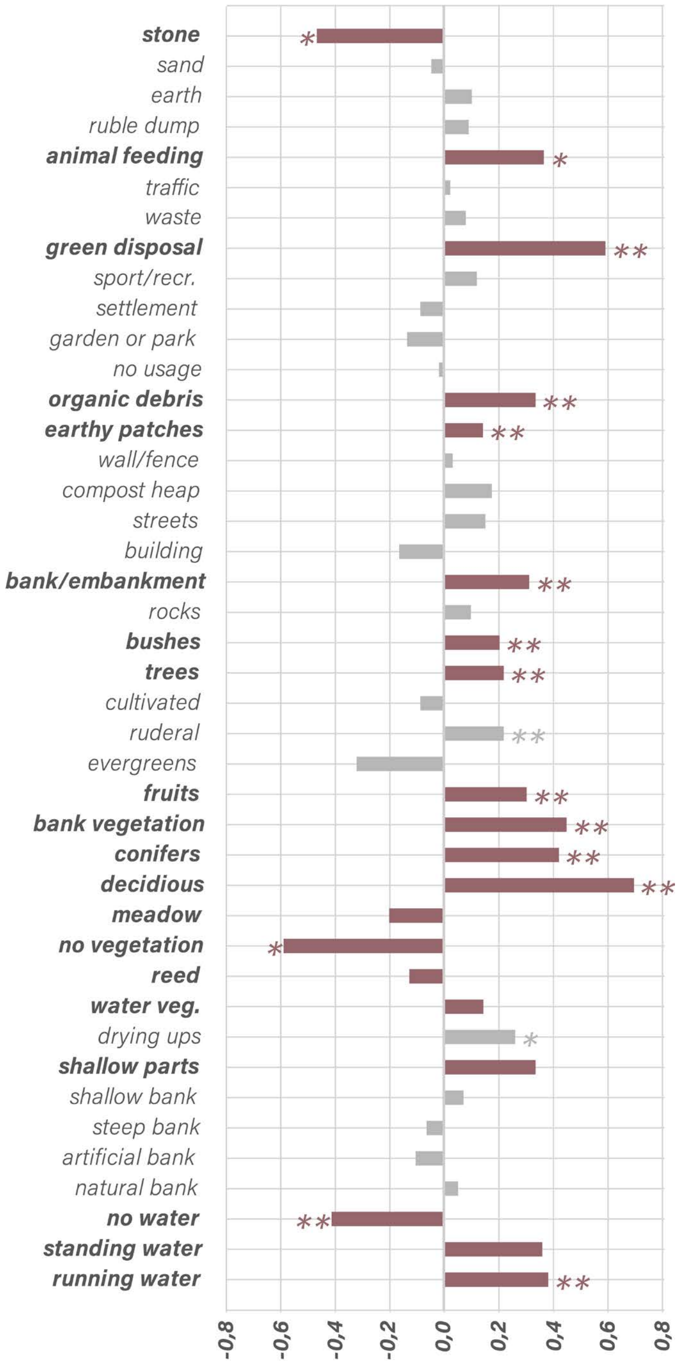


Figure 41 *Unvironmental characteristics brown rats (Colvin Bechtel et al, 1996) .*

2.2.b SHELTER OPPORTUNITY

NATURAL CANOPIES

The main reason to decrease the shelter opportunity for brown rats is to minimize the environmental protection of the animal against marten predation. This is another reason why the presence of rats in buildings is undesirable. Because of their size rats can fit through gaps two centimetres in width, even giving them an advantage over martens which could be a risk as described earlier (see discussion) (Zoogdiervereniging, no date). Niches and crevices in buildings are easily accessible where foliage reaches building facades, they can even be used as leverage to reach higher entrances. *Colvin Bechtel et al (1996) state that by minimally planting vegetation 0.9 meters away from walls this should occur less frequently [* ***6e*** *] (Van Adrichem et al., 2013).*

In figure 41 it is shown that the percentage of area occupied by urban green significantly increases the presence of brown rats. The rats preferred vegetation is matured and multi-layered (Van Adrichem et al., 2013). When choosing their habituated patches, shrub canopy coverage, with low visibility into shrubbery from the side, is one of the most important landscape characteristics. This makes broad-leaf evergreens and deciduous plants favourable over needled evergreens (Colvin Bechtel et al., 1996).

Furthermore, wet vegetation along banks, aquatic plants in running water and high grasses are favoured by brown rats. *Natural landscape elements designed within a marten's highly-occupied habitat will have the abovementioned preferred vegetation characteristics [* ***6g*** *]. Plantings in areas where the rat's presence is undesirable, as it does not provoke predation by martens, will contain natural landscape elements with less preferred vegetation characteristics [* ***6h*** *]. In this way brown rat occupational behaviour is possibly controlled.*

DEN PREFERENCES

Rats den in burrows, these consist out of a corridor system connecting multiple dens through under- or overground pathways, this is visible in figure 42. The dens within a burrow are occupied by multiple generations, also being used as nests (Zoogdier vereniging, no date). The corridors in this system are six to nine centimetres in diameter, making them accessible to stone martens. Out of all martens the adult males most frequently hunt for larger preys. For less adept juvenile and female martens, accessibility to rat dens is particularly important. This is because young rats in nests provide an easier food resource (Broekhuizen, Müskens and Klees, 2010).

Most literature suggest that brown rats have a preference for habitats in close proximity to water (i.e. ponds, rivers and sewers) as they prefer nesting in damp and cool areas (Colvin Bechtel et al., 1996; Traweger et al., 2006; Van Adrichem et al., 2013). Here the naturalness of the body of water, type of embankment, abundance of bank vegetation and presence of shallow parts can all play a role (see figure 41) (Van Adrichem et al., 2013). Burrows are often made in natural soil being neither to compact nor too loose, this is mostly found in bare soil along water bodies, often rooted by trees (Traweger et al., 2006). Yet, if not possible, the brown rat can find harbourage under paved surfaces or within banks. *Nesting opportunity for brown rats will diminish when suitable locations for rat dens are occupied by stone martens. For this reason, wherever possible, marten territories should be supplied in close proximity to water [* ***4f*** *], at surface level [* ***5e*** *] on bare soil [* ***5f*** *].*

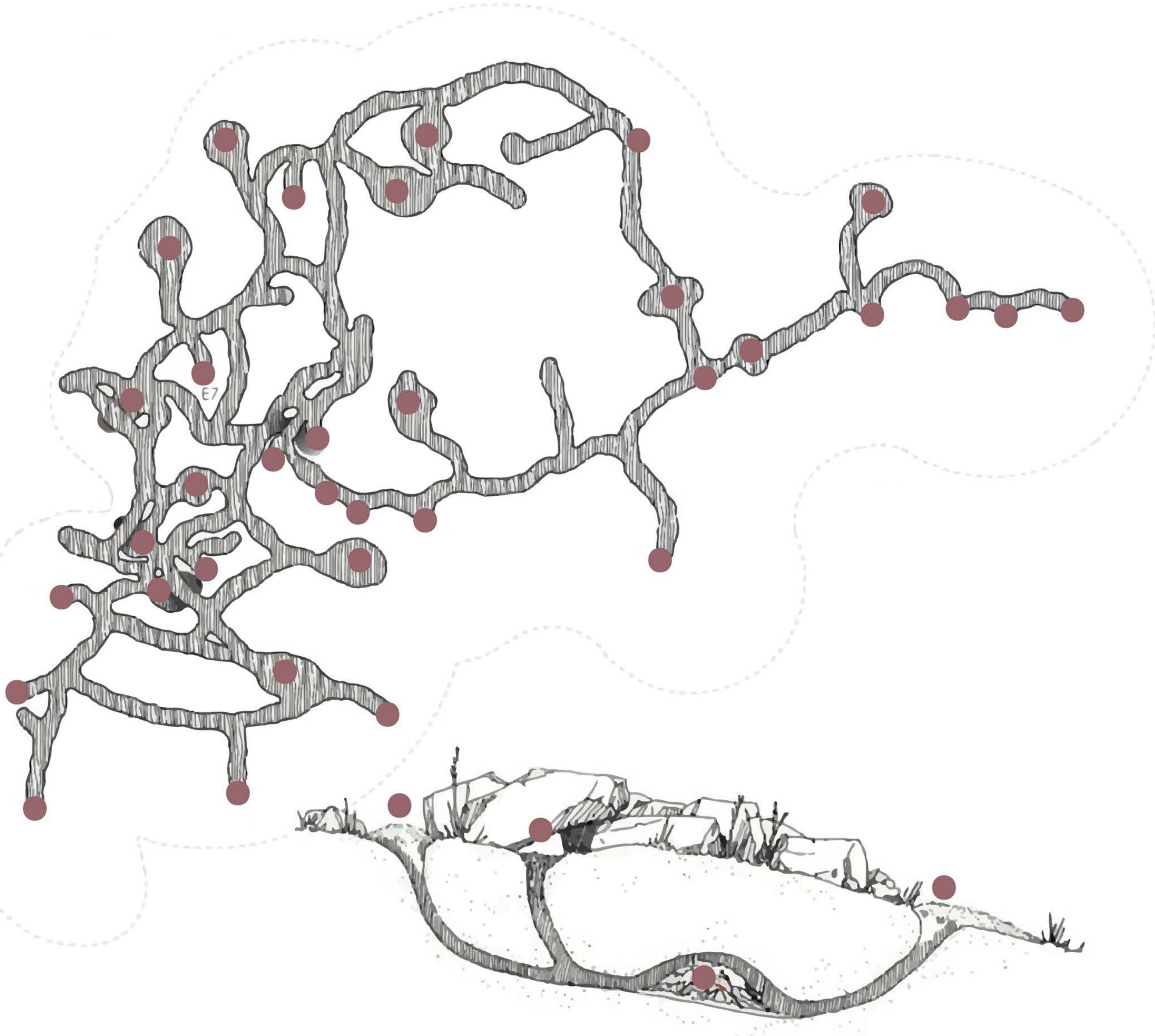


Figure 42 *Map and crossection brown rat den. Points indicate entrances, food caches and nests. Adopted from (Whistance, 2019).*

SEWAGE SYSTEMS

Traweger et al (2006) argue that to effectively manage urban brown rat populations continued inspection of sewers is needed. This is because sewers and other drainage systems form ideal foraging routes and provide year-round breeding possibility for rats due to a stable climate. Additionally predation threat here is low due to difficult accessibility (Van Adrichem et al., 2013). *By concentrating marten foraging sites and shelters in territories close to water, predation pressure is further induced [* ***4f*** *].*

CONCLUSION

By decreasing food availability and shelter opportunity through increased predation pressure, brown rat populations have to live at lower densities. For these measures to be effective it is important that they are executed all year-round and that no other habitable patches for rats can be found. Rats are highly adaptive animals; small changes in their environment can cause drastic changes in their behaviour. This is also why current preventive measures have difficulty effectively reducing rat populations (Verkem, De Maeseneer and Vandendriesche, 2003; Traweger et al., 2006; Van Adrichem et al., 2013).

Within Appendix 1 and below, the question-specific design criteria for SRQ1a are listed. Appendix 3 provides adapted diagrams that illustrate these. All criteria fall under one of two following design principles:

"Decrease food availability and shelter opportunity of the brown rat through increased predation pressure." [***II***]

"Utilize the small window of opportunity created by the differences in habitat requirements of both mammals." [***III***]

Teritories should concentrate marten foraging sites and shelters around waste disposal dumps. [***4e***]

Teritories should concentrate marten foraging sites and shelters close to water. [***4f***]

Dens should be placed at surface level. [***5e***]

Dens should be placed on bare soil. [***5f***]

Natural landscape elements should minimally be distanced 1,5 meters away from building facades. [***6e***]

Natural landscape elements (patchy) should connect marten movement to brown rat foraging sites/paths. [***6f***]

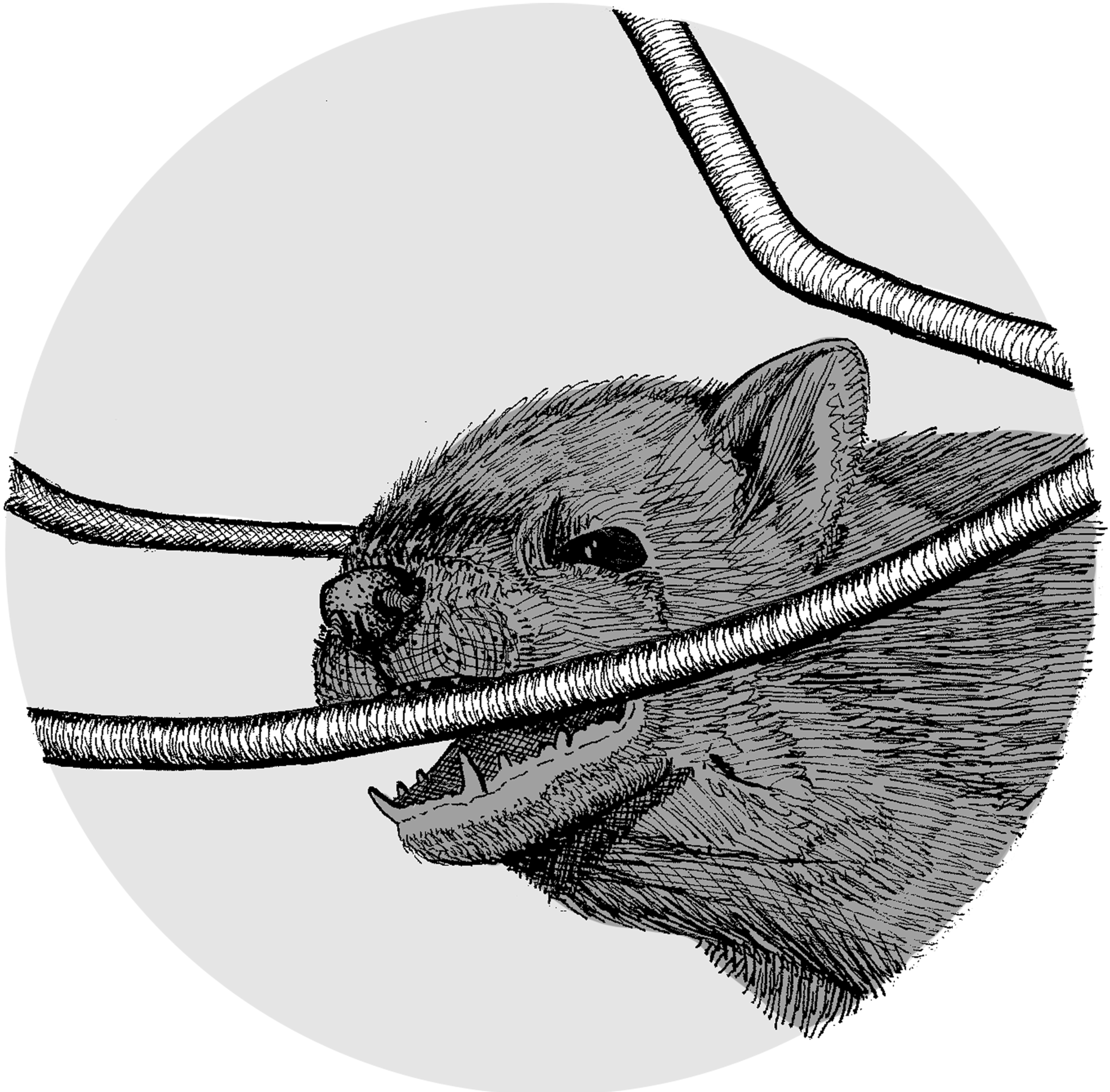
Natural landscape elements in core areas should have characteristics desired by rats. [***6g***]

Natural landscape elements in habitat edges should have characteristics undesired by rats. [***6h***]

Fruiting plants (trees) should have high-hanging fruits. [***7c***]

Fruiting plants (trees) should have fruits that are held for a long time. [***7d***]

Fruiting plants (shrubs) should be toxic to rats. [***7e***]



2.3 SRQ1.b - HUMAN-MARTEN CO-OCCURRENCE

INTRODUCTION

In the Netherlands, the stone marten has gotten a negative reputation. Various news articles about human-marten conflicts in the Netherlands are found online (see figure 43). There were major differences to be found in the severity of the various articles; property damage and related damage costs are most frequently mentioned, but certain cases were also related to human safety threats.

Even though the marten does not search for conflict with humans and larger mammals, sporadic dangerous situations can lead to strong public reactions (figure 44) (Nyhus, 2016). Only a few articles addressed the ecological value of the stone marten. Human-marten interactions are frequently portrayed negatively, with many articles questioning whether the marten should remain a protected species (Nyhus, 2016). This scepticism often stems from the belief that killing or capturing the martens could be a straightforward solution to reducing their nuisance.

"Een knagende steenmarter in je auto, hoe voorkom je dat?."

"Moordlustige steenmarter richt slagveld aan op Kinderboerderij."

"Steenmarters zaaien dood en verderf op het Sallandse platteland, weidevogelsbeschermers radeloos."

"Steenmarters zorgen voor schade aan auto's en huizen: 'Knagen alles kapot'."

"Kerk in Ede wekenlang dicht vanwege vlooienplaag door steenmarters."

"Aantal steenmarters in vijf jaar verdubbeld, bewoners de klos."

"Steenmarter veroorzaakt autobrand bij woning."

Figure 44 *Dutch headings from analysed news articles figure 43.*

Figure 43 *From 30 articles researched the following stone marten related topics were addressed: car damage (16), house damage (9), smell/sound nuisance (9), protected species status (6), ecological value (6) and egg consumption (3). Articles were researched on google using the search term "steenmarter" and filtering articles from 1/12/2022 to 1/12/2023.*

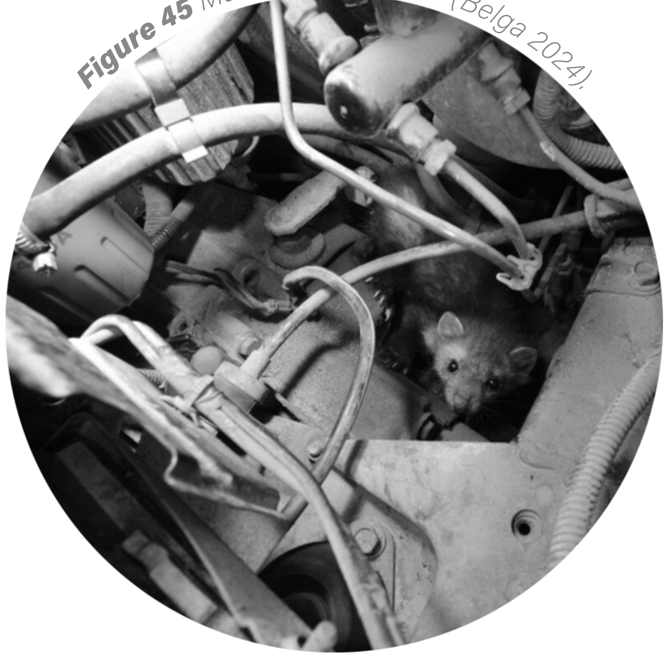


Figure 45 Marten hiding in car (Belga 2024).

However, such measures are prohibited in many areas under the Dutch Flora and Fauna Act (Buitenleven, no date). Effective solutions to mitigate stone marten nuisance should focus on preventing their access to vulnerable areas in urban environments (Broekhuizen, Müskens, and Klees, 2010).

2.3.a SPATIAL SEGREGATION

From the analysis in figure 43 it can be concluded that most frequent conflicts account for property damage. As explained in the introduction, insufficient habitat provision in UOS lead stone martens to, for example, use buildings as dens and parked cars as shelter. For this reason this thesis argues for designing human-marten co-occurrence instead of coexistence.

Here, martens and humans live in close proximity to one another within an urban area but with minimal overlap in their main area of occupation (Nyhus, 2016). This spatial division is visualized in figure 46.

For this concept to work effectively it is important to centre stone marten habitats within UOS, as far away from buildings, parked cars and other private property as possible. This can be achieved by differentiating marten habitat's into low and high habitat quality areas. These areas will be predicted to account for low/high intensity usage. From here on out, the terms 'core area' and 'edge habitat' will be used respectively. Within a home range (the area where an individual usually travels to acquire food, shelter, nesting ground, and mates), an individual frequently uses an area characterized by abundant food resources and shelter opportunities, this area is known as core area (Lee et al., 2022). The edge habitat is the peripheral part of an animal's home range that serves as a transitional zone towards the surrounding environment. While the habitat quality in this area is lower, it can still be utilized for movement and foraging (Lee et al., 2022).

Within the design, core areas will be situated in the centre of UOS (figure 46) which include marten dens, nests, foraging sites, and plenty of shelter possibilities (to both rest and move about) [**4g**]. Low habitat quality areas will be centred around buildings, private properties and parking areas [**4h**]. These contain lesser valued habitat characteristics like patchy coverage, scattered food resources and temporary shelter opportunities. Stress factors within edge habitat*, such as an increased level of human activity, can help in discouraging permanent occupation (Herr, 2008). Nests [**2h**], dens [**5i**], shelter [**6j**] and food [**7f**] will be concentrated in core areas*

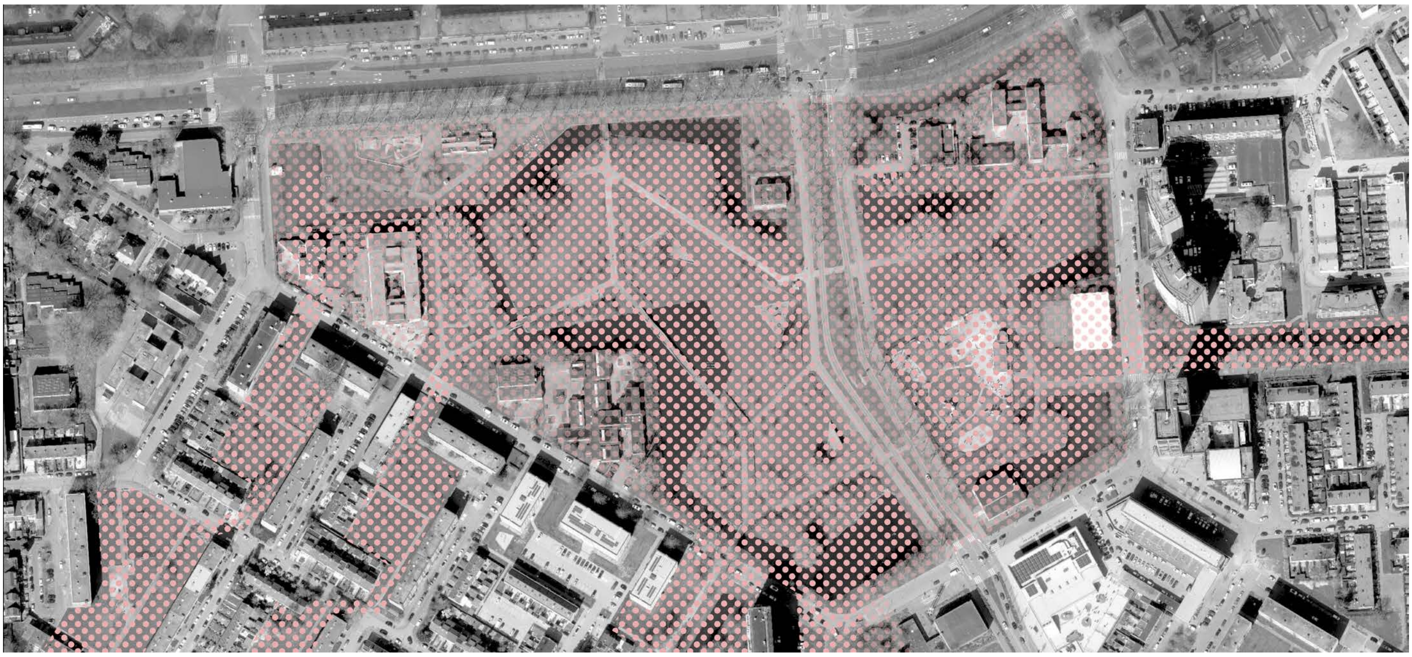
Core area

1. *Most suitable dens and nests*
2. *Accesible and reliable food resources*
3. *Dense vegetation with high coverage*
4. *Reduced human activity*

Edge habitat

1. *Mostly temporary shelter opportunities*
2. *Few, temporary foraging sites*
3. *Patchy vegetation and openness*
4. *Human activity*

Figure 46 *Below: example of human-wildlife co-occurrence (Spinozapark, Rotterdam) due to seperation human (grey) and marten (pink) occupational areas. Plausible differentiation between core area and edge habitat. Side: Rules on the design of the respective areas.*



In addition to decreasing the connectivity between habitat and built areas, directly reducing the reachability of buildings should be enforced by minimizing the potential of vegetation to leverage martens to reach building entrances. *This can be achieved by further increasing the minimum distance between vegetation canopies and buildings of design criteria [* ***6f*** *] from 0.9 meters to 1.5 meters, which corresponds to the marten's jumping distance (Klees, 2024).*

Research indicates that martens exhibit varying probabilities in the usage of different areas within their territory. For instance, most of their denning occurs in just a few specific dens. Moreover, during winter, martens reduce their activity and limit foraging to their immediate surroundings to access readily available food (Bisonette and Broekhuizen, 1995). This suggests that when adapting the aforementioned habitat model, it is likely that stone martens will utilize it in this manner. Apart from reducing human-wildlife conflict, this spatial differentiation can be used as limitation to stone marten overpopulation, this is elaborated in SRQ2.

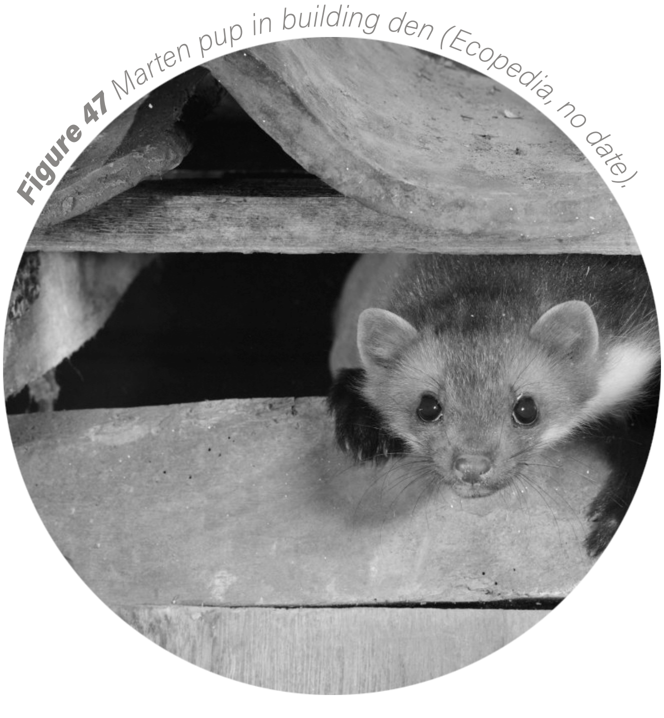


Figure 47 Marten pup in building den (Ecopedia, no date).

2.3.b NATURAL REFUGES

For such a model to be effective additional measures should be taken. As mentioned earlier, urban living stone martens tend to frequently den in buildings. A two-year tracking of 13 stone martens in two towns in southern Luxembourg by Herr et al. (2010) even found 97,1% of denning activity within buildings. Inhabited buildings were used more extensively in winter as they were warmer and better insulated. Additionally, uninhabited spaces in built areas, like attics or cavity walls, provide freedom from human disturbance, more than most shelters situated in open space do. For females, such spaces provide better nesting conditions (Herr et al., 2010). *To ensure that stone martens do not migrate to buildings for their resting places, it is important that dens and nests in high-quality habitat areas are well equally well insulated [* ***2g*** */* ***5g*** *] (Illustrated and explained in figure 26 on page 41) and isolated [* ***2c*** */* ***5h*** *].*

CAR DAMAGE

The marten is notorious for damaging cars, with theories suggesting that this behaviour is due to the thermal benefits of residual engine heat or the car's role as a safe resting spot, food storage, or refuge (Ecopedia, no date; Berge, Berlengee and Gouwy, 2021). However, research by Herr, Schley and Roper (2009) argues that these hypotheses are incorrect, finding that car damage is linked to territorial behaviour. Martens often associate with cars during late spring and summer, their mating season, using them for patrolling and scent-marking. The short duration of car visits supports this theory. The lack of cover when traversing through urban environments can enforce this behaviour (Dekker, 2024). *To reduce such incidents, territories will be designed to not overlap parking areas and edge habitat will be situated around them [* ***4h*** *]. With the addition of more acceptable traversal possibilities through natural landscape elements [* ***6*** *], this approach should reduce territorial behaviour in less valuable zones.*

HUMAN-MARTEN INTERACTIONS

Stone martens in rural areas often start or end their foraging activity during both sunrise and sunset, in urban areas marten activity is more nocturnal. This is believed to be the case because martens adapt their activity patterns so that it minimally overlaps with human activity (Herr, 2008). Only occasionally, during summer, there is a slightly increased chance of spotting a stone marten. As the sun is set for a shorter period of time, the animal can sometimes still be foraging after sunrise (Broekhuizen, Müskens and Klees, 2010). *Apart from the already mentioned fact that martens tend to avoid confrontation, few human-marten interactions create no need for the design to take this into account.*

CONCLUSION

Properly arranging and concentrating habitat requirements will help redirect stone martens away from areas where they might cause nuisance. Key design elements include providing warm, enclosed shelter; easily accessible food sources; and ample cover within green spaces. Important additional benefits are the retaining attractiveness for human recreation in urban open space and the management of marten population due to restricted space usage. Additionally, reduced marten activity may decrease the likelihood of rats foraging in homes.

Within Appendix 1 and below, the question-specific design criteria for SRQ1b are listed. Appendix 3 provides adapted diagrams that illustrate these. All criteria fall under one of two following design principles:

"Seperate human and marten occupied areas through low habitat quality dividers." [***IV***]

"Create more attractive shelter places and foraging sites." [***V***]

Nests should be located in quiet, secluded areas. [***2c***]

Nests should be well insulated. [***2g***]

Nests should be mostly concentrated in core areas. [***2h***]

Territories should have core areas in the centre of open spaces. [***4g***]

Territories should have habitat edges around buildings, private properties and parking spots. [***4h***]

Dens should be well insulated. [***5g***]

Dens should be located in quiet, secluded areas. [***5h***]

Dens should mostly be concentrated in core areas. [***5i***]

Natural landscape elements should mostly be concentrated in core areas. [***6j***]

Fruiting plants plants should mostly be concentrated in core areas. [***7f***]

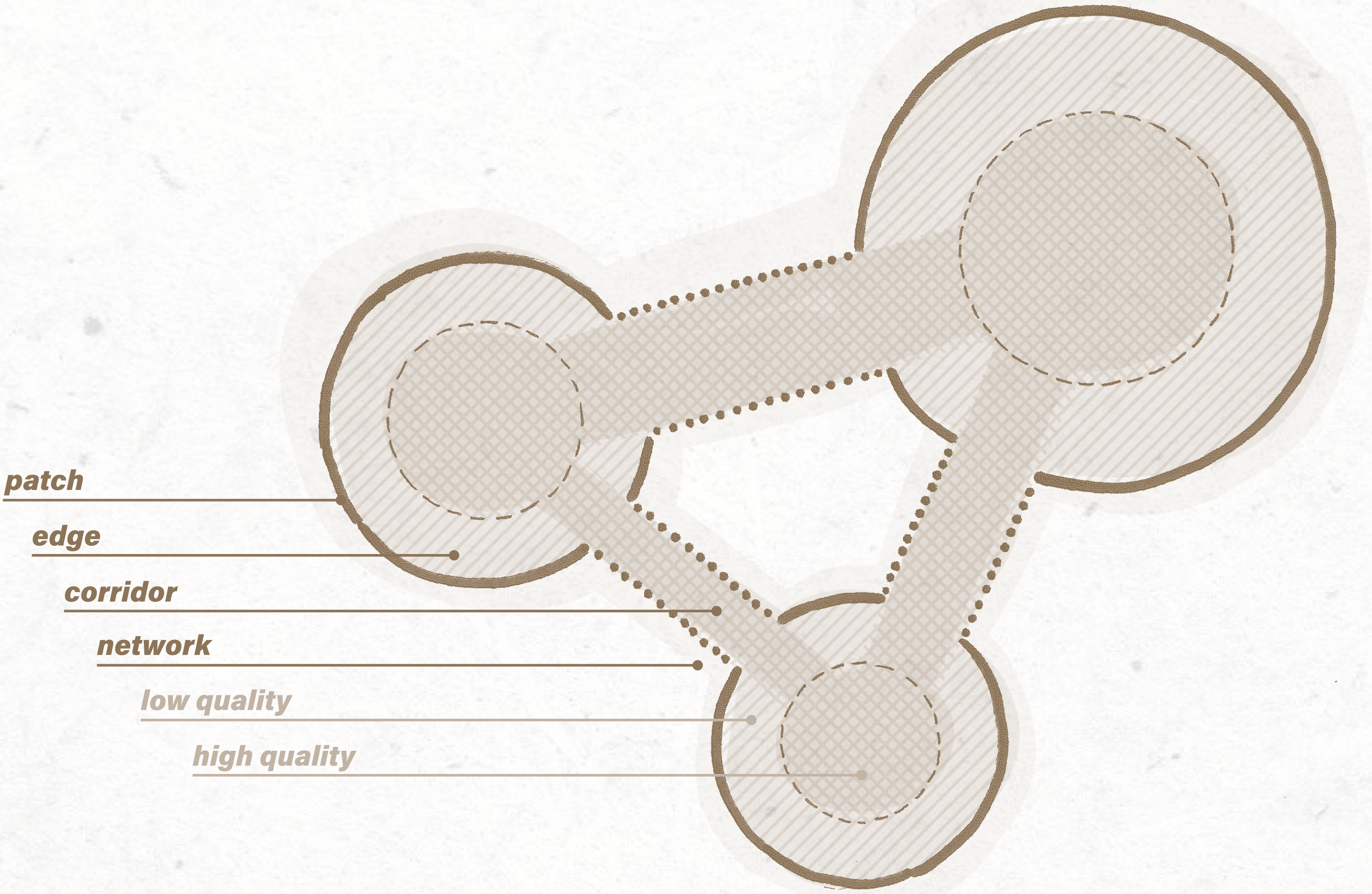
Figure 48 *Marten on ladder (Meeuwsen, 2023).*

OPE

3

N SPACE SYSTEM

Figure 49 *Spatial elements of the open space system design used for stone martens.*



INTRODUCTION

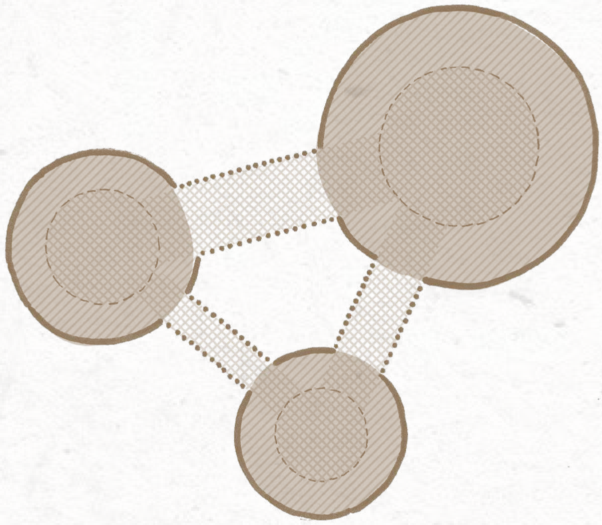
The proposed design guidelines and criteria of previous chapters have provided the ingredients needed within the design. To fit set ingredients into urban open green spaces, a framework is needed. This chapter aims at the creation of this framework, using spatial concepts to adapt an open space system design inspired by "Patches and structural Components for a Landscape Ecology" (Forman and Godron, 1981). Although this source focusses its design criteria on a plausible ecosystem constituting of multiple species, design criteria are still applicable to one. This thesis focuses solely on examining the interaction between stone martens and the urban landscape, this species-landscape relation is seen by (Forman and Godron, 1981; Foreman, 1995) as a mosaic of spatial elements.

Design criteria are visualized in figures accompanying the text on the adjecent design guideline. Appendix 1 delineates the referenced design critera.

This mosaic commonly consists of three key spatial elements: patches, corridors, and the matrix. These elements are so fundamental that the patch-corridor-matrix model serves as a spatial language, transcending disciplinary boundaries (Foreman, 1995). In this thesis, these theories will be utilized to connect the realms of behavioural ecology and landscape architecture. The matrix, which encompasses the urban landscape itself, encapsulates the ecological network of, in this research, the stone marten.

This thesis adds two additional layers to the (habitat) patches and (dispersal) corridors of the proposed model, which are particularly important within the open space system design for stone martens: habitat edges and ecological network. They help in accounting for the mammals socio-spatial organization, design for human-marten co-occurrence and (most importantly) provide tools that help limiting population density/movement if necessairy. (Dramstad et al., 1996).

3.1 HABITAT PATCHES



"Patches will constitute the inhabited territories of stone martens within the species' ecological network."

LARGE PATCHES

Large patches can potentially inhabit multiple male martens. By spatially dividing these into smaller ones, similar to design guideline [***1***], more male habitats can be created and their potential territoriality disturbance on humans and conspecifics is reduced (figure 50) (Dramstad et al., 1996).

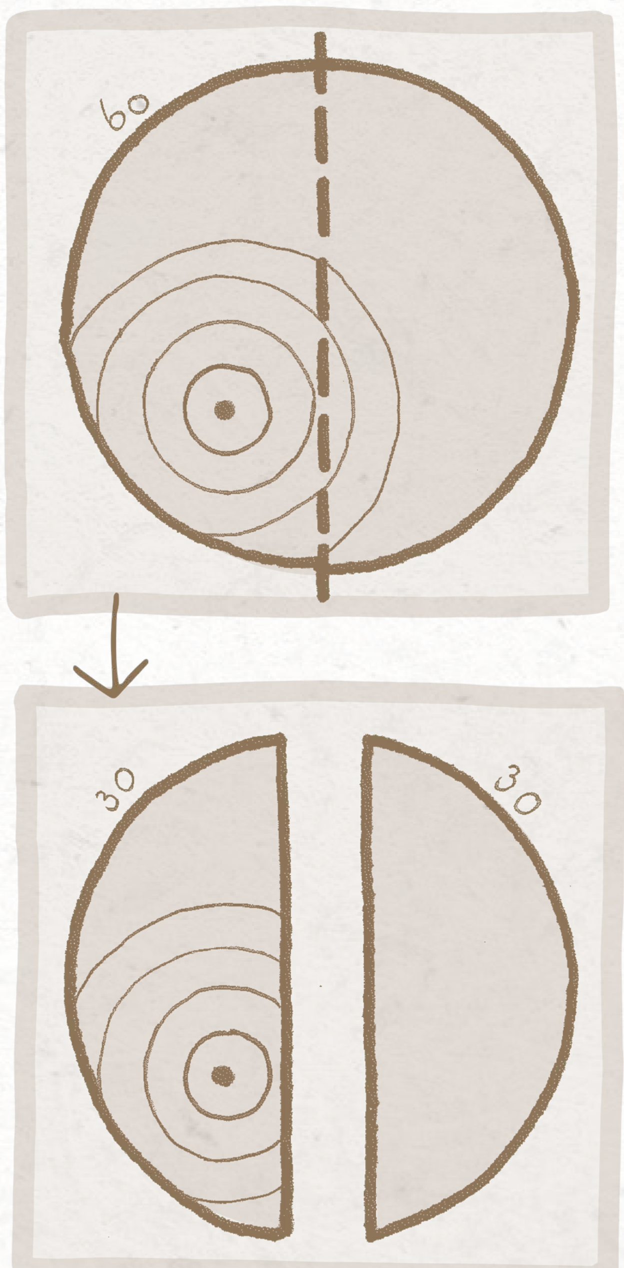


Figure 50 *Design criteria [* ***8a*** *]. Adapted from (Forman and Godron, 1981).*

PATCH SIZE

Within a single male marten habitat patch, multiple female territories can be fitted, as stated in design guideline [***4***]. Research on home ranges of stone martens living in the Dutch city of Nijmegen (Bisonette and Broekhuizen, 1995) has stated that female marten territory size varies between 15 and 55 hectares whilst male territory size varies between 30 and 80 hectares. The lower values will be used, meaning the adaptatioj of a female-male ratio of 2:1 respectively (figure 51). Even though lower values are observed (Müskens and Broekhuizen, 2005), using values based on the smallest possible territory size increases the chance of creating a pest species.

This territory size was therefore chosen in consultation with Bakker (2024) and Klees (2024). Additionally, the urban environment analysed in Nijmegen and Rotterdam show the most similarities.

SMALL PATCHES

Probability extinction of species is greater in smaller patches or patches with low habitat quality (Aida et al., 2016). Smaller patches, mainly those between 15-30 hectares, have to account for their size by creating a respectively larger or qualitatively better core area (figure 52).

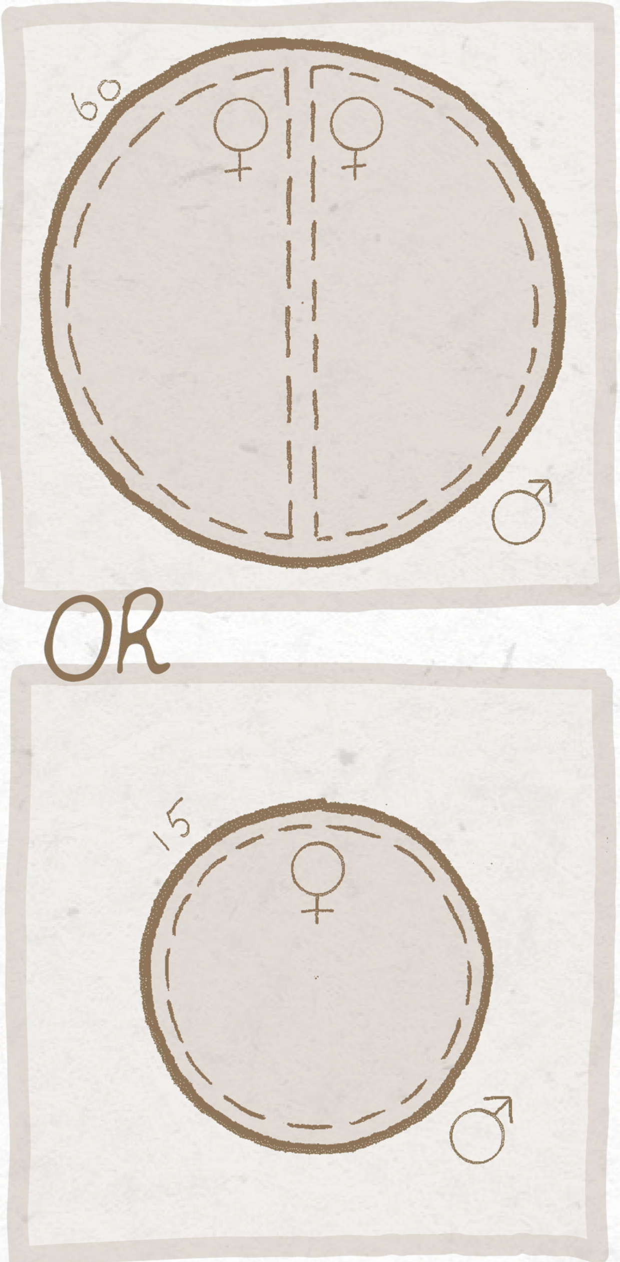


Figure 51 *Design criteria [* ***8b*** *]. Adapted from (Forman and Godron, 1981).*

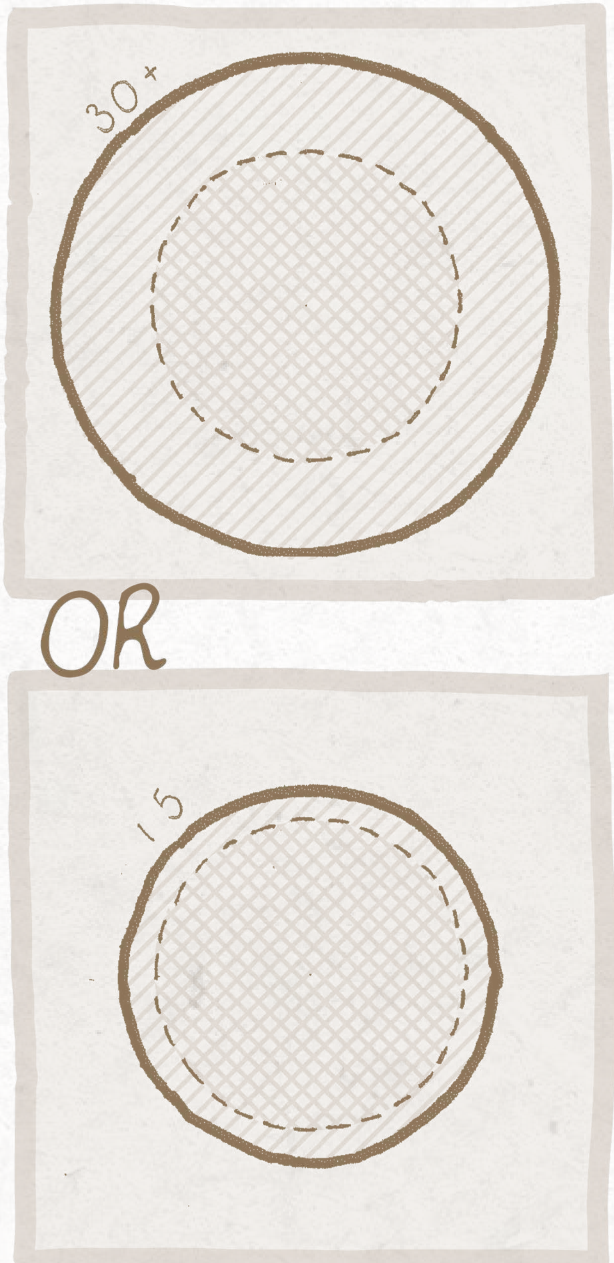


Figure 52 *Design criteria [* ***8c*** *]. Adapted from (Forman and Godron, 1981).*

MALE-FEMALE PATCH RATIO

A study on a stone marten population in central Bulgaria Peeva (2017) has found a shocking average sex ratio of 2.7 males to 1 female, which opposites the fact that most male territories are larger than and contain multiple female territories (Müskens and Broekhuizen, 2005). Within her research, Peeva (2017) describes that when using different research methods a wild variety in results on the same population was found. The large variety in results between different observational data (Herr, 2008; Herr, Schley and Roper, 2009; Larroque et al., 2016; Peeva, 2017) puts in perspective that it is very difficult to pinpoint the territory size and usage martens.

As male territoriality is led by securing exclusive access to multiple females, and female territoriality is led by the availability of suitable nesting locations, all possible territories should therefore be made suitable for female inhabitation. A male biased natal dispersal, combined with a positive M:F sex ratio at multiple ages do make densification of male marten habitats probable (Peeva, 2017). As a result, the design will provide habitat requirements for both sexes within areas 15 hectares or larger, meaning that designed core areas between both sexes will overlap, as was stated in guideline [***4a***] (figure 53).

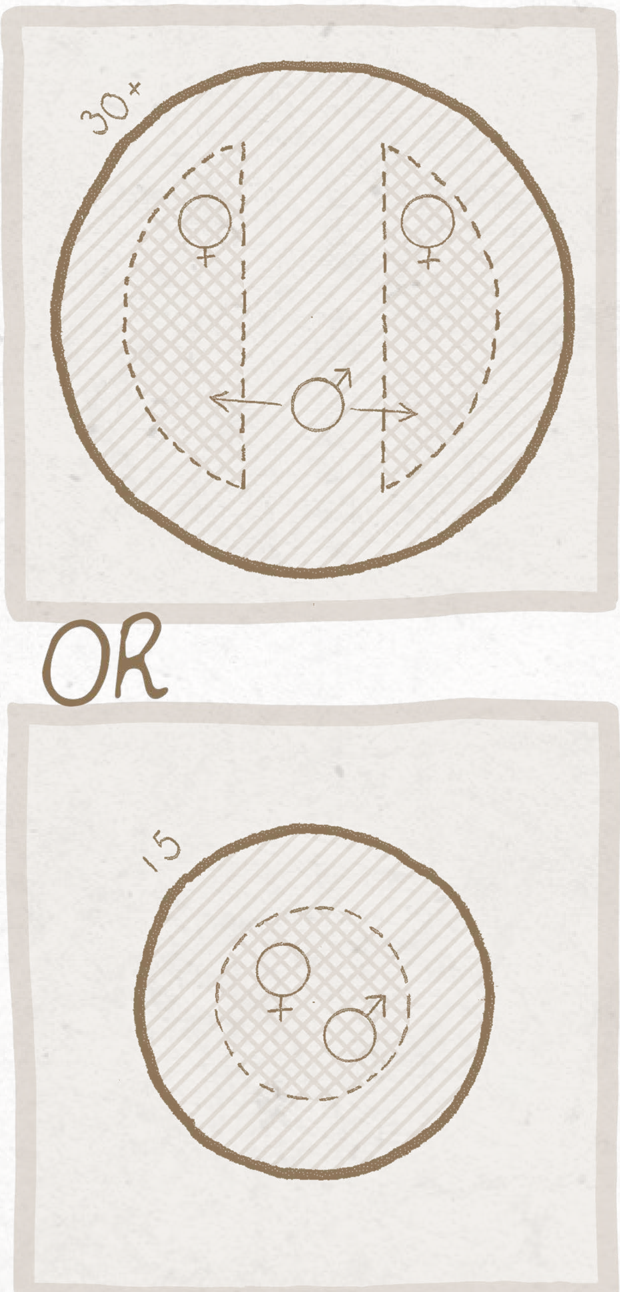


Figure 53 *Design criteria [* ***8d*** *]. Adapted from (Forman and Godron, 1981).*

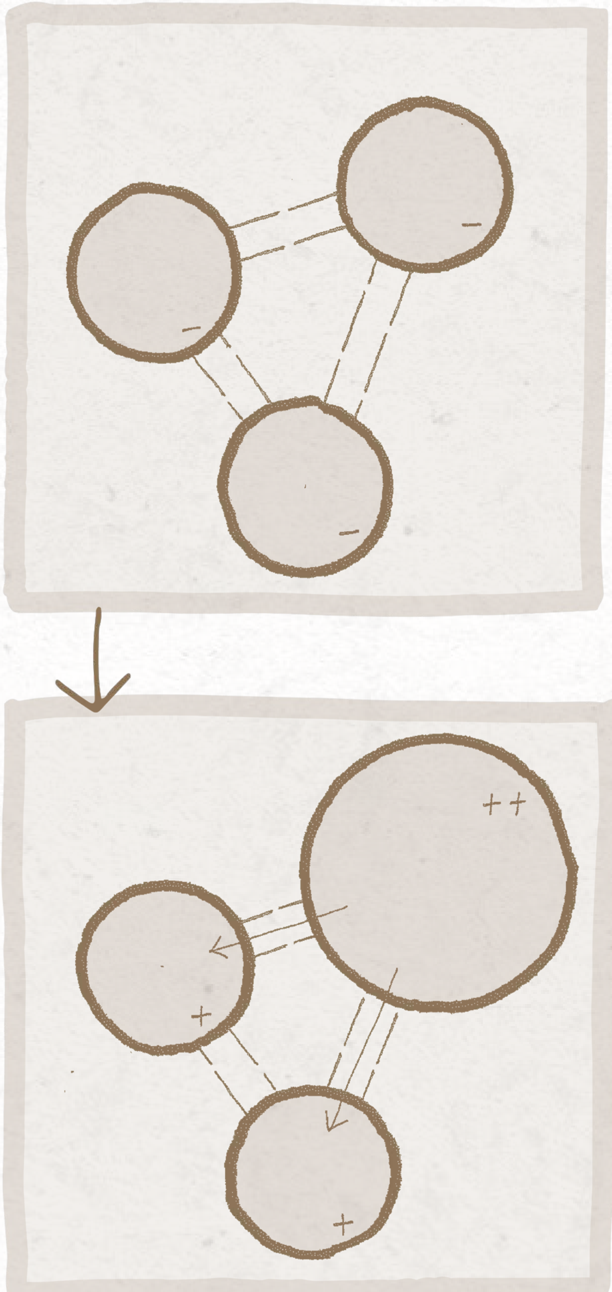


Figure 54 *Design criteria [* ***8e*** *]. Adapted from (Forman and Godron, 1981).*

SOURCE PATCHES

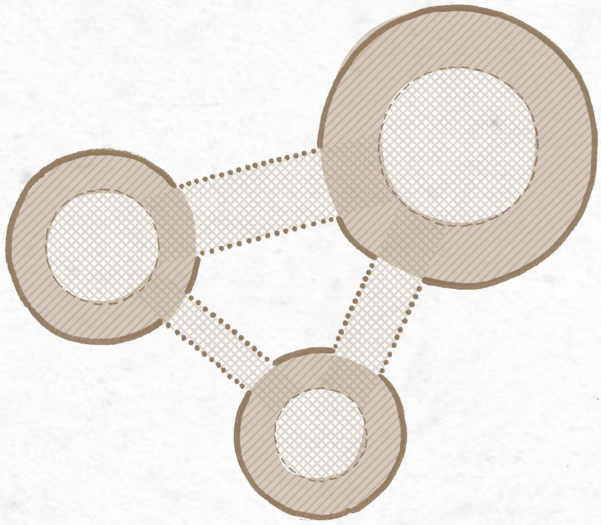
In general, for efficient population distribution, especially in areas where population densities of species are low and disturbances are high large patches are of necessity for animals to avoid those disturbances. Large patches of natural vegetation are the only structures in such landscapes that sustain viable populations of species (Dramstad et al., 1996).

SOURCE-SINK LANDSCAPE THEORY

To elaborate, the source-sink landscape theory can be used. This theory distinguishes "source" and "sink" landscapes. Source* landscapes, in landscape ecology, are landscapes that promote the development of an ecological process, such as population distribution. Sink* landscapes are the ones that may stop or retard the development of an ecological process, whilst still attracting animals to disperse towards them. This is called an 'ecological trap' (Chen, Fu and Zhao, 2008).

Because stone martens are highly adapted to urban environments, such sink patches where a stone marten population would decline or retard are thought to minimally occur (Bisonette and Broekhuizen, 1995). Including larger 'source' patches within an ecological network, especially if the environment to be inhabited is large and disterbances are plenty, source patches would help to ensure an exponential increase in population size, functioning as breeding grounds for increased species dispersal (figure 54, previous page). Smaller patches with lower habitat qualities can still serve as stepping stones, whereas smaller patches with low habitat quality can be disadvantageous for survival and inhabitation (Forman and Godron, 1981).

3.2 HABITAT EDGES



"Edges are designed as the lesser valued outer portion of (joint) habituated patches (with high qualitative core areas)"

EDGE ACTIVITY

The environment in edge habitat differs significantly from the interior of the patch(es) (Dramstad et al., 1996). As previously described, the main goal of edges is to provide a lesser valued area that is still a suitable part of an individual's home range, but discourages martens from stepping outside of territorial borders. In Herr's research (2008) the home range and core area define as 95% and 50% of a marten's occupation, respectively. If necessairy, edges could therefore account for half or more of the marten's foraging activity as core area usage is also largely defined by resting (figure 55).. This design criteria is an addition to criteria [***4b***] and in line with criteria [***4c***].

Nonetheless, divisions between core areas are divined by the animal's activity and movement patterns and do not totally align with how they are designed.

EDGE ABRUPTNESS

The edges make up the shape of an inhabited patch, their form is important for controlling the movement of species along or across an edge into the built environment. Firstly, the abruptness of an edge is important, an abrupt edge is favoured as it guides stone martens to traverse along their territorial border instead of over them (figure 56).

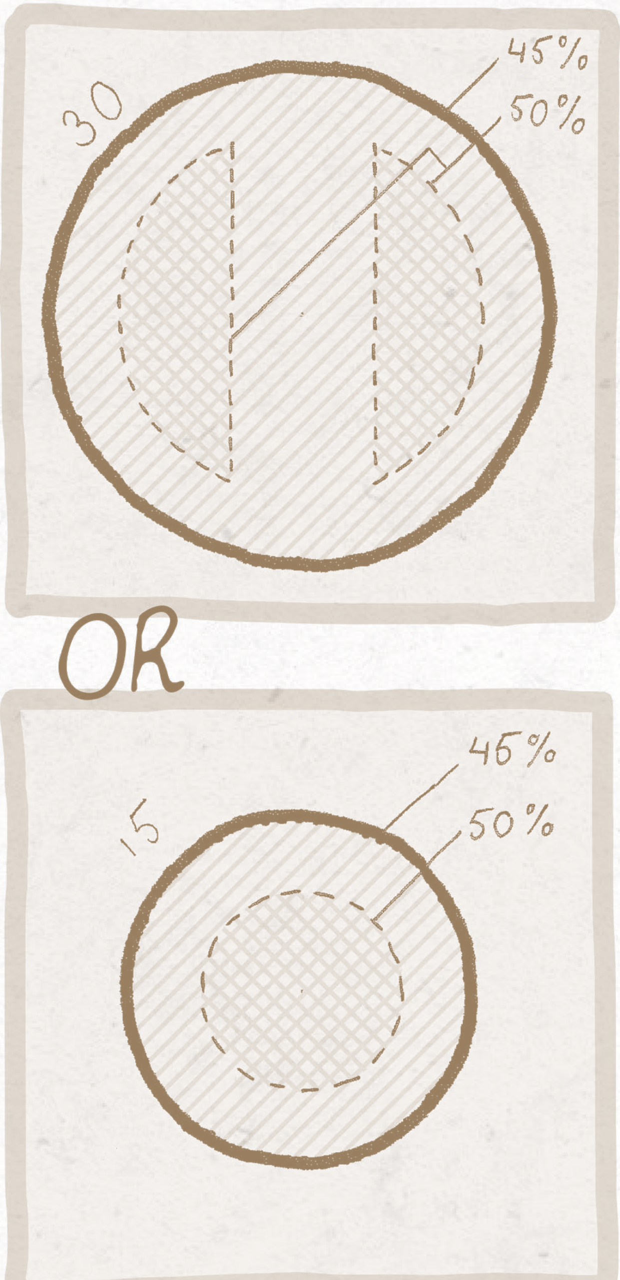


Figure 55 *Design criteria [* ***9a*** *]. Adapted from (Forman and Godron, 1981).*

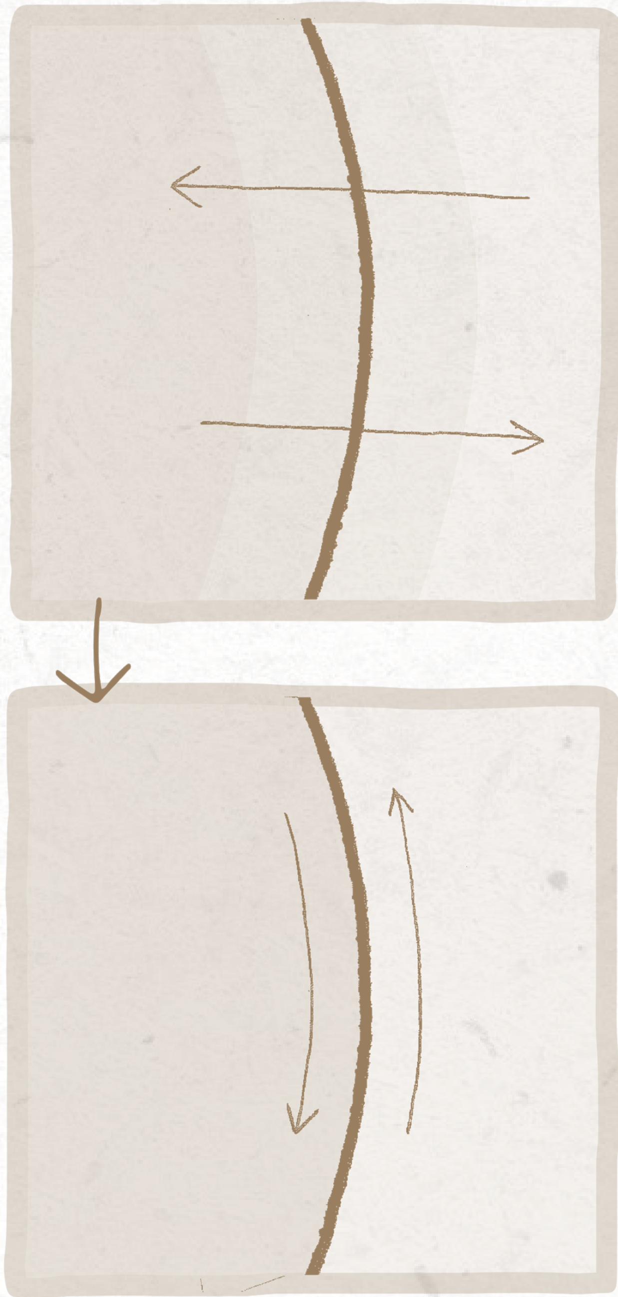


Figure 56 *Design criteria [* ***9b*** *]. Adapted from (Forman and Godron, 1981).*

INTERIOR-EDGE SPECIES

This is further substantiated by the fact that stone marten is an 'interior-edge species*': species that make use of both edge and interior habitats (Imbeau, Drapeau and Mönkkönen, 2003). The stone marten thrives on greater vegetative complexity available on these edges between different landscapes within edge habitat as they promote safe traversal and can provide food resources (Dekker, 2024).

EDGE STRAIGHTNESS

The straightness or curvilinearity of an edge can similarly influneces marten movement, convoluted edges can encourage entering the built environment (van der Gaag, 2024) (figure 57).

EDGE ABRUPTNESS

In similar vein, the shape of the patch determines the amount of interaction there is with the surrounding urban matrix (figure 58). A less convoluted patch can also potentially create a larger high habitat quality area (Dramstad et al., 1996).

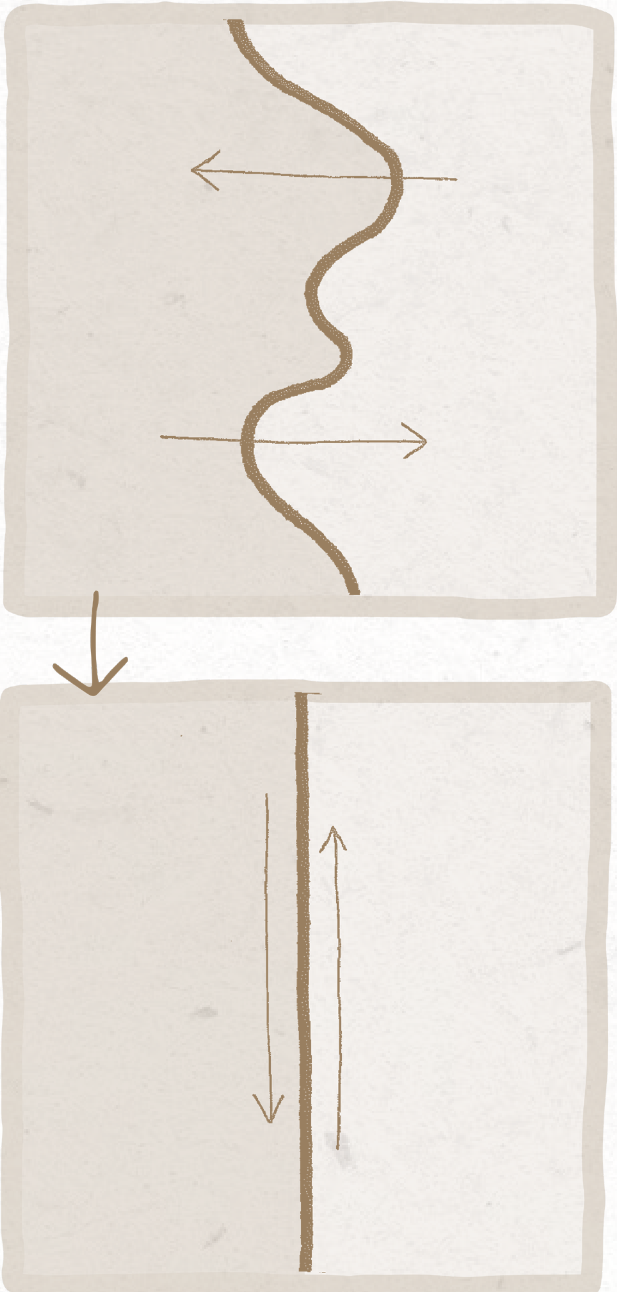


Figure 57 *Design criteria [* ***9c*** *]. Adapted from (Forman and Godron, 1981).*

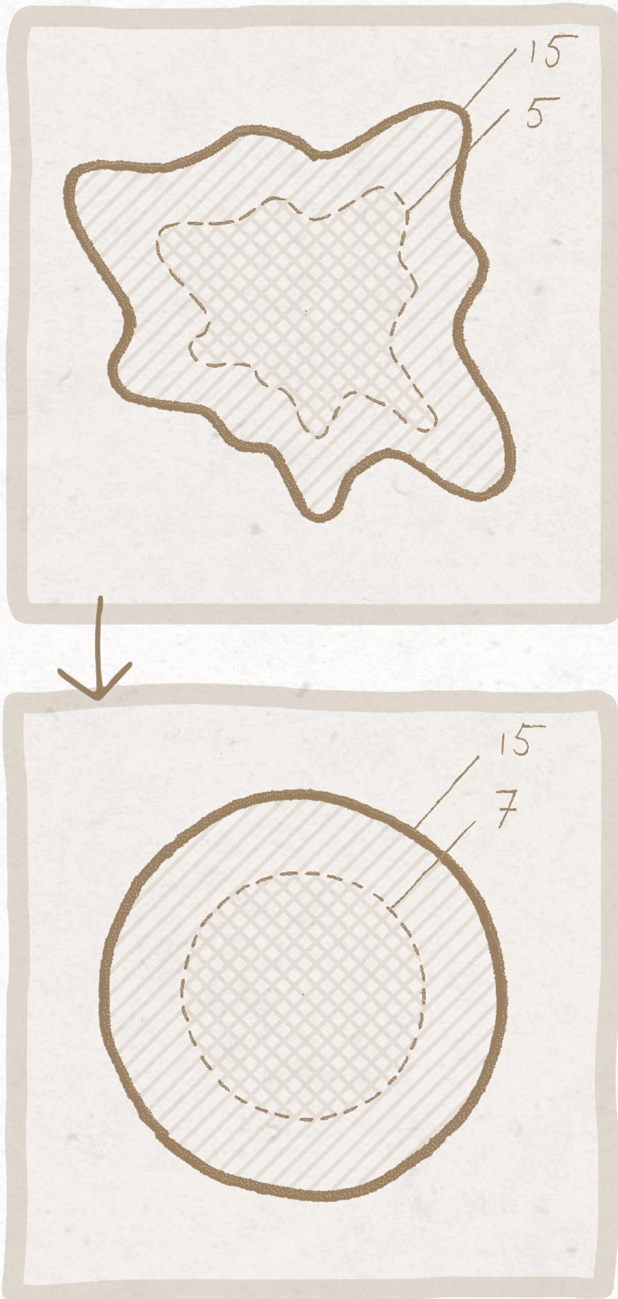
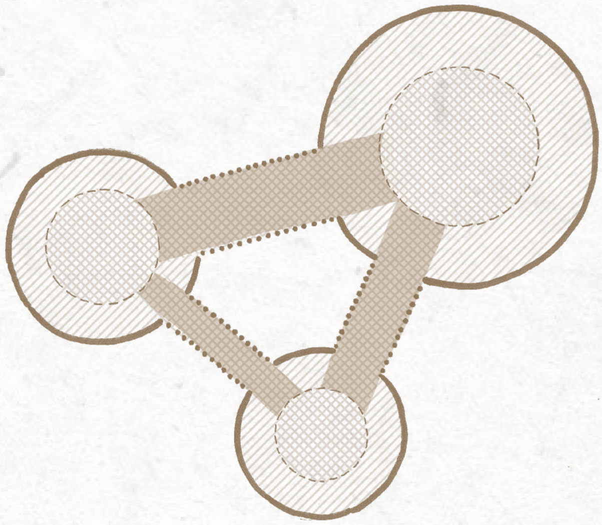


Figure 58 *Design criteria [* ***9d*** *]. Adapted from (Forman and Godron, 1981).*

3.3 DISPERSAL CORRIDORS



"Corridors form the links between plausible marten habitats that are consequently designed solely for pup dispersal. "

CORRIDOR SHAPE

Through loss and isolation of habitats within a matrix, a need for habitat connectivity translates itself into the implementation of corridors (Dramstad et al., 1996). The adaptability of stone marten to traverse through built areas obstructs the use of solely stepping stones: small patches of land, suitable for temporary inhabitation when traveling over long distances (Saura, Bodin and Fortin, 2014). Individual pups could disturb humans by travelling through built areas; the population could also familiarize itself with this space usage. The marten network is therefore in need of highly qualitative, uninterrupted corridors as to direct the animal's population dispersion (figure 59).

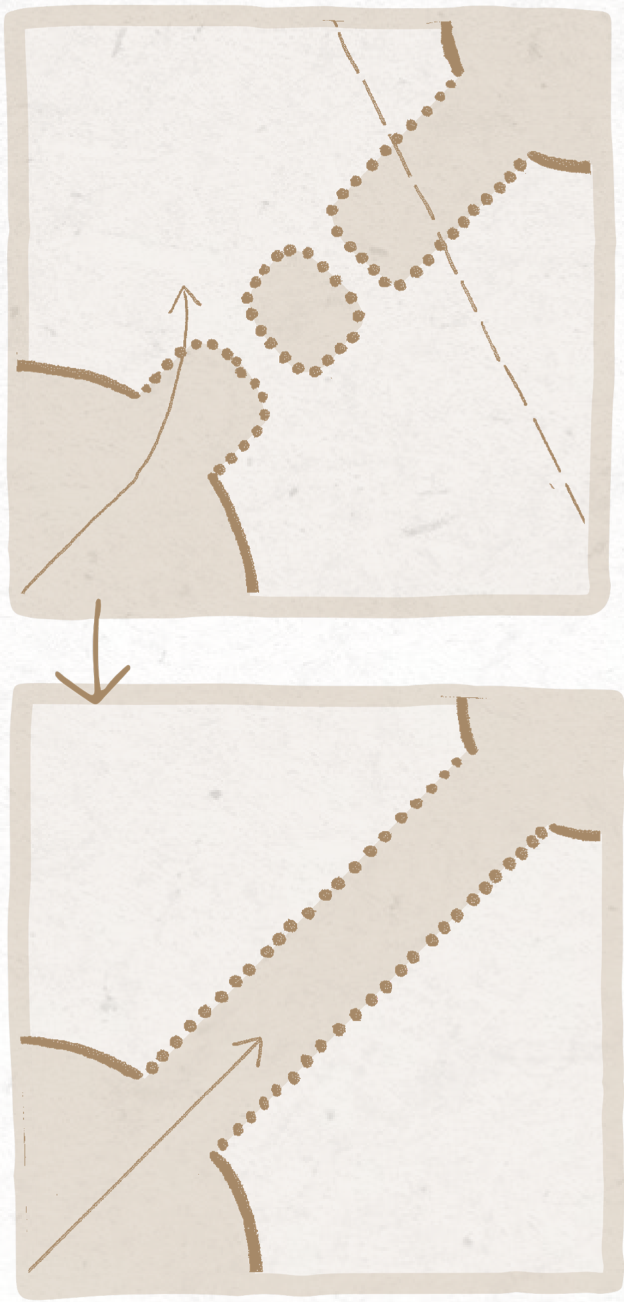


Figure 59 *Design criteria [* ***10a*** *]. Adapted from (Forman and Godron, 1981).*

CORRIDOR SIZE

Even though the animal could be forced to cover long distances during a single night, the animal's dispersal capability is great (Broekhuizen, Müskens and Klees, 2010). Their agility and flexibility make it possible for the pups to move about safely and quickly. Temporary shelters for longer journeys can already be found in simple locations such as thickets and treetops (Genovesi and Boitani, 1997). The dispersal distance and thus length of the corridors is unlimited (figure 60). The width of the corridors will depend on the amount of space available in the street profile, but a minimum of 3 metres is thought to suffice (Klees, 2024).

CORRIDOR QUALITY

Corridors can be designed as highly qualitative areas with no low-quality edges dividing them from the urban fabric, without the chance of marten causing nuisance (Dramstad et al., 1996). This is because the investment time of pups in finding temporary shelters whilst dispersing is minimal, this means that there will be little disruptance in buildings (Klees, 2024). In addition, pups do not yet have a territory to demark, which is decrease the probability of damage to cars (Klees, 2024). Both conditions argue that the differentiation between low-quality and high-quality habitat areas does not apply when designing corridors (figure 61).

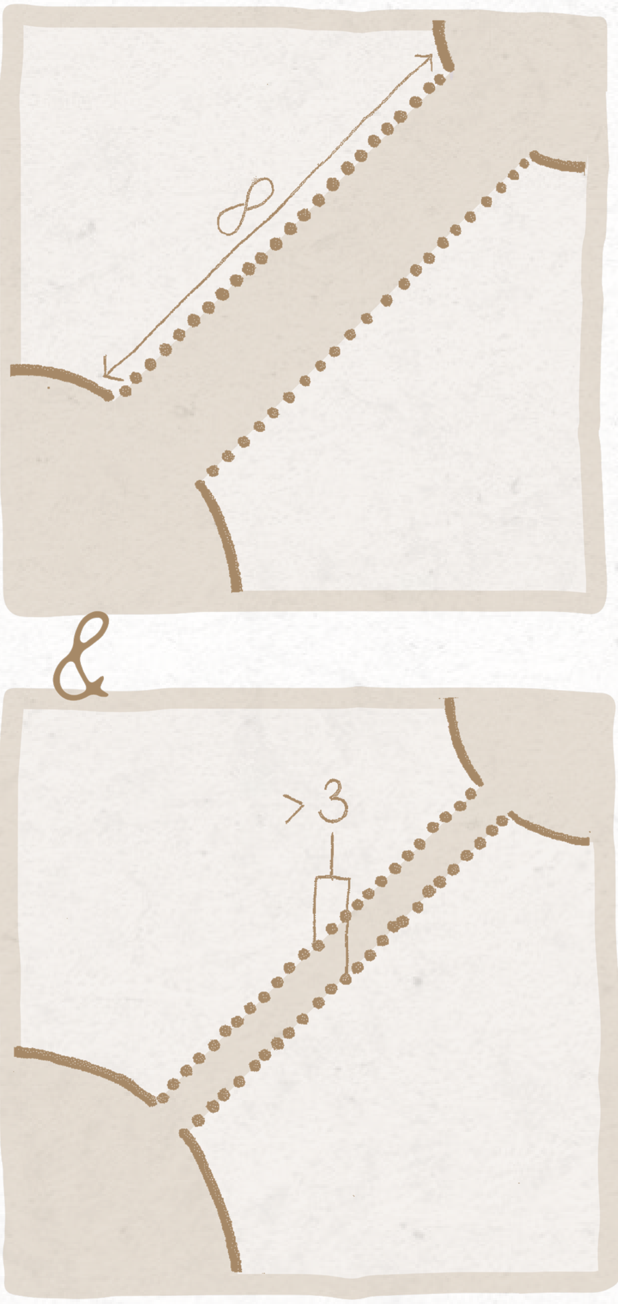


Figure 60 *Design criteria [* ***10b*** *]. Adapted from (Forman and Godron, 1981).*

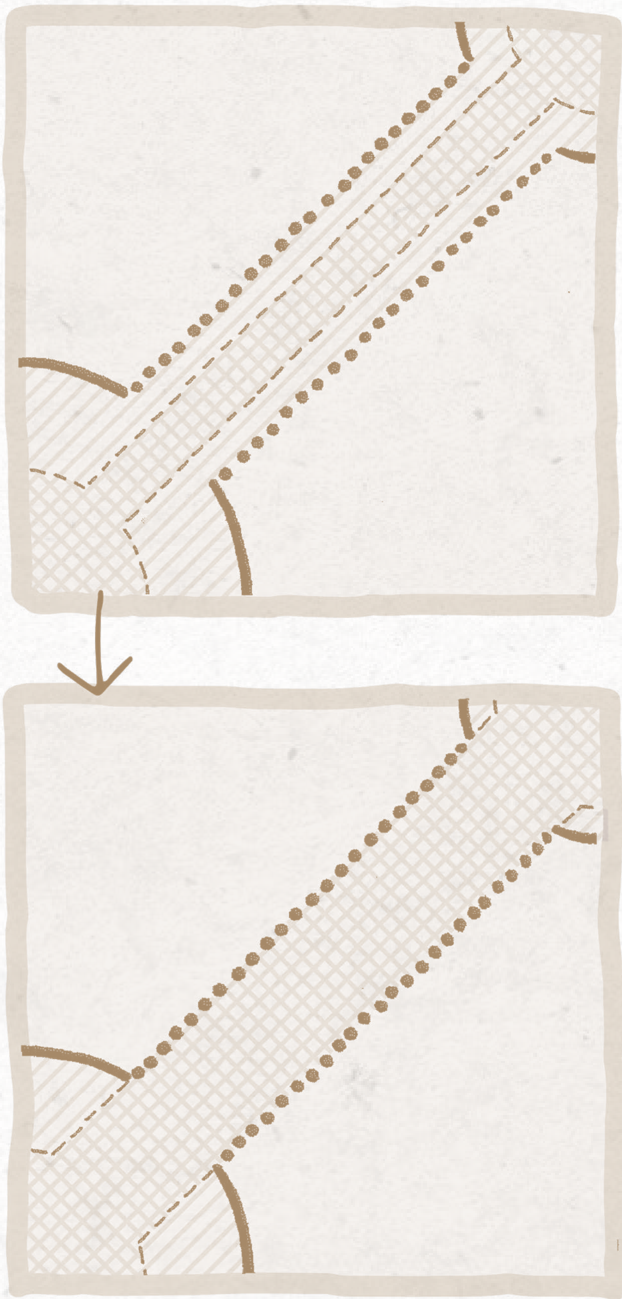


Figure 61 *Design criteria [* ***10c*** *]. Adapted from (Forman and Godron, 1981).*

CORRIDOR-PATCH RELATION

the boundaries of a marten's territories are flexible and depend on the location of the individual (Klees, 2024). Excellent scent-marking and confrontation avoidance make it possible for pups looking for their own habitat to quickly pass that of a conspecific (Broekhuizen, Müskens and Klees, 2010). For this reason corridors do not have to be laid around marten territories (figure 62). Habitat patches can even be used as stepping stones for pup dispersal if interconnected in such a way.

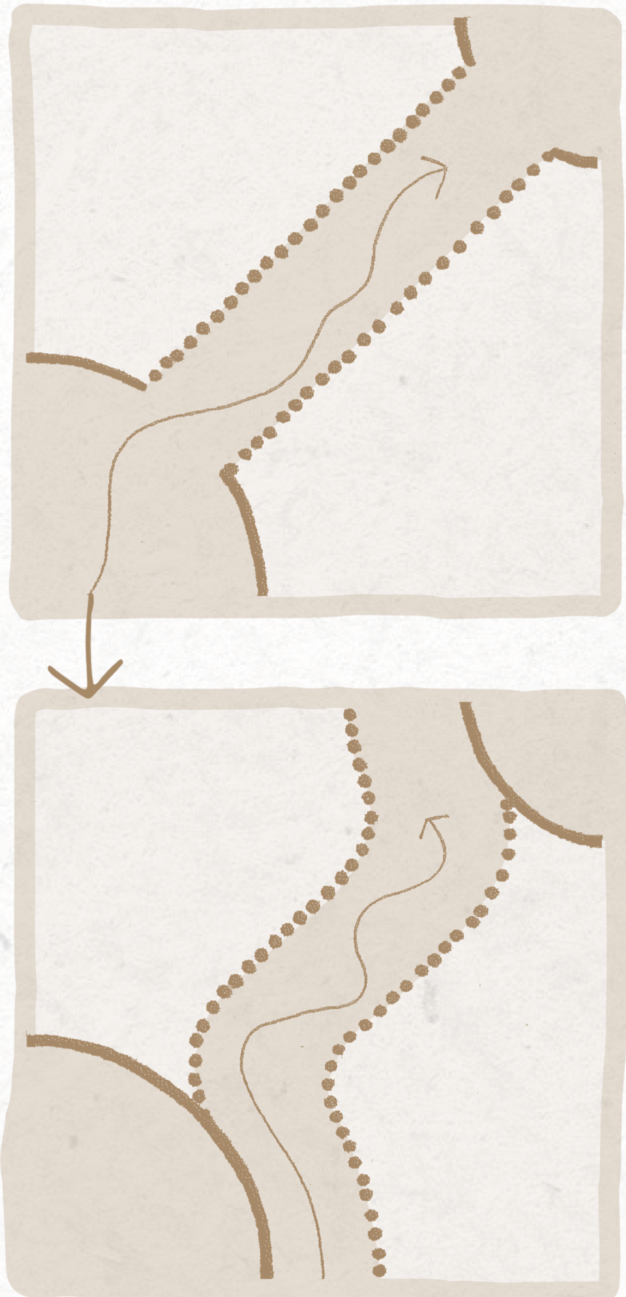
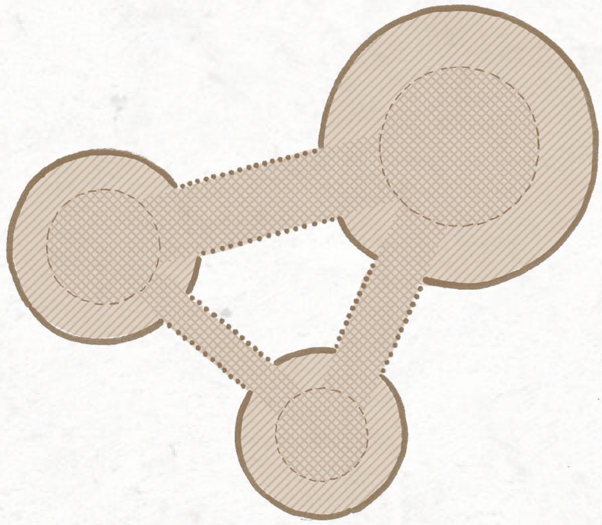


Figure 62 *Design criteria [* ***10d*** *]. Adapted from (Forman and Godron, 1981).*

3.4 ECOLOGICAL NETWORK



"The interconnection of patches, edges and corridors throughout a matrix, providing the ecological network for a marten population."

NETWORK SOURCE-SINK DENSITY

To combat loss and create usability of habitats it is important that all patches are interconnected (Dramstad et al., 1996). By creating a large network it is possible for pups to spread themselves over large distances. The proposed 'Source' landscapes for population distribution have an increased need for network connectivity as they have higher pup dispersal rates, which leads to increased movement. Smaller patches that inhabit few martens, or are mainly used as stepping stone for species dispersal, do not have this need (figure 63). This results in higher corridor density near large patches and lower corridor density near small patches (Dramstad et al., 1996).

NETWORK AND MATRIX MESH SIZE

The corridor density is also dependent on the mesh size of the urban matrix. If the mesh size of the matrix is low, such as in a high-rise district, the corridor density is low yet the corridors are wider due to a large amount of open space available. If the mesh size is high, such as in a suburban district (where building density is high), the corridor density is high but the corridors are smaller due to the minimum amount of open space available (Dramstad et al., 1996) (figure 64).

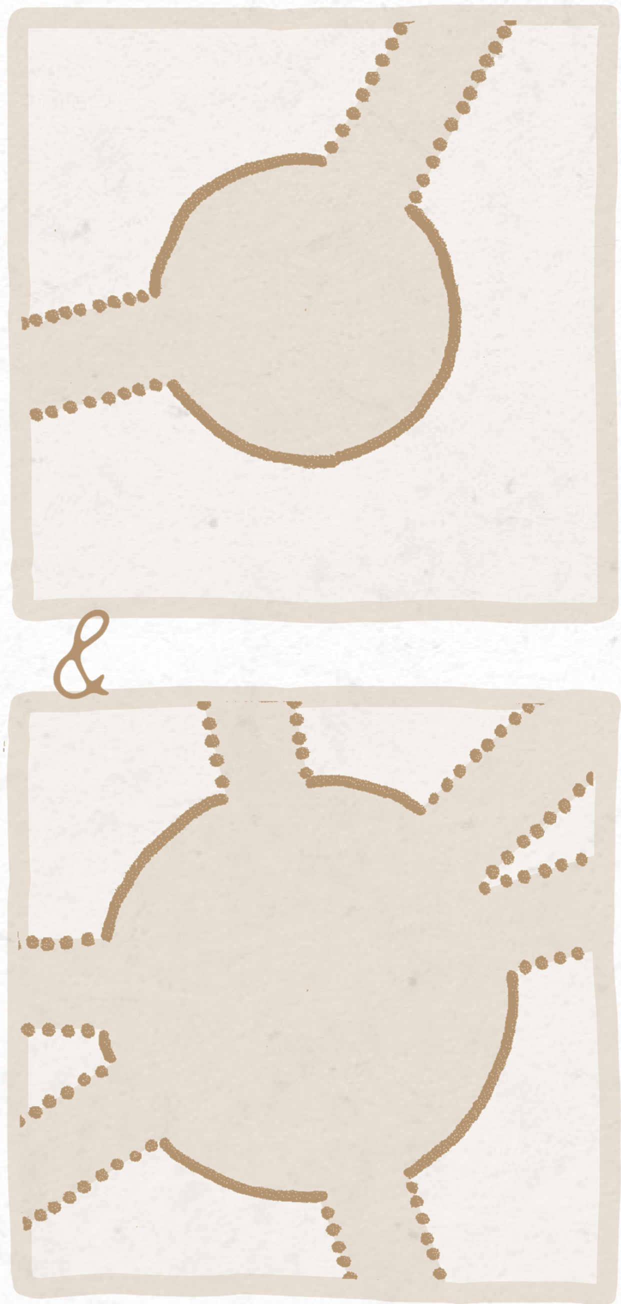


Figure 63 *Design criteria [* ***11a*** *]. Adapted from (Forman and Godron, 1981).*

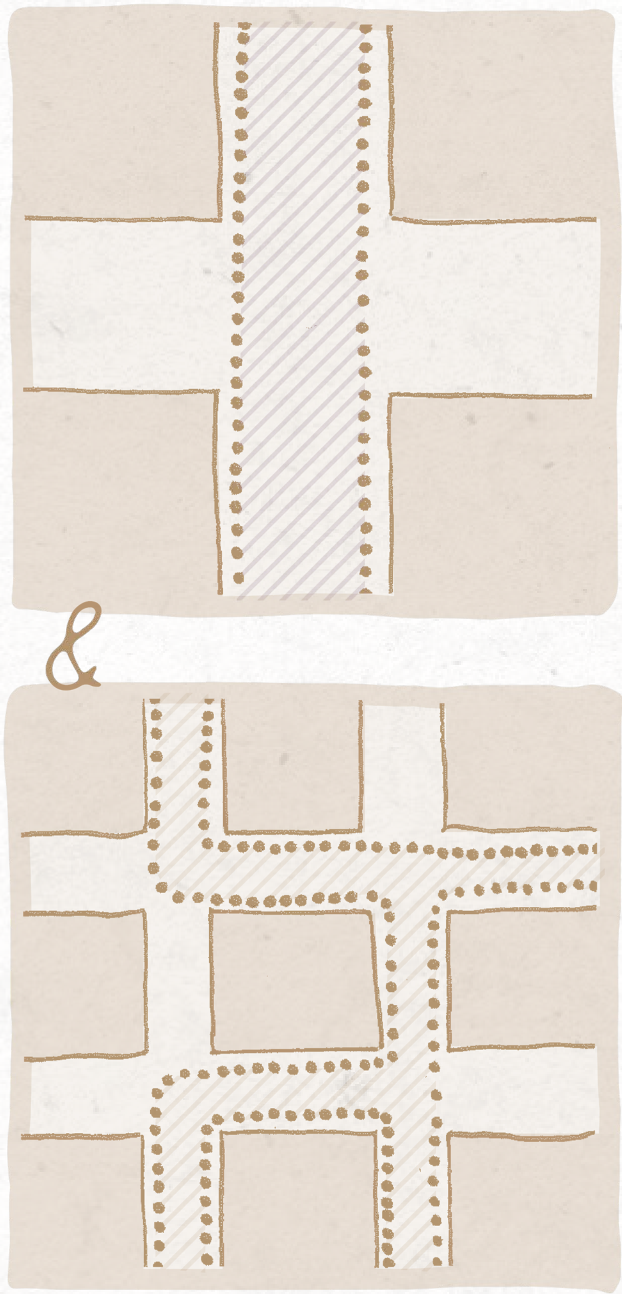


Figure 64 *Design criteria [* ***11b*** *]. Adapted from (Forman and Godron, 1981).*

CONCLUSION

The open space system that has been deconstructed within this chapter can be used as a framework that fits the habitat requirements outlined within the first chapter. In this way an ecological network for a stably growing stone marten population in urban open space can be created [***VII***].

Adapting a rigid system is especially important in assuring limited population growth. The habitat patch areal significantly limits the amount of habitat requirements to be added in UOS [***8b***]. The addition of habitat edges ensure that marten space usage is further minimized [***9***]. The co-occurrence between humans and martens is upheld by adapting adjacent design criteria [***9b*** / ***9c*** / ***9d***]. While such measures maintain limits to the high-habitat quality areal within an urban environment, smaller areas are designated to still create habitats for both sexes [***8c*** / ***8d***].

Within the design of an ecological network the amount of source patches determines the rate at which the population grows, this is very site-dependant [***8e***]. The amount and quality of corridors is important in ensuring population growth. They can become a bottleneck for efficient population distribution [***10***]. The fact that a wide variety of corridor layouts, in terms of length and width, can be applied in open space system helps [***10b***]. But based on their design their actual usage could wildly vary [***10a*** / ***10c***]. Here, again, uncertainty of proposed design and actual usage can pose a problem (see discussion).

The degree to which the proposed design guidelines and criteria can be adapted is highly dependent on space availability. Especially the requirement for minimally disturbed and well-defined habitats of several hectares will be problematic in urban areas that lack large green spaces.

In general, four distinct design guidelines can be distinguished:

Habitat patches [***8***]
Create habitat patches that meet female martens requirements.

Habitat edges [***9***]
Create rigid edge habitats that contain a selection of habitat necessities.

Dispersal corridors [***10***]
Create an interconnected network of pup dispersal corridors that respond to the available space

Ecological network [***11***]
Create an ecological marten network that enforces population distribution through effectively integrating source patches.

URBAN GREEN IN

4

IFRASTRUCTURE

INTRODUCTION

The aforementioned foundational matrix is largely formed by the urban environment. It encompasses diverse environmental traits that present both challenges and opportunities for sustaining a stone marten population (Jones et al., 2022). This chapter explores how such traits can be used, adapted, changed or added into UOS. Expanding knowledge on landscape design with a primary focus on ecological value over aesthetic and functionality (Weisser and Hauck, 2017). This chapter delineates the characteristics of the spaces to be designed for martens residing in urban settings, and proposes design interventions aimed at effectively addressing challenges and leveraging opportunities inherent to its urban habitats. UGI is assessed on the characteristics of typology (1), vegetation (2), barriers (3), urban wildlife (4) and human usage (5).

Although often forgotten, stone martens most predominantly occur in forested habitats (Genovesi and Boitani, 1997). Their foraging activity is often focussed on human settlements or rural areas, yet most of their home range exists within forested environments (Herr, 2008). Even in highly fragmented landscapes, such as urban landscapes, stone martens show a preference for wood and scrub vegetation as they often provide the most food and shelter (Rondinini and Boitani, 2002). In urban areas with minimal greenery, built structures often provide most of the marten´s habitat requirements (Herr, 2008). As previous chapters have argued, this is because of limited qualitative greenery available in urban areas. If marten habitat will be facilitated in open space, meaning that the correct balance between naturalization and design within existing and new green spaces will be of utmost importance (Alberti et al., 2003). Simply put, green spaces are both the easiest and most effective spaces to design when accounting for urban wildlife in general (Aida et al., 2016).

4.1 UGI TYPOLOGIES

Due to significant discrepancies in the definition and typologies of UGI across different sources, a comprehensive list of UGI typologies has been compiled by integration of multiple sources. These are presented in figure 67 (p.82), and their definition for this research is to be found in Appendix 4 (Braquinho et al., 2015; Ecological Institute, 2020; Jones et al., 2022) These typologies of UGI have undergone self-assessment (figure 66) as it is extraordinarily complex to evaluate the ability of UGI's to support biodiversity, especially when focussing on a particular animal, through scientific literature. Even UGI's within a typology can still differ wildly (Jones et al., 2022). For assessing the suitability of UGI's the following questions have been asked, elaborated in the diagram of figure 65:

1. Does the UGI provide a suitable space for martens to mate, grow, settle, stay, rest, move and/or forage?
2. Is the UGI suitable for provoking brown rat predation by stone martens?
3. Is the UGI suitable for human-marten co-occurrence?
4. Is the UGI suitable as patch, edge and/or corridor?

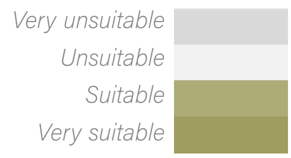


Figure 66 *Right: Self-assesment table on marten suitability of UGI's. Top: legend to table*

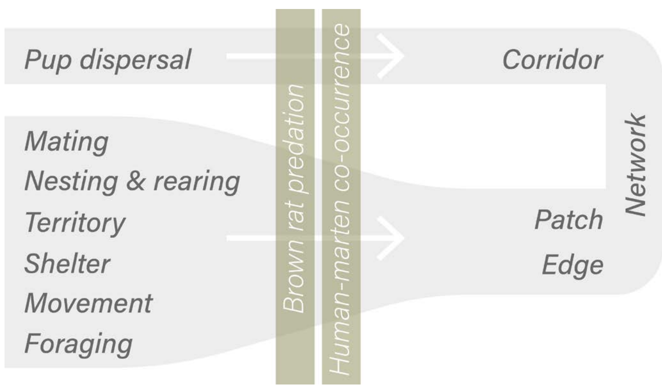


Figure 65 *Diagram on the assessment of UGI suitability for stone marten habitats. The second and third question act as a filter to whether UGI's, suitable for different marten habitat requirements*


Mate
Grow
Settle
Stay
Rest
Move
Forage
Predation
Acceptance
Patch
Edge
Corridor
Network
Building greens
Ground-based green wall
Facade-bound green wall
Balcony green
Green roof
Roof garden
Atrium
Private frontyard
Private backyard
Constructed on grey infrastructure
Green pavement
Green fence
Green pergola
Green noise barrier
Associated with grey infrastructure
Tree alley
Hedgerow
Green verge
Railroad bank
Green parking lots
Parklet
Recreational green space
Neighbourhood green space
Institutional green space
Shared open space
Green playground
Green sport facility
Camping area
Cemetery/churchyard
Parks and gardens
Large urban park
Pocket park
Historical park/garden
Botenical garden/arboreta
Nursery garden
Zoological garden
Natural areas
Forest
Shrubland
Grassland
Ruderal area
Wetland
Riperian woodland
Urban agriculture
Allotment garden
Community garden
City farm
Arable land
Orchard
Blue-green infrastructure
Lake/pond
River/stream
Dry riverbed
Canal
Estuary/delta
Sea coast
Used for water management
Rain garden
Bioswales
Flood control channel
Attenuation pond

Figure 67 *Visualizers of the UGI typologies suitable for integration witin an ecologcal marten network, numbered according to the appendix.*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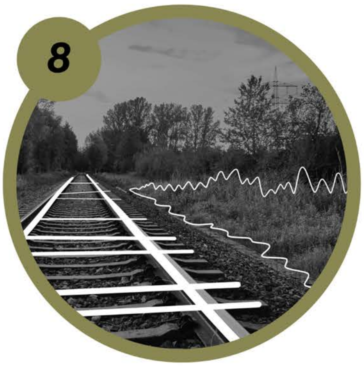
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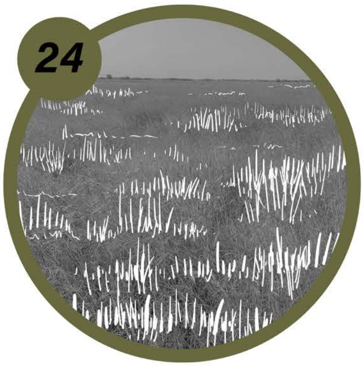
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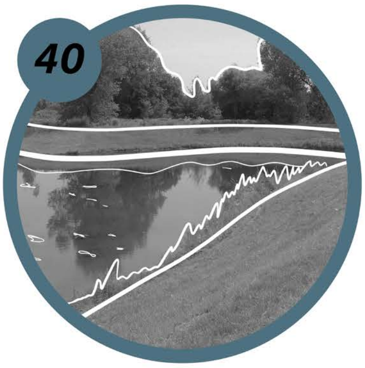

40

The table on page 81 presents the results of the self-assessment. UGI's deemed totally unsuitable for incorporation into this thesis' design are not in the reference images visible on the previous page (figure 67). The usable UGI's within this figure are numbered according to appendix 4. Main outtakes of assessment are as follows:

- Most ground-based building greens are believed to be suitable UGI's for marten movement, private gardens can even provide resting sites and food resources. Yet, due to property damage risks and the increased accessibility of buildings for brown rats all UGI's associated with or constructed on buildings are assumed to be unfavoured within the design (Colvin Bechtel et al., 1996).

- L-UGI's constructed on elevated grey infrastructure are thought to be particularly usable for marten movement, not supporting high quality habitats for species in general (Jones et al., 2022). Especially in smaller corridors where space is limited, such structures can find useful application. Green pergolas could score particularly well as their form and function can differ wildly, as long as they do not connect to buildings.

- L-UGI linked to grey infrastructure usually has limited ecological value, making it suitable for marten edge habitats. However, strategic design can significantly enhance their ecosystem services (Phillips et al., 2020). Incorporating linear elements like street trees and hedges can improve the connectivity of shelter and foraging areas, as well as aid in pup (Herr, 2008). L-UGI's should be chosen to guide marten movement [***12a***].

- In general, recreational green spaces offer ideal edge habitats for stone martens. They possess adequate habitat qualities while also presenting a sufficient level of human activity-induced stress, discouraging the animals from resting in those areas (Lewis et al., 2021). However, cemeteries and churchyards represent exceptions to this trend, as these areas are typically more natural and experience reduced human activity, making it an excellent UGI for patches and corridors (Sallay et al., 2023).

- Overall, parks and gardens form excellent patches, dependant on their size and shape they could also function as corridors (Jones et al., 2022). More strictly designed and intensively recreated gardens (botanical, nursery and zoological gardens) could possibly lack in the provision of all habitat requirement needed for stone martens.

- Among all (semi-)natural habitats, forests are the most suitable for fulfilling all of the marten's habitat requirements. Conversely, the suitability of other green areas, which may exhibit lower levels of vegetation stratification, depends on the availability of food and shelter. The structural diversity of UGI's with trees or woodland generally provides higher levels of biodiversity (Jones et al., 2022).

- Urban agricultural areas, rich in food resources for martens, are suitable habitats. Yet residing in such areas might be unfavourable as crop consumption and property damage could occur. Additionally pest pressure, by brown rats for example, could increase as more food is available (Lin, Philpott and Jha, 2015). therefore these UGI's are possibly suitable as corridors, areas where martens can quickly pass-by. Or a level of crop loss should be accepted.

- Lakes, ponds, rivers, and streams with semi-natural banks can provide excellent habitats if riparian vegetation is high-quality (Jones et al., 2022). Smaller features like rain gardens and bioswales also offer valuable habitat. Blue-green infrastructures attract brown rats, so connecting these features to marten ecological networks is beneficial (Traweger et al., 2006).

In general UGI typologies should be chosen based on how well they correspond to their usage and position in figure 66 [***12b***].

4.2 VEGETATION

The characteristics of the vegetation used within urban green infrastructures very much reflects the usefulness of these green spaces for martens. Although dependent on which habitat qualities stone martens are in need of within certain UGI's, a handful characteristics remain generally important when choosing the vegetation to be designed with.

FOLIAGE

The constant pressure of people in urban areas does not limit the presence of stone martens provided that there is suitable cover for the animals to move around undetected (Duduś et al., 2014). Vegetation with large canopies and dense foliage are therefore favoured within the UGI's design. The suitability of vegetation for flexible day shelters also increases. Especially shrub vegetation with dense foliage is important, in general it is seen to positively correlate with small mammal activity (Loggins et al., 2019). An added benefit is that perceived predation risks by rodents (such as the brown rat) is smaller with higher shrub coverage, even though predation risk by martens is actually higher (Loggins et al., 2019) [***13a***].

STRATIFICATION

Urban areas with high-density housing, although often densely populated, are frequently inhabited by martens as it is possible for martens to move from house to house, through attics or on roofs (Duduś et al., 2014). Within UGI this freedom of movement can be created if sufficient vertical stratification in vegetation layers is provided. By selecting plant species with extensive (possibly thick) branching, traversal routes at different heights can be fostered. Added benefit is that branches and tree hollows can be used as flexible day shelters. Klees (2024) argues that especially in small corridors, movement possibilities at different heights are important for safe traversal. For marten movement, the canopy, understory, shrub, herb and grass layer are expected to be most important (as visualized in figure 69). In general, increasing understory vegetational layers will benefit urban biodiversity (Threlfall et al., 2017) [***13b***].

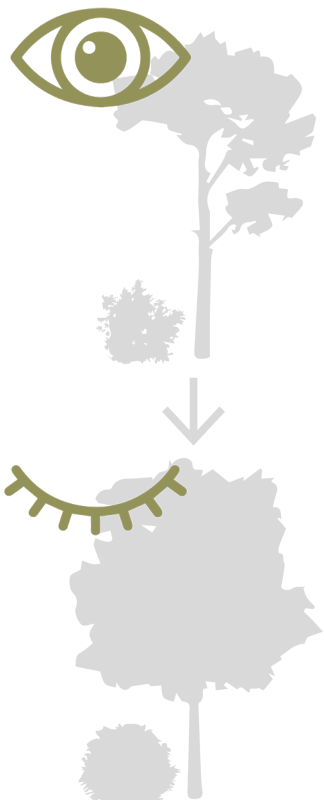


Figure 68 *Design criteria [* ***13a*** *]: Vegetation should have large canopies with thick foliage*

Figure 69 *Design criteria [* ***13b*** *]: Vegetation should be provided at multiple layerss*

NATIVENESS

Research by Rondinini and Boitani (2002) on rural living martens have shown tracked marten individuals to prefer residing in riparian vegetation, baring the most similarity to their home ranges there, instead of moving to agricultural land or farmhouses where (at least) food availability is better. In relation to this research, choosing nature types and plant species that are native to The Netherlands, or commonly used in Dutch urban areas, have the best chance of being inhabited. Native vegetation possibly bares the most resemblance to their habitat (Broekhuizen, Müskens and Klees, 2010). Especially vegetation in pup dispersal corridors should bare resemblance to breeding grounds found in core areas (Dramstad et al., 1996). In general, increasing native vegetation (and redressing simplified, exotic vegetation) (Ikin et al., 2015; Threlfall et al., 2017) [***13c***].

FRUIT-HOLDING

As has been argued in SRQ1, vegetation should include plenty of fruit trees and berry bushes. Native species, often found in urban areas, can be used (figure 71) [***13d***].

4.3 BARRIERS

The characteristics of the vegetation used within Urban Green Infrastructures very much reflects the usefulness of these green spaces for martens. Although dependent on which habitat qualities stone martens are in need of within certain UGI's, a handful characteristics remain generally important when choosing the vegetation to be designed with.

VERGES

Research has shown that road verges with high cover of small shrubs were associated with more marten roadkills. Roadside usage for predators is encouraged as foraging activity is more sheltered. Additionally, there is an increased vehicle collision risk as driver visibility is reduced when shrub cover is high (Silva et al., 2019). *Just as hinted in design guideline [* ***12a*** *] , road-accompanying L-UGI, such as hedgerows, will encourage movement along roads if corridors are situated parallel. If infrastructural barriers are dangerous or need to be crossed, roads will be accompanied by patchy vegetation in the road's verges [* ***14a*** *].*

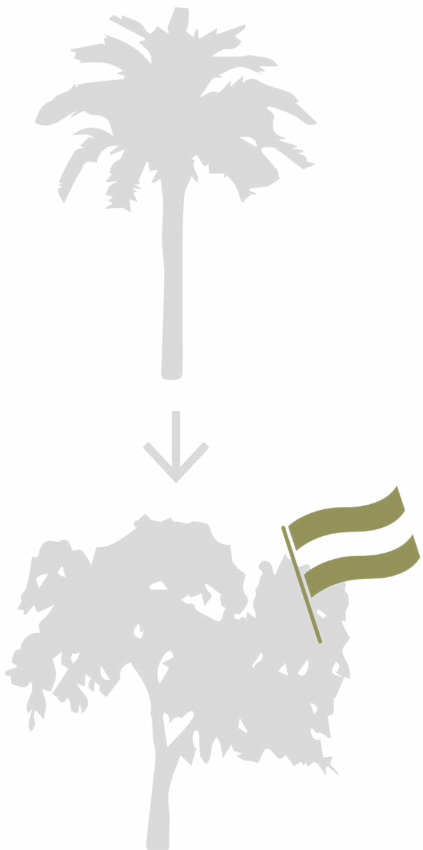


Figure 70 *Design criteria [* ***13c*** *]: Vegetation should be chosen that is native to the site.*

Figure 71 *Design criteria [* ***13d*** *]: Vegetation should be fruit-holding*

During the season of dispersal, marten roadkill rates are high as pups tend to pay little attention to oncoming traffic (Broekhuizen, Müskens and Klees, 2010). The need for effective wildlife crossings within these pup dispersal corridors is therefore high. *For all corridors, accompanying vegetation is important, this consists mostly out of L-UGI and/or natural landscape elements that (if applicable) bares resemblance with that used within the wildlife corridor [* ***14b*** *]. Where possible, decreasing trafficking through speed limit reduction can help in directly tackling the proposed problem in vulnerable areas [* ***14c*** *] (Ministerie van Infrastuctuur en Waterstaat, 2021).*

WILDLIFE CROSSINGS

Apart from grey infrastructure, blue infrastructures could also form a possible barrier for stone marten movement. As previously stated, martens are good swimmers but they do like to avoid it (Zoogdiervereniging, no date). Within corridors, perpendicularly situated linear waterways are hypothesized to affect the dispersal movement of pups.

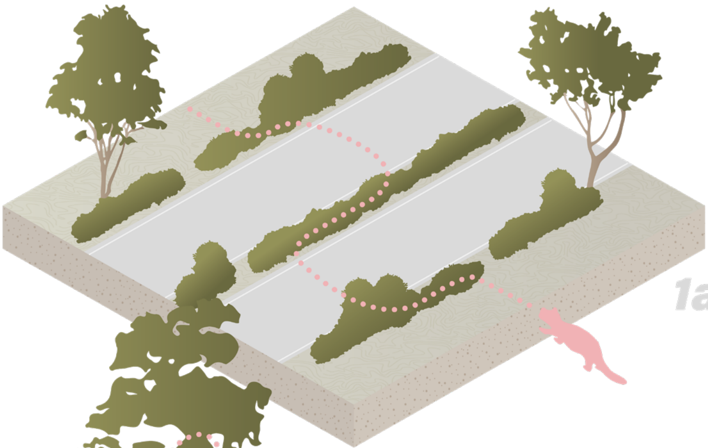
The "Leidraad faunavoorzieningen bij infrastructuur 2021" (Ministerie van Infrastuctuur en Waterstaat, 2021) provides a catalogue of wildlife facilities that are aimed add crossing grey/blue infrastructural barriers, improving the relation between wildlife species and infrastructure common to the Netherlands. For this thesis certain fauna measures that reduce barrier effects, from here on out described as wildlife crossings, for stone martens will be adapted. These measures are listed in appendix 5 (Ministerie van Infrastuctuur en Waterstaat, 2021). Appendix 5 includes descriptions used within this thesis and matching dimensions, the later according to the measurement for mustelids given within the used source.

In figure 72, these measures are categorized based on three characteristics of barriers:

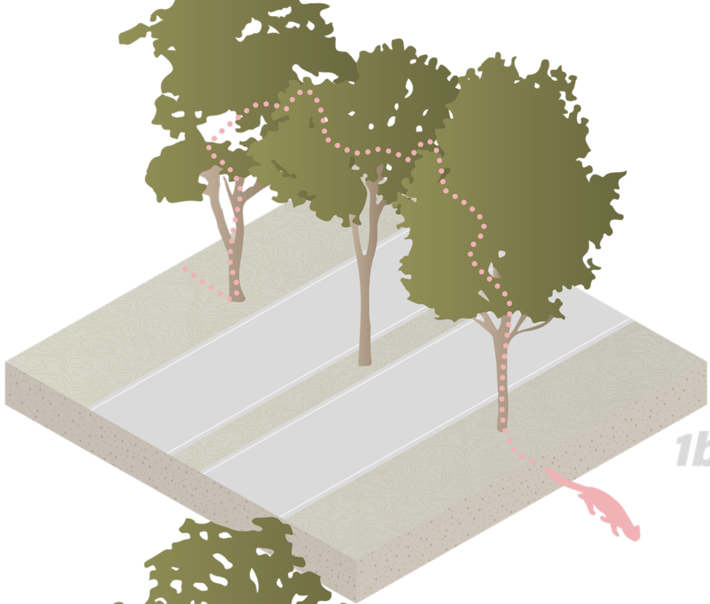
1. Does the barrier consist of grey or blue infrastructure?
2. Can the barrier be crossed overground or underground?
3. What is the width of the barrier?

Figure 73, spread on the pages therafter, contains illustrations of the wildlife crossings to be used within a marten-friendly green space [***14d***].

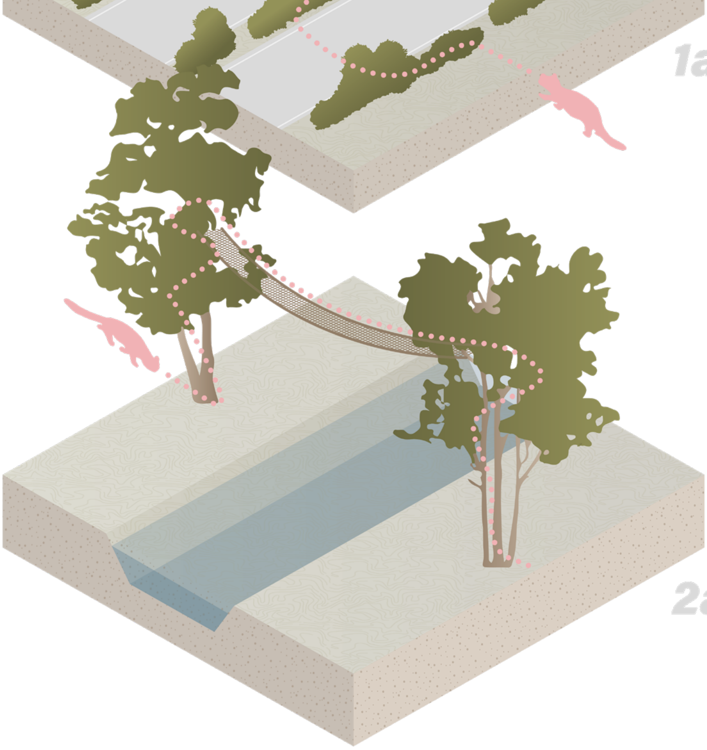
Figure 72 *Categorization wildlife crossings suitable for martens.*



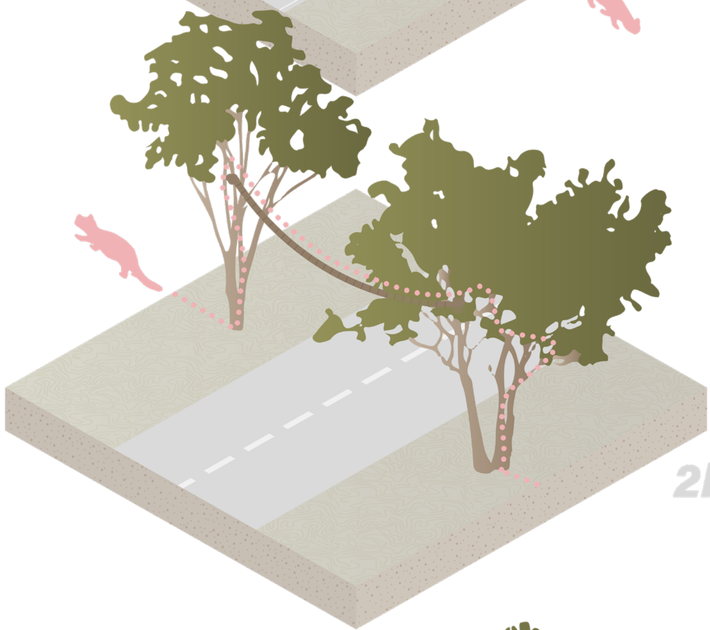
1a



1b



2a



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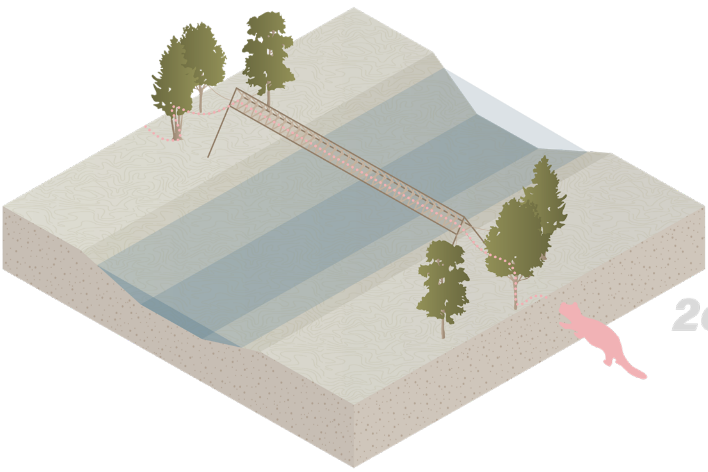
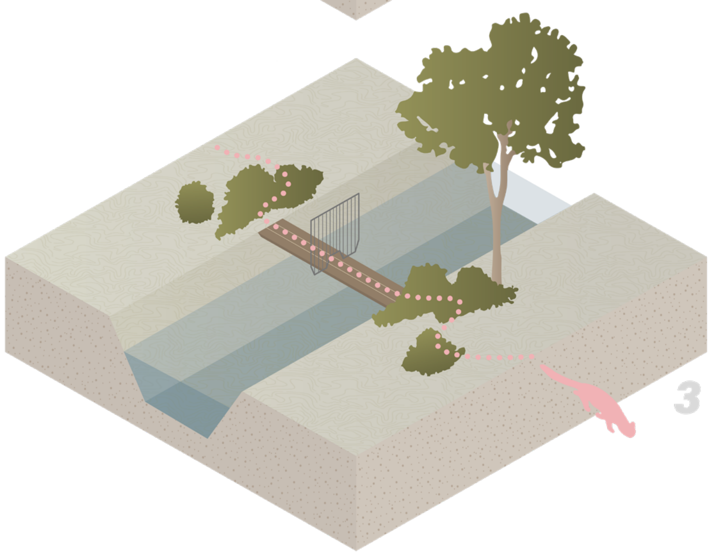


2c



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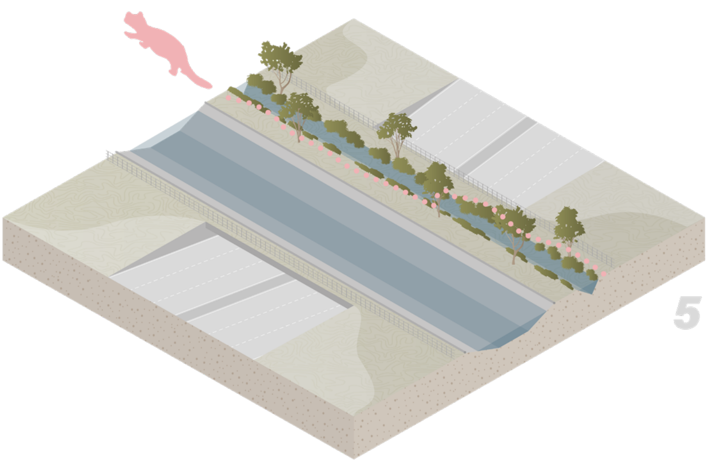

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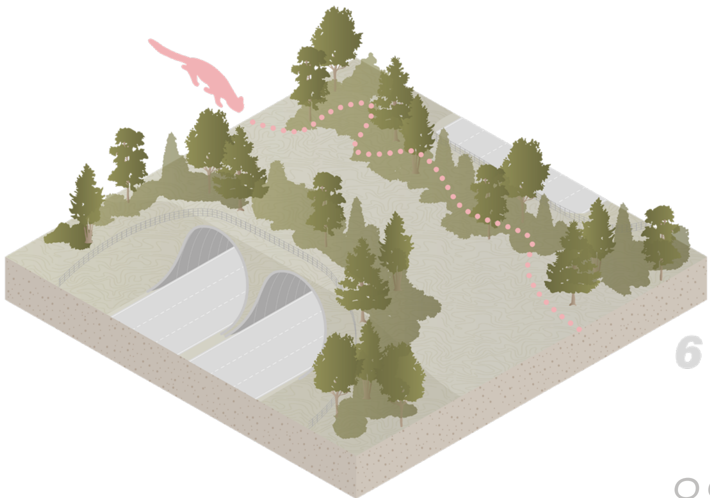

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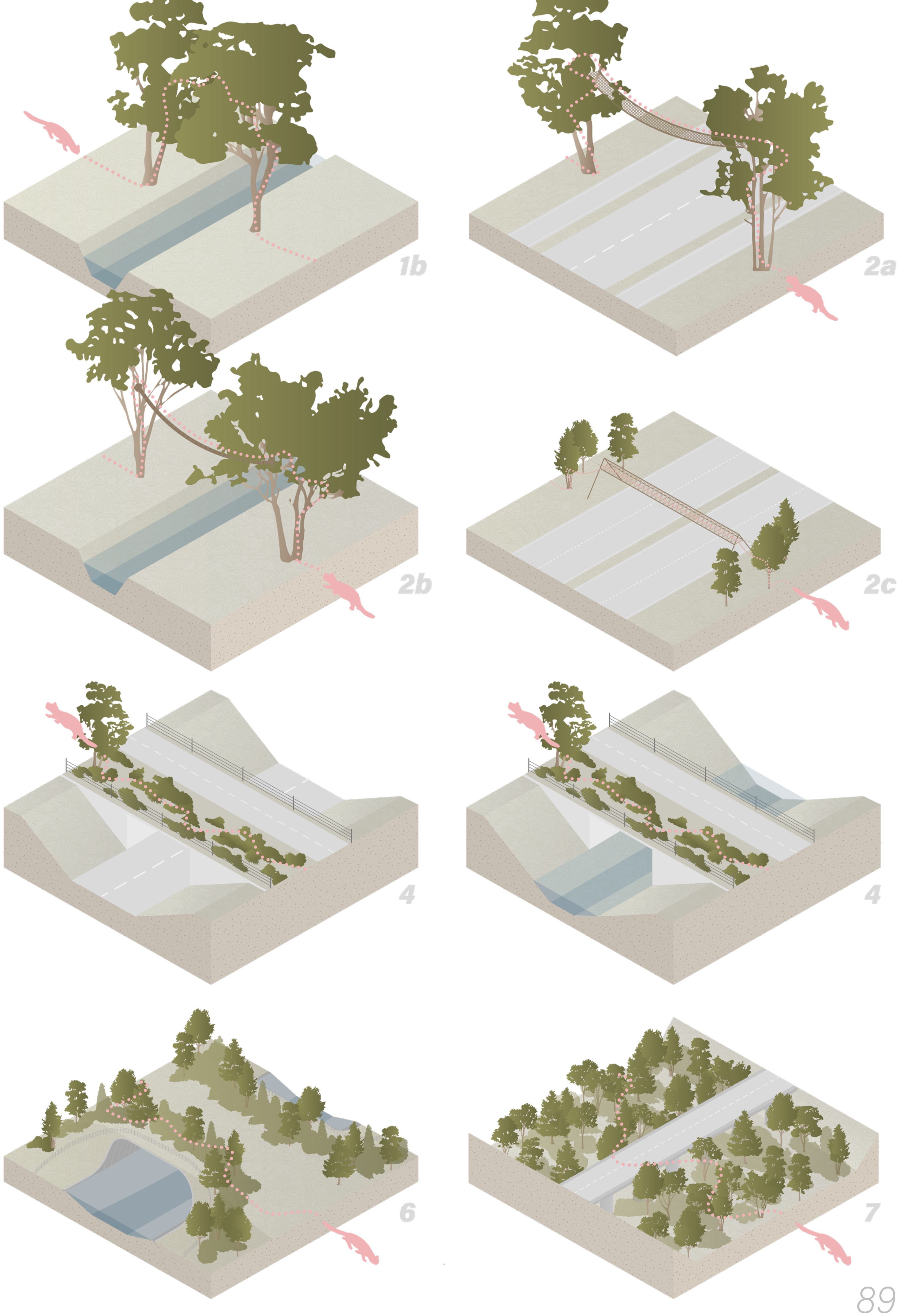
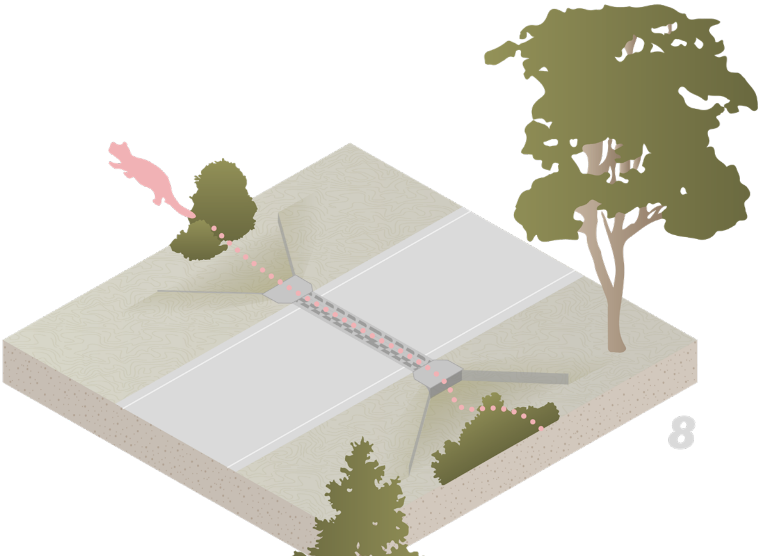

1b
2a
2b
2c
4
4
6
7



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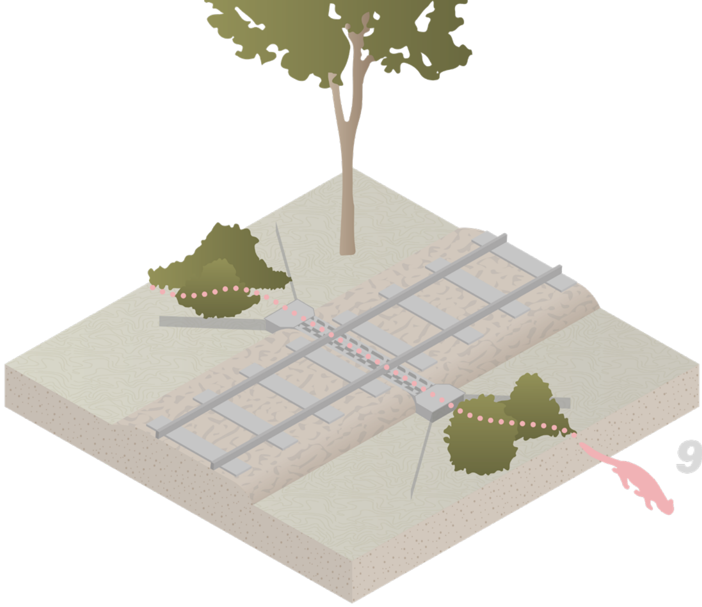

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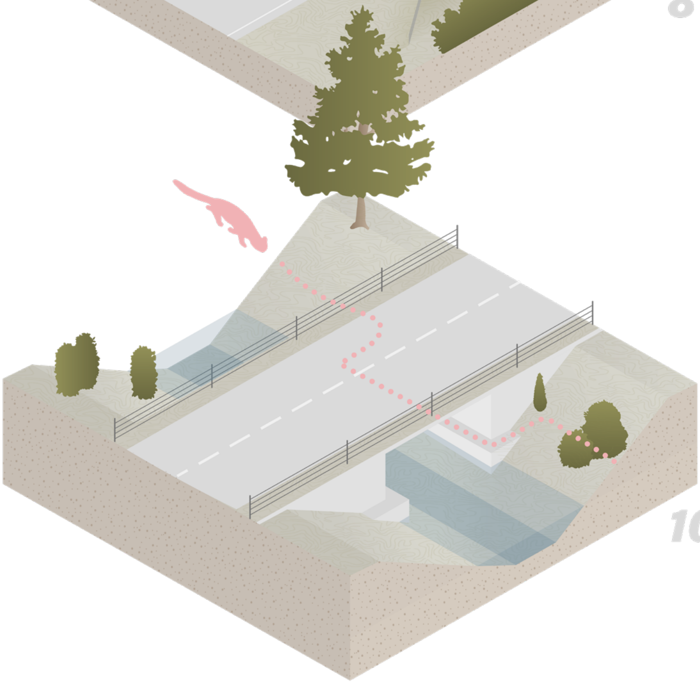
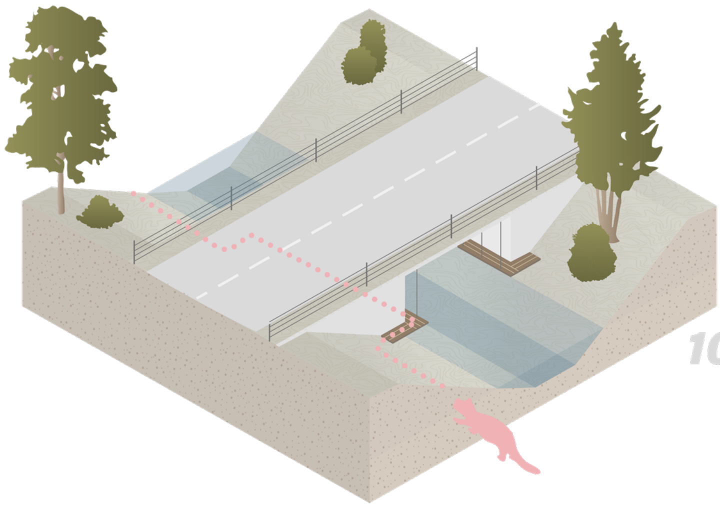


10a



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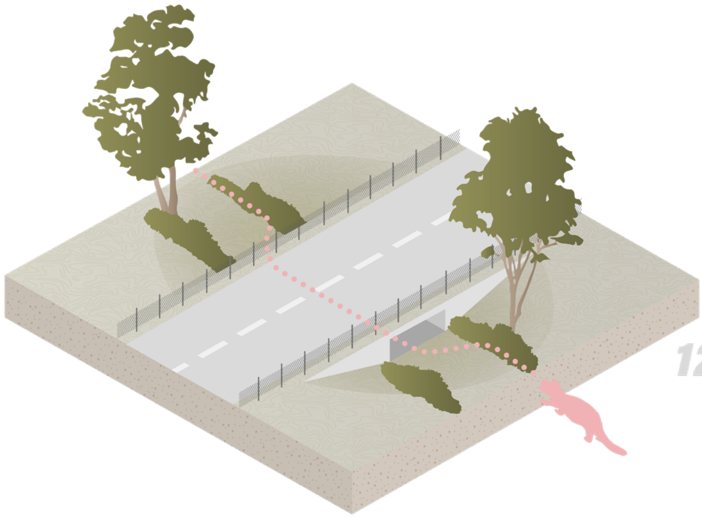
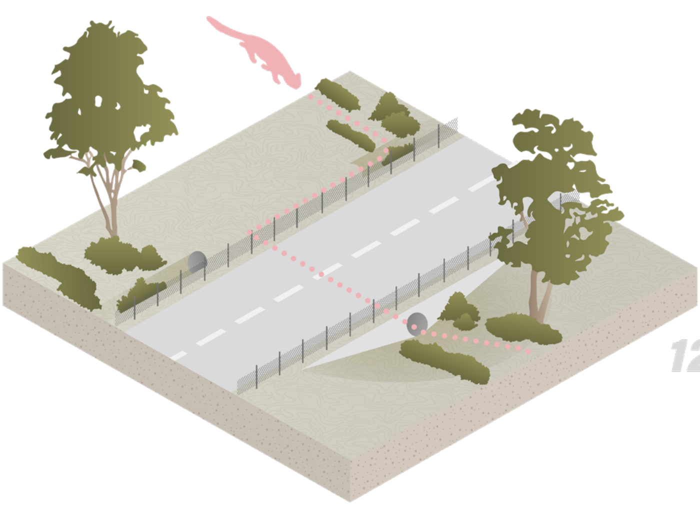
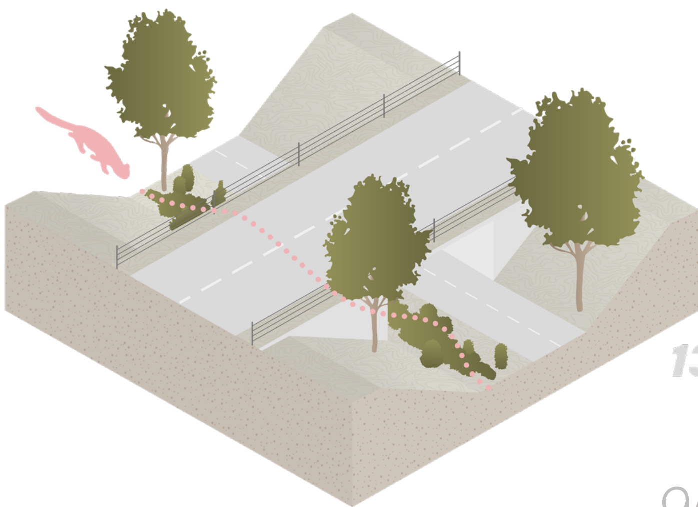


12a



12b



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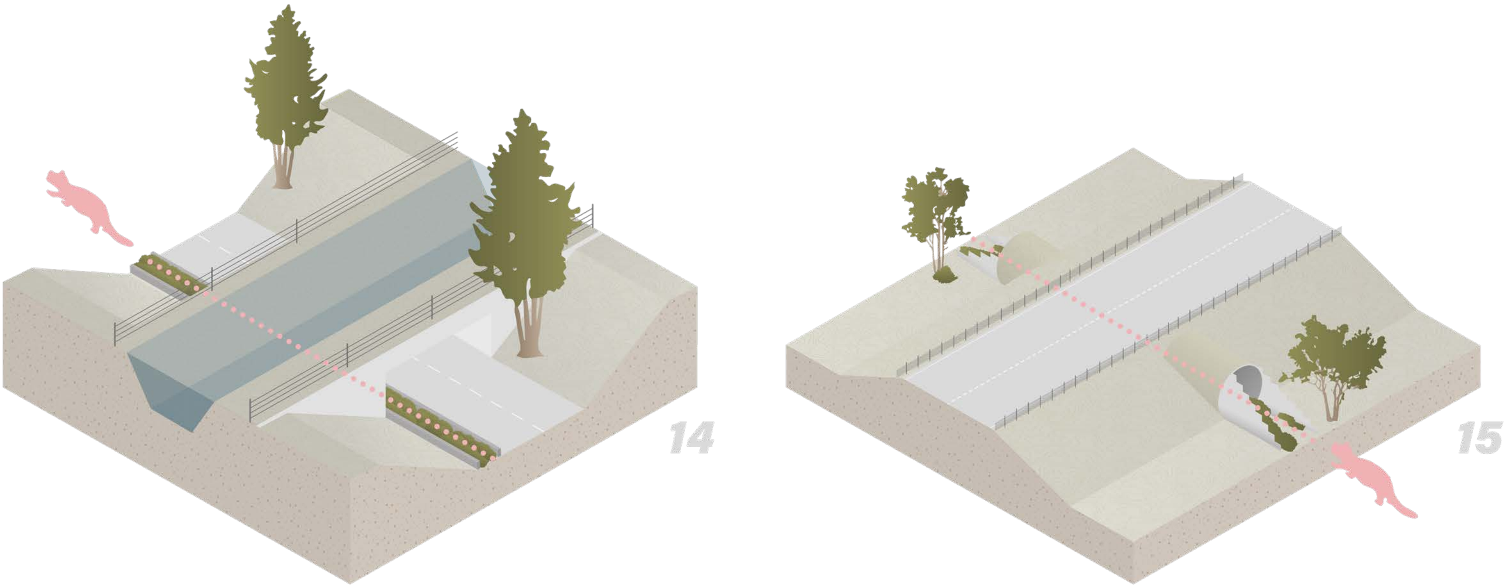


Figure 73 *Diagrams of wildlife crossing suitable for stone marten, numbered accoring to appendix 5.*

4.4 URBAN WILDLIFE

Stone martens are part of a complex urban ecosystem consisting of many different species. Around half of the urban wildlife, and most of an urban area's biodiversity, resides in urban green spaces (McKinney, 2002; Gallo et al., 2017). So, to successfully fit a stable stone marten population within these green spaces, the marten's relation to both its predators and preys should be taken into account.

This thesis focuses on a single species and a specific predator-prey relationship involving that animal. Although the approach is narrowly defined, redesigning with the stone marten in mind will benefit a range of other urban wildlife as well (Weisser and Hauck, 2017). Such a redesign contributes to greater biodiversity, serving as a positive byproduct of animal-aided design.

Through creation of a more natural landscape, possible predators and preys of the marten are introduced to urban open space. *When designing urban greenery vegetation types can be chosen that correspond to such species [* ***15a*** *]. Other potential predators to brown rat can inhabit urban areas, further increasing predation pressure [* ***15b*** *].*

This chapter will highlight how possible interspecies relationships involving the stone marten can be integrated into landscape design. However, further exploring the design implications for more complex urban ecosystems is beyond the scope of this thesis. This dilemma is further elaborated within the discussion

MAMMALS

Mammals (especially rodents) are consumed the most by urban stone martens (26%) (Nelck and Van Pelt, 1996; Szocs and Heltai, 2007). It is difficult, if not impossible, to adapt a stone marten-friendly design to most ground-based mammals as only their size limits accessibility of areas with small entrances. In general, a marten-focussed design will greenify urban open space. So, apart from an increased predation risk, the provision of other habitat qualities within urban green spaces for other urban mammal species, especially mustelids, increases (Pavid, no date; Broekhuizen, Müskens and Klees, 2010). This is believed to create a robust design where a new equilibrium between different species could exist (Russo and Cirella, 2021).

By adapting a design that prioritizes brown rat predation by martens, it is hoped that other ground-based mammals will be afforded a greater degree of solitude [***15c***]. Research on urban stone martens in Budapest has shown that these animals exhibit opportunistic behavior, selecting the easiest possible food sources. In environments where rodents are plentiful, martens have frequently been observed co-occurring with potential prey, such as hedgehogs and squirrels. These prey are left undisturbed because they are only slightly more challenging to catch (Szocs and Heltai, 2007).

Figure 74 *Design criteria [* ***15c*** *]: Urban wildlife (mammals) should be considered by prioritizing brown rat predation in design.*

BIRDS

In urban areas, certain avian species often find nesting sites in buildings (Sandström, Angelstam and Mikusiński, 2006). The absence of martens in the vicinity of buildings, as the design guidelines and criteria propose, makes these nesting locations more suitable. Other avian species do prefer nesting in green structures or using natural materials to build their nest (Sandström, Angelstam and Mikusiński, 2006). Urban areas such as large urban parks often house the highest percentage of bird species within urban areas (Jones et al., 2022). For avian species residing in green spaces, marten-proof measurements can be adapted [***15d***].

"Marterkragen" (on solitary trees) or "Marterkorfen" (on nest boxes) (figure 76) can be used as marten-repellent measures for bird nests (Ecopedia, no date). In general, increased tree planting in urban areas has proven to helpfull for avian biodiversity [***6***] (Aida et al., 2016).

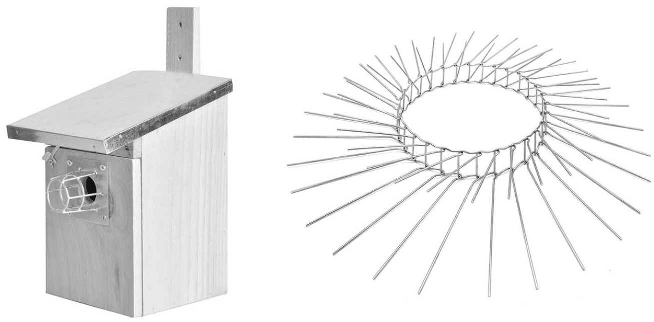


Figure 76 *Marten-repellent measures for bird nesting (Ecopedia, no date).*

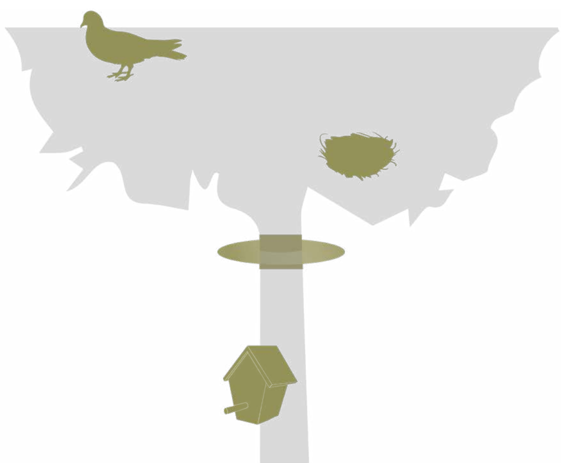


Figure 75 *Design criteria [* ***15d*** *]: Urban wildlife (avian) should be considered by adapting marten-proof measurements.*

PREDATORS

Within urban areas, little natural predators of stone martens occur. In the Netherlands, foxes (Vulpes Vulpes) are its predominant predator (Zoogdiervereniging, no date). About 25 Dutch cities house fox populations, within the municipal borders of Rotterdam around 30 to 50 foxes occur (Gemeente Rotterdam, no date b). The population sizes of urban foxes are small enough to not form a big threat to the establishment of stone martens (Bakker, 2024). By planting tall, branching, multi-layered vegetation and creating denning sites with small entrances, sufficient escape options for martens are formed that are difficult (if not impossible) to reach for possible predators that are less agile [***15e***] (Zuidema, no date).

These measures also apply to avoiding cats, which sporadically have been found hunting marten pups. Adult stone martens are too large and resilient to fall prey to cats. (Broekhuizen, Müskens and Klees, 2010). Within the realm of domestic animals, dogs also form a possible threat. In urban areas they have been seen to occasionally snatch a stone marten (Cöhrs et al., 2020). This problem only occurs when there are unleashed dogs in green spaces. Requiring dogs to be leashed falls under open space management, which is beyond the scope of this thesis. This topic is discussed in more detail in the discussion section.

Wolves, eagles, and Eurasian eagle-owls are natural predators of the stone marten in most European cities. Yet, similar to foxes, they have not been seen to densely populate our urban areas (Zoogdiervereniging, no date). The relationship between stone martens and other mustelid species has not been thoroughly researched. Fieldwork has often shown that closely-related species, like the pine marten. often show habitat segregation, especially when dealing with urban areas where other mustelids only sporadically occur (Wereszczuk and Zalewski, 2015). Avoidance of most of the abovementioned (domestic) predators can be tackled by designing nesting/denning sites with small entrances [***15f***].

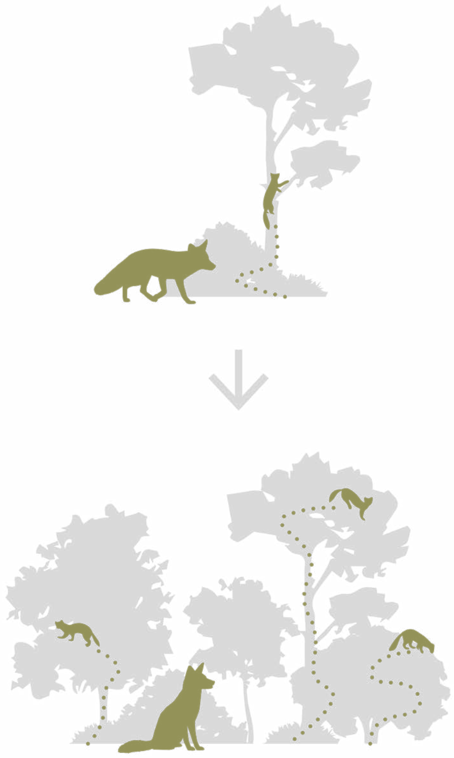


Figure 77 *Design criteria [* ***15e*** *]: Urban wildlife (predators) should be considered by providing sufficient traversal routes.*

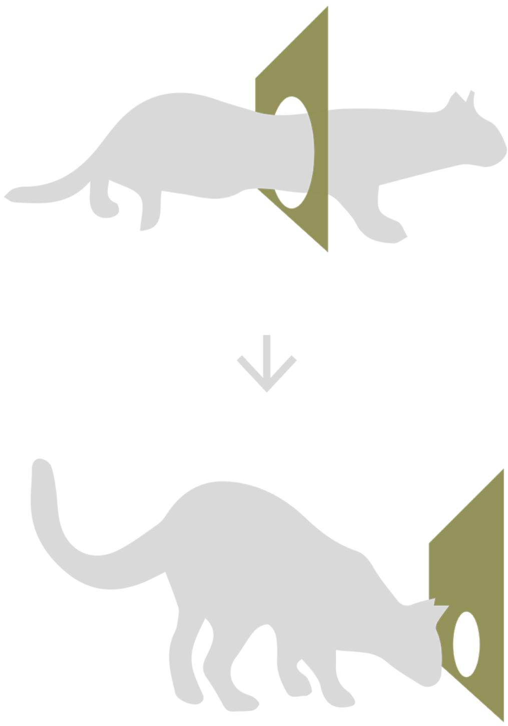


Figure 78 *Design criteria [* ***15f*** *]: Urban wildlife (predators) should be considered by designing denning/nesting sites with small entrances*

4.5 HUMAN USAGE

Even though the primary focus of this research is on designing stone marten habitats, the design is, through including the needs of animals, also enriched in beauty for humans (Nyhus, 2016). The animal's requirements can inspire the design of the green space, even serving the needs of humans (Weisser and Hauck, 2017). In addition, inspiration for new recreational value can be found within the enriched urban open space. Apart from indirect ecological-, socio-cultural benefits are created through adaptation of the proposed design guidelines.

Dependent on the culture of the urban area to be designed, design interventions can find multifunctional usage amongst animals and humans. A combination of good open space design and species conservation should be aimed for. To quote Chappel (2007): *"In merging nature and culture, the most successful cities combine such universal needs as maintaining or restoring contact with the cycles of nature, with specific, local characteristics."* Site-specific ways of merging green space design, important for a successful design, will be further researched when designing the chosen site in Rotterdam.

PARK PROGRAMMING

For creating marten habitats, and retaining biodiversity in general, it is recommended that large, undisturbed areas within urban open space are retained from urban development. A division in urban open space can be made between areas of predominantly ecological and social significance (Ikin et al., 2015). For a marten-friendly design that is in need of densely vegetated, undisturbed core areas, it seems beneficial to concentrate the program of green spaces towards its edges [***16a***]. The semi-recreational green space typologies previously assessed, would form a great basis for green space programming. Greenifying recreational areas in open space might help in increasing the attractiveness of existing spaces (Ikin et al., 2015). Nocturnal animals have even been observed to often make use of recreational areas for foraging when human disturbance is minimized (Lewis et al., 2021).

RECREATIONAL INTENSITY

In relation to other nocturnal animals in urban areas, human activity is not directly avoided, but for certain activities such as resting, nesting or growing, species are more sensitive to human disturbances (Lewis et al., 2021). For stone martens, day-time human disturbances close to or within core areas should thus be avoided. So, whenever the space allows it, intensive programming in proximity to these core areas should be avoided [***16b***]. Simple measurements, such as lowering the maximum permitted driving speed or prohibiting festivals in proximity to core areas, are expected to already prove helpful.

ARTIFICIAL LIGHT

Another approach is to reduce artificial lighting near core areas. Less light can decrease the perceived predation risk for martens, as most of their prey rely on sight for hunting. Additionally, martens do not need much light to access fruit or human food waste found near core areas (Wereszczuk and Zalewski, 2023). By decreasing the illuminated area (either by lowering street lighting, increasing spacing between lights, or adjusting light intensity) core areas can become less attractive to martens (figure 82). For hunting, however, martens can effectively use street lighting. Thus, strategically placing lighting in areas frequented by brown rats can be beneficial [***16c***] (Wereszczuk and Zalewski, 2023).

Figure 82 *Column lights and in-ground lights can reduce light nuisance for marten (Wereszczuk and Zalewski, 2020).*

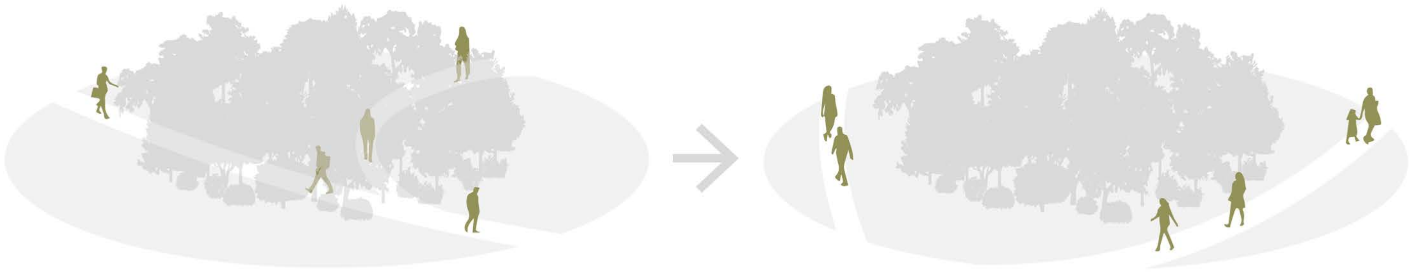


Figure 79 *Design criteria [* ***16a*** *]: Human usage should be limited to edge habitats due to edge programming.*

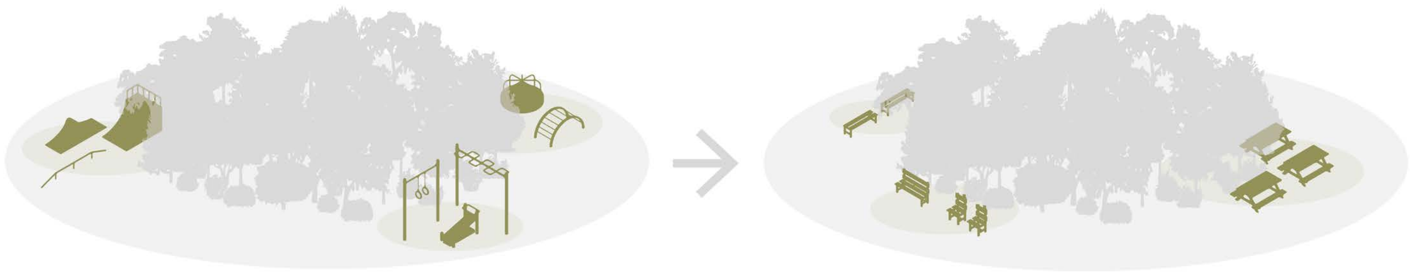


Figure 80 *Design criteria [* ***16b*** *]: Human usage during the day should limit recreational intensity close to core areas.*

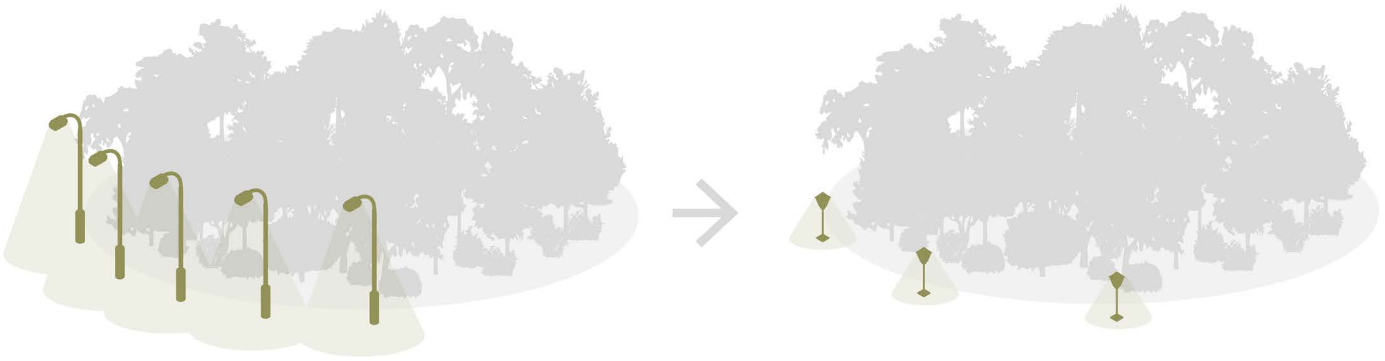


Figure 81 *Design criteria [* ***16c*** *]: Human usage of artificial light should be strategically placed to shelter or aid martens.*

CONCLUSION

This chapter aims to provide tangible design tools for adapting design principles, guidelines and criteria of SRQ1 and SRQ2. Significant parallels exist between the design criteria of these previous questions and those related to UGI's, as illustrated in Appendix 1. This alignment occurs because habitat requirements are addressed through greenery, and the open space system is intended to be integrated within green spaces.

There are many variables that affect the usability of different UGI's and their characteristics [***12a***]. In addition, the assessment of green space in a larger socio-ecological context, although important, this subject matter is too extensive for the parameters of this study. Still, species-cautious design criteria within SRQ3, related to other urban wildlife, are of significant importance [***15c*** / ***15d***]. In general, this chapter argues that naturalizing green spaces benefits stone marten populations and the overall urban biodiversity [***15a*** / ***15b***]. Within naturalized greenery, a better balance can be found between eating and being eaten to keep the stone marten populations stable.

To stabilize the marten ecological network, spatial values should be adjusted for stone marten habitats by finding the right balance between ecological and recreational value. Urban open space design should therefore seperate ecologically and socially significant Urban green infrastructures [***VIII***]. This can be achieved by strategically placing park elements that serve functional purposes for human use [***16a*** / ***16b*** / ***16c***].

A key element to successful open space usage by marten is the placement of L-UGI's to guide population dispersal/movement [***12b***]. They can also be used to mitigate widespread overpopulation. B-UGI's are similarly effective as dispersal corridor. Essential for desired population movement are wildlife crossings and the correct provision of usable vegetation. Variation in vegetation density can influence areas for staying and moving through [***13a*** / ***13b*** / ***14a*** / ***14b***]. Additionally, simple wildlife crossings can already help in successfully bridging infrastructural barriers [***14d***].

In general, four distinct design guidelines can be distinguished:

UGI typologies [***12***]
Select or implement UGI typologies and their placement to meet specific habitat requirements.

Vegetation [***13***]
Enhance vegetational diversity through naturalization and native planting.

Barriers [***14***]
Develop safe overpasses and underpasses across blue and grey infrastructure using the simplest possible methods.

Urban wildlife [***15***]
Implement adaptive measures that create habitats for both predators and prey of the stone marten.

Human usage [***16***]
Use human activities as a strategic tool to influence marten occupancy patterns.

Figure 83 *Marten walking through green space (Natuurpunt, no date).*

Figure 84 *Areal of Rotterdam's city centre from 'Het Park' (Djedj, no date).*

CIT

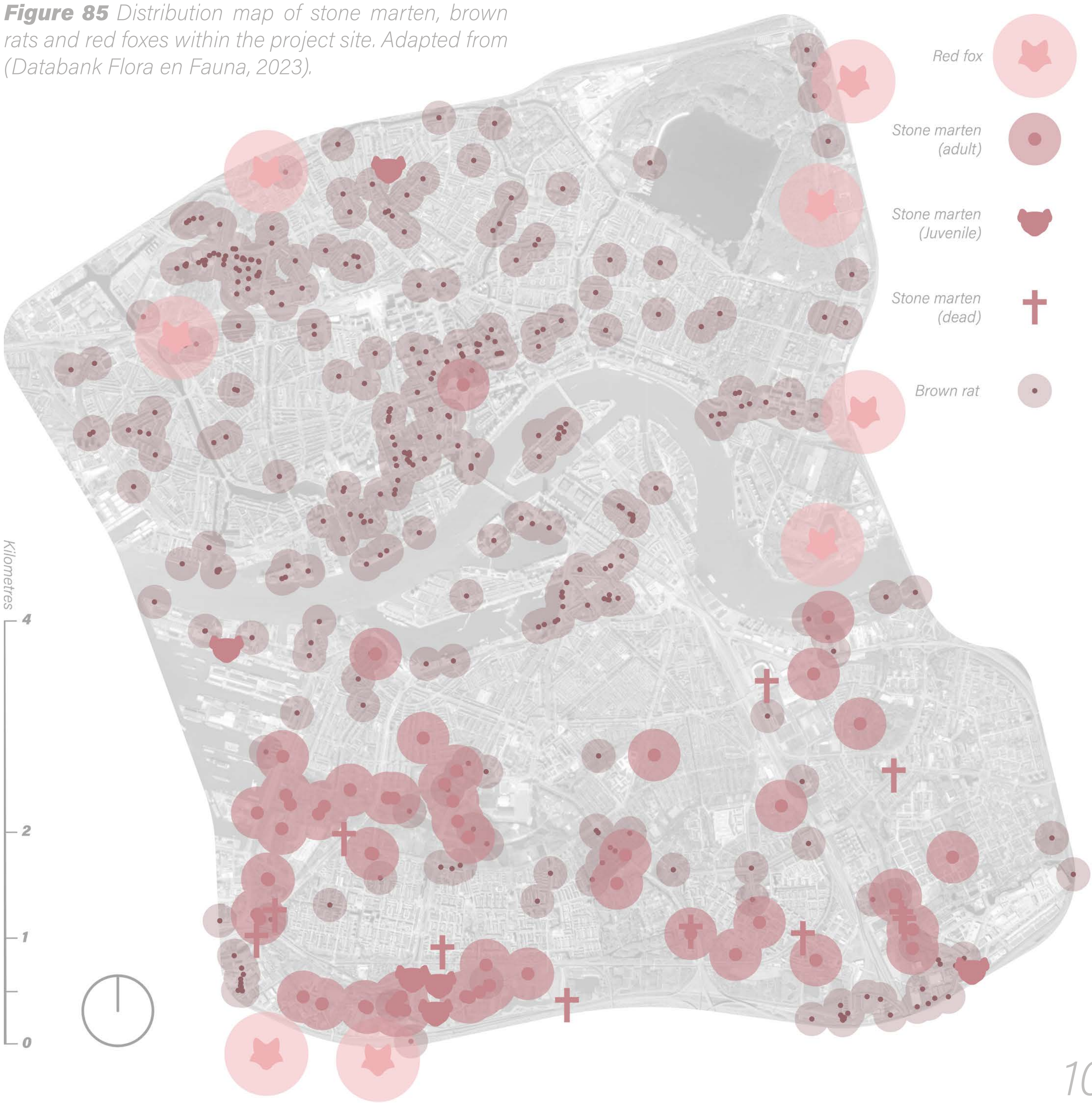

5
Y-SCALE DESIGN

INTRODUCTION

This chapter addresses the main research question by designing the selected site as a possible adaptation of the design guidelines and criteria derived from the sub-research questions. This first scale focusses on designing an ecological network for a stone marten population to inhabit the city centre of Rotterdam. Large-scale design guidelines and criteria will be highlighted here.

For this design a thematic landscape analysis of the site on the topic of the SRQ's is needed to correctly integrate the proposed design interventions. Additionally, observation data for stone martens and brown rats at the chosen location are needed to understand the population distribution (see figure 85). In-text references to urban green spaces in Rotterdam are numbered and can be located [1, 2, 3, ...] using figure 95 on page 107.

***Figure 85** Distribution map of stone marten, brown rats and red foxes within the project site. Adapted from (Databank Flora en Fauna, 2023).*



5.1 LANDSCAPE ANALYSIS

5.1.a POPULATION DISTRIBUTION

STONE MARTEN

As mentioned earlier, the emergence of stone martens within the Randstad finds a sizable population inhabiting Rotterdam (figure 9, p.16) (Maanen, 2022). Zooming in at the selected site (figure 85, p.100), we find a significant concentration of individuals within the Zuiderlijk Randpark [1]: a green buffer between the neighbourhood of Rotterdam Zuid and the A15 highway, consisting of smaller forests where enough of its dietary needs, are met (Moeliker, 2015). Other concentrations of stone martens within Rotterdam can be found in IJsselmonde Zuid [2] and Zuiderpark [3]. The far distances between this population and those inhabiting other cities leads us to believe that the animal hitched a ride on cars that stopped along the highway, one of the reasons for the species' quick distribution (Bakker, 2008; Dekker, 2024).

Looking at the population movement overtime, the park seems to function as a source landscape for the animal's distribution over the south of Rotterdam. This argumentation is further strengthened by the amount of juvenile's spotted within this area (figure 85). The concentration of martens within the south of the site is partly explained due to the high habitat quality of the green space, it even seems that the territory size of individuals is smaller than found in research by Herr (2008). It should be noted that there is a significant possibility that multiple observations have sighted the same individual, for this reason an accurate depiction of the current population size and estimate of the mean territory size cannot be made (Bakker, 2008; Broekhuizen, Müskens and Klees, 2010)

Examining the project site, there is a noticeable lack of marten sightings north of the Nieuwe Maas [9], despite the presence of high-quality urban green infrastructure like the Kralingse Bos [4], and an ample supply of prey, particularly brown rats. Both design alternatives will focus on this. While the presence of predators could be a possible cause, the marten's only natural predator in Rotterdam is the fox. Bakker (2024) argues that their large territories and relatively thin population does not pose a significant threat for the establishment of marten in Rotterdam. The sightings of two foxes near the current population (figure 85) suggest minimal spatial segregation between both species' populations (Gemeente Rotterdam, no date b; Bakker, 2008).

By looking at the individual sightings of stone martens, some similarities can be found. In general, most sightings are located either in, close to, or at the fringe of large green spaces (figure 87, next page). For both designs, existing green spaces will there be most crucial to housing the stone martens This possibly has to do with wildlife cameras frequently being mounted on houses. And, apart from one sighting, all dead martens in the database (Databank Flora en Fauna, 2023) found were roadkill (figure 85).

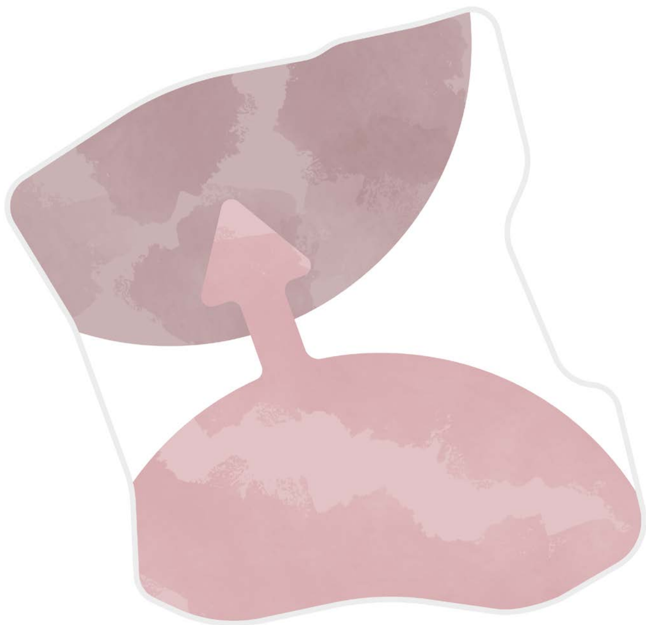


Figure 86 *Desired marten population movement to the north (pink) for increased prey (brown rat) availability (purple).*

Figure 87 *Stone marten sightings from 11-12-2021 to 11-12-2023 (Waarneming.nl, 2024)*

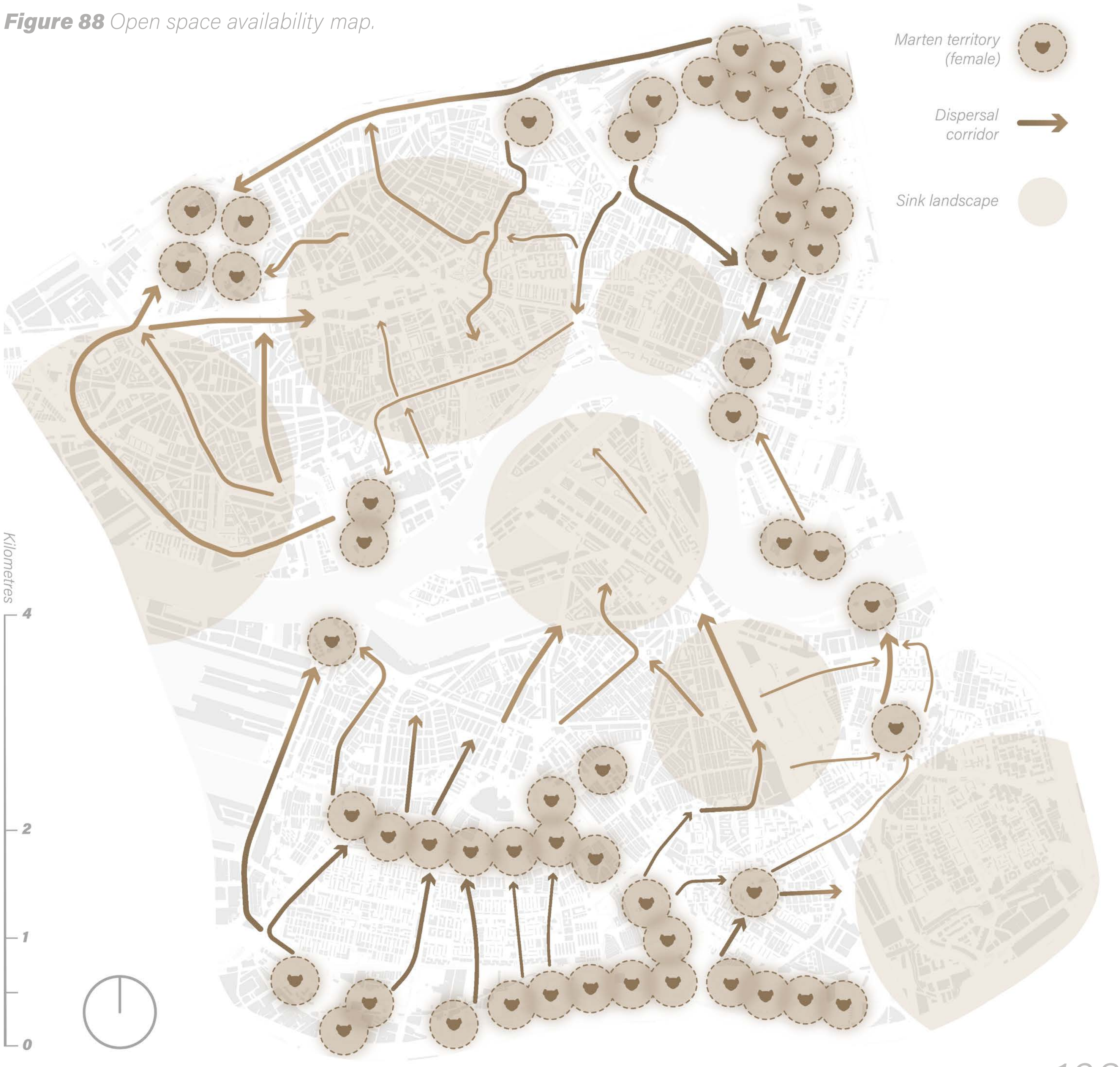
BROWN RAT

The dispersal of brown rats in Rotterdam (figure 85, p. 100) is mostly guided by the amount of public litter. Entertainment districts (such as Diergaarde Blijdorp [5]), areas with heavy tourist traffic (such as the Binnenrotte [6]), and waterfront locations where animal feeding is common (such as Neighbourhood Crooswijk) are excellent foraging sites for brown rats (Didde, 2019). The general lack of greenery in the north of Rotterdam, especially in comparison to the south of Rotterdam creates a lower predation pressure on brown rats by other urban wildlife that is in need of a green environment (Rijnmond, 2024). This is leveraged in both design alternatives.

5.1.b OPEN SPACE AVAILABILITY

In figure 89 (on the next page), a Nolli map of the project site is visible, this two-dimensional black & white plan drawing is often used to understand and document the accessibility and flow of open spaces within a city (Ji and Ding, 2021). In this thesis, the Nolli map is utilized to explore how the open space configuration of Rotterdam can be optimized to support a stable stone marten population.

Figure 88 *Open space availability map.*



The map in figure 89 shows unavailable private spaces, composed of private properties and building footprints, in black. The building footprints are outlined by a 1,5-meter-wide border [***6g***]. In addition, on-street parking spaces are also highlighted [***4h***]. The resulting map reveals the differences and similarities between traditional and modern urban spaces (Ji and Ding, 2021). In Rotterdam specifically highlighting the historical layering of city districts (built in different time periods).

Figure 89 *Nolli map of UOS in Rotterdam suitable for the design*

As a resut, figure 88 (previous page) shows the possible location of 54 female (15 ha) and, consequently, 27 male (30 ha) habitat patches within Rotterdam's current open space. This map will guide the spread of habitat provisions for both design alternatives. Although the total amount of available space is larger than the combined areal of these territories, the dense urban matrix in certain parts of the city does not allow for unbuilt open spaces with the required size and shape as described in design guideline [***8*** / ***9*** / ***10***]. For this reason, figure 88 identifies sink landscapes* within Rotterdam where UOS needs to be created in both design alternatives, in order to create a wholistic ecological network. Potential dispersal corridors connecting marten habitats are identified based on available space within the street profiles. Larger road, train, and water networks appear crucial for establishing extensive connections between habitat patches scattered throughout the city.

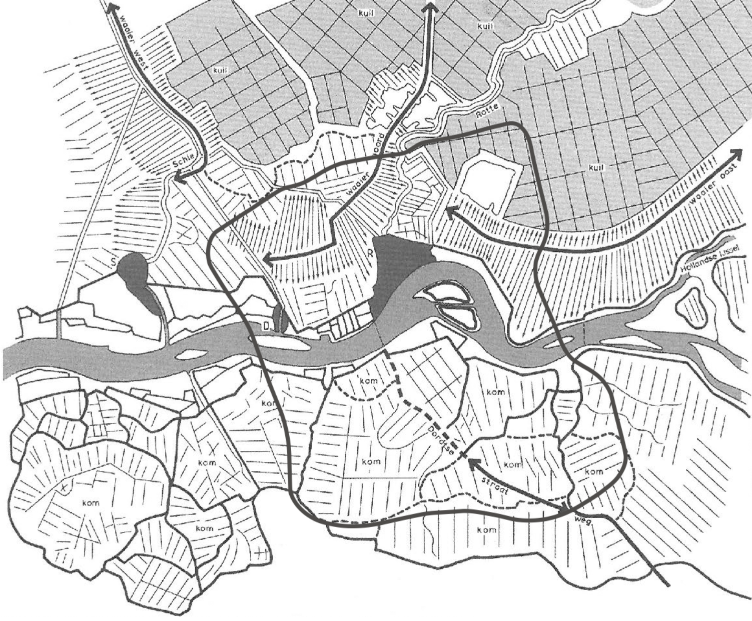


Figure 90 *Map of regional connection with site through landscape structures (Dutch) (Gemeente Rotterdam, 2014).*

5.1.c INFRASTRUCTURAL BARRIERS/CONNECTIONS

GREY INFRASTRUCTURE

Grey and blue infrastructure have been defined as possible barriers for the safe dispersal of martens within urban areas. Especially considering the existing living environment of stone marten in Rotterdam, most roadkill accidents have occurred on the A15 highway that borders the current population concentration, referring to recent and dated death marten documentations in Rotterdam (Bakker, 2008). These highways are one of the most important factors affecting the ability of wildlife, in general, to move in or out of the city, respective design alternatives focus either on avoiding (alt. 1) or crossing (alt.2) these large barriers. The A15 and A20, both bordering the project site, physically fragment wildlife habitat. The A15 crosses the blue-green connection to the south [7] and the A20 crosses the production forest to the north [8], also causing increased mortality through vehicle collisions (McCleery, Moorman and Peterson, 2014).

The bordering of highly ecologically valued, areas can form an important stepping stone in the population dispersal on a regional scale, connecting to a larger green network, as is visible in figure 90 (Gemeente Rotterdam, 2014).

Ecological research on roads has also focussed on the benefits that man-made infrastructure can have on the functional connectivity of wildlife habitats (McCleery, Moorman and Peterson, 2014). The green buffer zones between the highways and green verges that accompany them can be used as infrastructural connection within an ecological network. Within the infrastructural barrier/connectivity map this area is visible (figure 91). The municipality of Rotterdam (2014) has already designated these areas as such, even choosing the related stoat as its indicator species.

Based on a map of the average nighttime traffic density, visible in figure 92 (next page) , an estimate is made of road parts that either need to be avoided or made safely passable by designing effective wildlife crossings and detrafficking if possible, visualized in figure 91. This was reasoned by their proximity to or bordering of open spaces suitable for marten inhabitation.

Figure 91 *Infrastructural barrier & conncetivity map*

Figure 92 *Average nighttime traffic density Rotterdam (RIVM, 2022).*

Figure 93 *Common quay profile along the Nieuwe Maas (Julianus, 2020).*

BLUE INFRASTRUCTURE

Within the city itself exists another large barrier: De Nieuwe Maas [9]. Bakker (2024) sees this river as a plausible reason for the lack of marten sightings in the North of Rotterdam. The river is wide and has a strong current. Water traffic density is high and the bridges crossing the river are similarly heavily trafficked, even during the night (figure 92). The banks of the river are high so even if individuals attempt to make the crossing, it's too difficult to find a place to enter or exit the water (figure 93) (Dekker, 2024).

Just as many other cities in the Randstad, Rotterdam has an integrate system of canals, moats and ditches. These waterways were originally connected to the Nieuwe Maas to function as water drainage, transportation route or sewage system. Due to modern urban planning a lot of the blue infrastructure has been moved underground (Gemeente Rotterdam, 2010; In de buurt, 2022). Apart from creating more attractive nesting ground for rats, according (Van Adrichem et al., 2013), the function of blue infrastructure as ecological corridor is diminished (Biscaya and Elkadi, 2023). Both design alternatives argue that therefore reconnecting existing waterways aboveground, and redesigning water banks to become natural and accessible, could help the marten's dispersal (figure 91). Even being part of stone marten habitats as those have been observed to be located close to drinking water sources (Dudus et al., 2014).

5.1.d URBAN GREEN SPACE

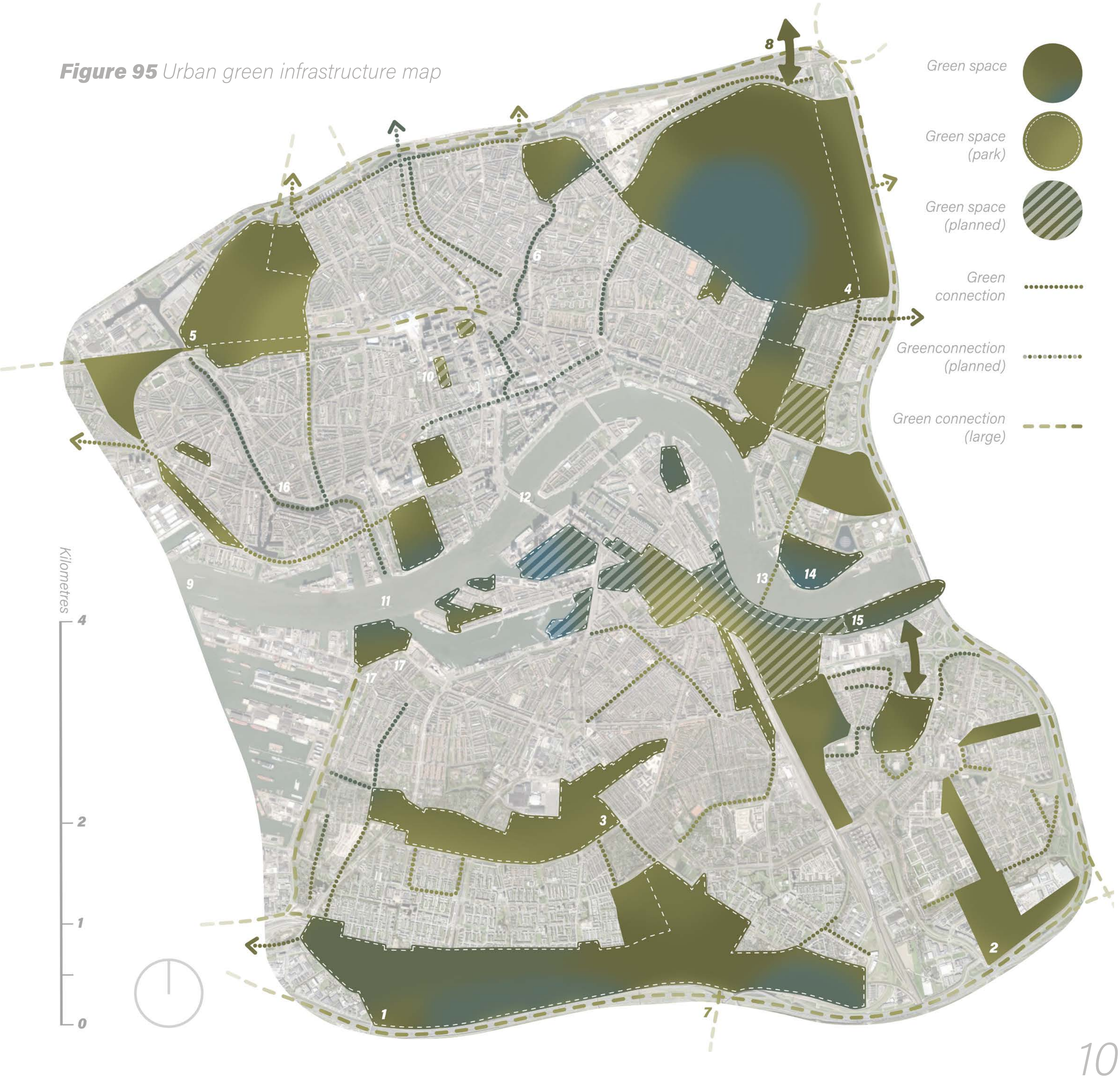
Rotterdam pronounces itself as one of the greenest cities in the Netherlands, it counts more trees than inhabitants and even has the most square meters of grass per inhabitant in the world (Gemeente Rotterdam, 2014). Rotterdam is especially rich in its variety of green spaces, more exceptional UGI's such as roof gardens, community gardens and pocket parks are in abundance within the city (de Keijzer, Mouwen and Vollaard, 2016).

Figure 94 *Nolli map of green space in Rotterdam.*

When looking at the distribution of green spaces in Rotterdam (figure 94, previous page), we mostly observe a fine-mazed green structure. In comparison, the quantity of high-quality greenery (such as city parks and natural reserves) is thought to be relatively scarce (Boekhoudt, 2024). Still, recreational green spaces that vary from semi to high habitat quality for stone martens are abundant. These contain, but are not limited to, mosrtly green sport facilities, allotment gardens, city farms,

Figure 95 below illustrates the inventory of all green spaces in Rotterdam that are potentially suitable for integration into the ecological network as patch or corridor for a stone marten population. This data was gathered through self-assessment, using a green space catalogue (de Keijzer, Mouwen, and Vollaard, 2016), a nature ambition policy document (Gemeente Rotterdam, 2014), and several grey literature sources concerning future zoning plans with green integration. Numbers in this map correspond to locations referenced in-text from the landscape analysis onward.

Figure 95 *Urban green infrastructure map*



GREEN STRUCTURE VISIONS

Now follows a brief overview of two prominent city-wide visions addressing Rotterdam's green structure. Each spatial plan underpins one of the design alternatives discussed. This thesis aims to connect these plans with current urban developments, grounding an animal-aided design within a broader ecological context that considers multiple ecosystem services beyond just enhancing liveability for stone martens. This approach may improve the feasibility of adapting the proposed plans. The organizations behind each vision (the Municipality of Rotterdam and Bureau Stadsnatuur Rotterdam) have been instrumental in evaluating the respective design alternatives, as detailed later on.

Rotterdamse Stijl

Publication Date: 2010-2012
Commissioner: Gemeente Rotterdam

The style of Rotterdam and its accompanying handbook provide guidelines for the design of public space in Rotterdam, used to create an open space characterized by tranquillity, unity and recognizability. The bombing of Rotterdam in 1940 and the reconstruction of the city after the war have resulted in a patchwork of different spaces. The fragmentation of open space is thought to distract from the spatial characteristics of Rotterdam, and for this reason the Rotterdamse Stijl has emerged. The style divides the city in spaces, lines and places.

Spaces

The most important pillar of the handbook is strengthening the urban network by creating unity in design elements, still respecting diversity and identity of the different city districts by playing with landscape and urban planning characteristics. Greenery within these spaces emphasizes quality over quantity (Gemeente Rotterdam, 2012)

Lines

Rotterdam is a city of long lines (roads, dikes, quays, and waterways) that, among other places, connect green areas. The profile of these lines contrasts sharply with the fine-mazed layout of residential neighbourhoods; therefore the municipality focuses on these structures to create a robust green network. Unfortunately, continuity in structures primarily focuses on tree planting, with little discussion in the handbook about other ground-covering vegetation types. Furthermore the book only emphasizes wide grass verges and green tram lanes. Maintaining diversity in lines, predominantly concerning canals like the Rotte and Schie, is essential. The handbook notes the importance of a cohesive water system. Unfortunately there is little emphasis on waterfronts directly connecting water and the city (Gemeente Rotterdam, 2012).

Places

Regarding Rotterdam's parks, the Rotterdamse Stijl aims to preserve their individual identities. Semi-public green spaces such as sports fields, allotment gardens, and cemeteries play significant roles. Peripheral parks are designated with an enhanced ecological corridor function (Gemeente Rotterdam, 2012)

Currently, a toolbox for nature-inclusive design is being developed within the municipality, extending the Rotterdam Style handbook with context on greenifying Rotterdam (van der Gaag, 2024). Unfortunately, it has not yet been published.

Future map Rotterdam

Publication Date: 2023
Commissionesr: Bureau Stadsnatuur, Witteveen+Bos & Heijmans

Nationaal park Rotterdam is an exposition in the Natural History Museum Rotterdam that showcases the importance of nature in the port city of Rotterdam and how urban wildlife has adapted to our urban environments. Part of this collection is the future map "Rotterdam as national park" (figure 96), which envisions a symbiosis between humans and wildlife in Rotterdam in the year 2030. This idyllic utopia is in stark contrast with the realism of the Rotterdamse Stijl, therefore providing a strong opposer (Nationaal park Rotterdam, 2023).

National Park Rotterdam focuses on an intensive interaction between people and nature. By viewing the city as an ecosystem in which its residents are an integral part, many qualities can be achieved or restored within the city. In addition to biodiversity, nature here provides enjoyment, coolness, health, and well-being (Nationaal park Rotterdam, 2023).

Three nature reserves form the main connections of nature through the city: a forest area in the Kralingse Reserve (5, figure 96), riverbank nature in the Biesbosch Reserve (9), and a marshland in the Southern Sponge Reserve (13). Green veins run through the city, connecting these reserves. Roads, dikes, quays, and waterways become green routes where people and animals live and move, thereby reducing traffic congestion. Fine-grained green structures within residential neighbourhoods are also part of this network.

The used planting within open space design is layered and more diverse by selecting trees, shrubs, and herbs that are suitable for Rotterdam's soil and groundwater. Different green heights and species create a diverse, resilient nature that attracts a wide variety of animal species. This plan, like this thesis, argues the importance of a complex urban food web in which potential pest species are controlled by natural predators due to high biodiversity. A certain degree of wilding will accelerate the succession process of vegetation types in the city, transforming Rotterdam into a high-quality playground for species like the stone marten (Nationaal park Rotterdam, 2023).

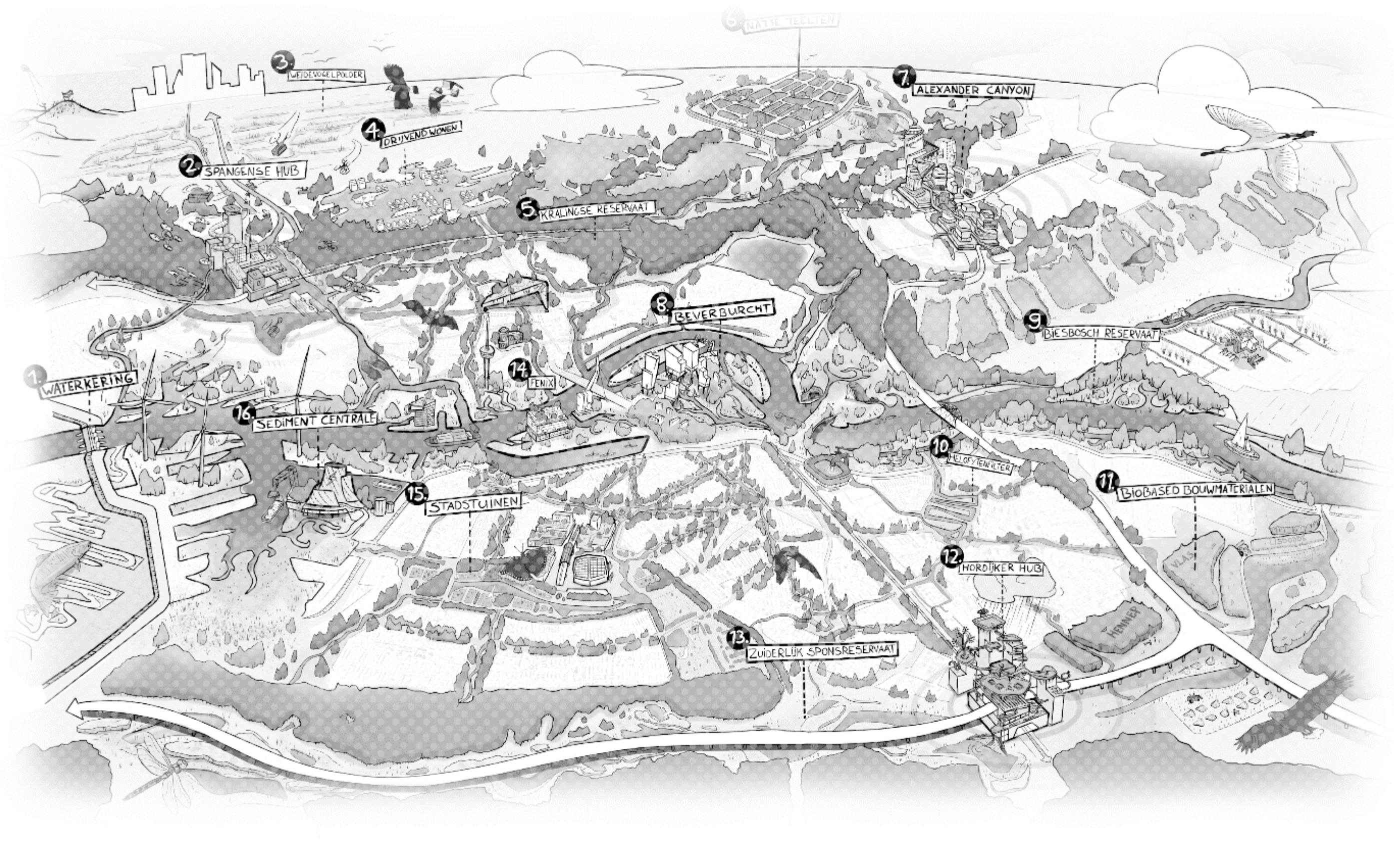


Figure 96 *Future map Rotterdam used as inspiration for design alternative 2 (Nationaal park Rotterdam, 2023).*

5.2 DESIGN ALTERNATIVES

Two design alternatives for the project site have been developed, combining the design guidelines and criteria from the research with the landscape analysis. They are elaborated on the topics of habitat, corridor and overall network. They are, respectively, visible in figure 99 and 102 on page 112/113 and 116/117. Design differences between both alternatives are visualized in figure 103 on page 118/119. Reference are made in-text to the respective legends (A, B, C, ...), and the inspiration taken from the two green structure visions.

Figure 97 *Visualizer design alternative 1 made using adobe firefly.*

5.2.a PARK CITY ROTTERDAM

Design alternative 1 aims at creating a city of large urban parks that contain multiple "pocket forests": undisturbed forested areas with high habitat provision for stone martens. The forests are divided by edge habitat with semi-recreational green spaces for citizens. Habitat patches are connected through strong lines consisting of layered L-UGI's. This network is surrounded by dense building blocks, enhancing the experience of nature in the city. In general, Park city uses a set of design tools, taken from the research, to add on to the Rotterdamse Stijl.

HABITAT PATCH

When looking at the first design alternative, three large source patches (A) can be distinguished that are aimed at growing the stone marten population within the city: The Diergaarde Blijdorp, Kralingse Bos and Zuiderlijk randpark habitat. Just as the Rotterdamse stijl, similar design elements are used for the respective places, identity can still be shown in their landscape planning characteristics. The source patches can eventually inhabit large metapopulations that disperse individuals towards smaller patches that are more centralised in the city centre [***8e***]. These and other patches, larger than 15 ha, are divided (C) into multiple female marten habitats of similar size [***8a*** / ***8b***]. This division of territory is based on existing infrastructural barriers [***1b***]. Male martens can inhabit one or more female territories, dependant on the number of female habitats within a certain areal [***4a***]. Within certain sink landscapes, as found in the analysis, sites are chosen with an area slightly smaller than 15 ha, as can be seen at Oude Westen (B) for example. Here, inhabitation of city parts with high building density is still made possible.

The pocket forests, that function as core areas (D) for the individual habitats, account for about half the designed territories [***9a***]. They are situated as a patchwork within a multitude of existing parks and gardens that vary from historical park to zoological garden. New habitats will solely be situated in new urban parks, here the edge habitat (E) could become any type of recreational green space that are similar to the semi-public green spaces that characterize the city, as identified by the Rotterdamse Stijl [***12b*** / ***16a***]. Important is that the pocket forest provides a multitude of unmaintained thick vegetational layers with native species that are fruit-holding [***13a*** / ***b*** / ***c*** / ***d***]. The edge habitats do so to a lesser degree [4h]. This also goes for the denning and nesting sites, which will be designed within pocket forests [***2*** / ***5***]. This way inhabitation of non-designated urban areas is discouraged on multiple levels [***4g***]. Open spaces have been chosen that are minimally convoluted due to their positioning in the urban tissue and boundary with infrastructure [***9d***]. Therefore edge habitats are both abrupt and straight (which will be elaborated in the next design-scale) [***9b*** / ***9c***].

DISPERSAL CORRIDOR

Corridors (F) make use of the long lines, identified in the Rotterdamse Stijl, in the city; they are situated in street profiles with a green border more than 3 meters wide that is minimally 1,5 m away from building facades [***6g*** / ***10b***]. At dangerous intersections wildlife crossings (H) are appointed that often use dual-purpose underpasses with existing waterways or simple overpasses such as hop-overs and tree bridges with continuous patchy vegetation [***10a*** / ***14a*** / ***b*** / ***d***]. The corridors can consist of a combination of multiple L-UGI's, selected from those in figure 98. In line with the Rotterdamse Stijl, characteristic waterways are reconnected. Tree lanes, hedgerows, green verges and natural banks are most frequently used to line such corridors [***12a*** / ***b***]. Hereby this alternative aims at expanding the tree-structure-vision of the Rotterdamse Stijl with additional vegetation layers, such as a 'shrub-structure-vision.' Corridors start or and in the nearest habitat patch. Adjacent habitats are not connected through a corridor [***10d***]. Corridor density is highest near the appointed source patches [***11a***], smaller patches situated within the city centre are reachable via multiple corridors.

ECOLOGICAL NETWORK

Source patches are directly connected with each other through large landscape corridors (G), aimed at ensuring the inhabitation of the northern source patches that are currently uninhabited. This aligns with the Rotterdamse Stijl appointing such spaces with an enhanced ecological corridor function. The existing Nieuwe Maas tunnel, Erasmusbrug and to-be-built bridge will form larger wildlife crossings (I) for the stone marten population distribution from south to north. Secondly, in order to create urban green spaces large enough for distributed marten inhabitation certain building block are removed (J) and densified (K) in areas close by [***4c***]. These areas will provide dense housing that still respects the characteristics of that city district, for this reason building blocks are solely combined within such a district. Lastly, certain areas within the network are highlighted that currently are part of brown rat hotspots (L). Apart from increasing predation pressure by providing habitat for martens in the north of the site, these habitats are designed to be in close proximity to rat hotspots. The accentuated areas adapt evergreen plant species and vegetal food sources with minimal attractiveness for rats [***5e*** / ***f*** / ***7c*** / ***d*** / ***e***] .

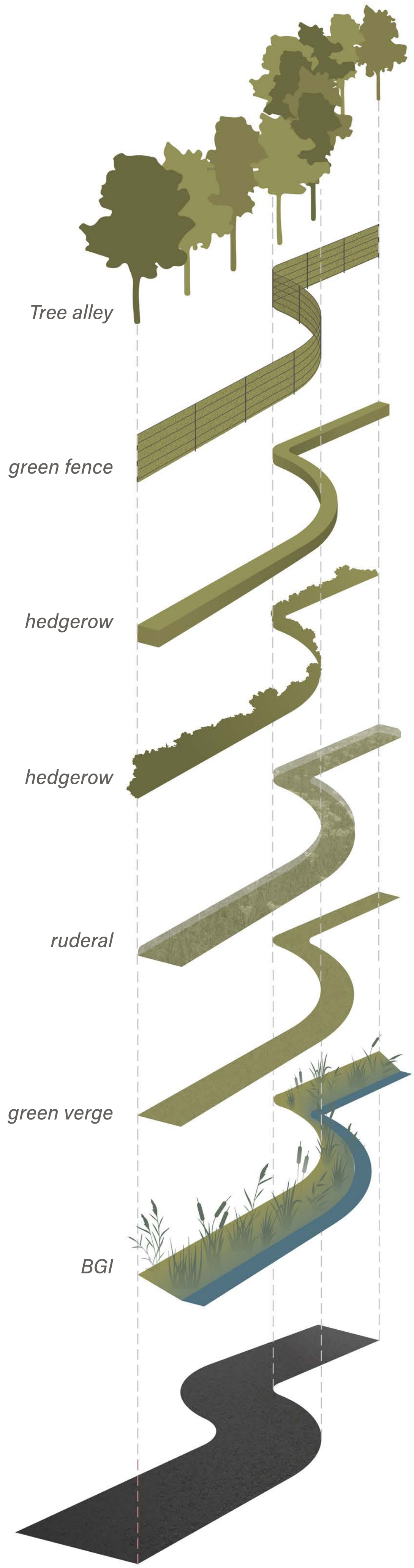


Figure 98 *L-UGI's to be layered within corridors of design alternative 1, also usable in other designs.*

Figure 99 *City-scale design alternative 1.*

PARK CITY ROTTERDAM

City-scale alternative 1

A *Source patch Diergaarde, Kralingen, Zuiderlijk*
B *Small patch example Oude Westen*
C *Territorial border female*
D *Core area canopy, understory, shrub, herb, grass*
E *Edge habitat shrub, herb, grass*
F *Corridor hedgerow, tree lane, waterway (L-UGI)*
G *Large landscape corridor liniear park*
H *Wildlife crossing small to medium-sized*
I *Wildlife crossing large*
J *Building replacement*
K *Building densification*
L *Evergreens/grassland brown rat occupation*

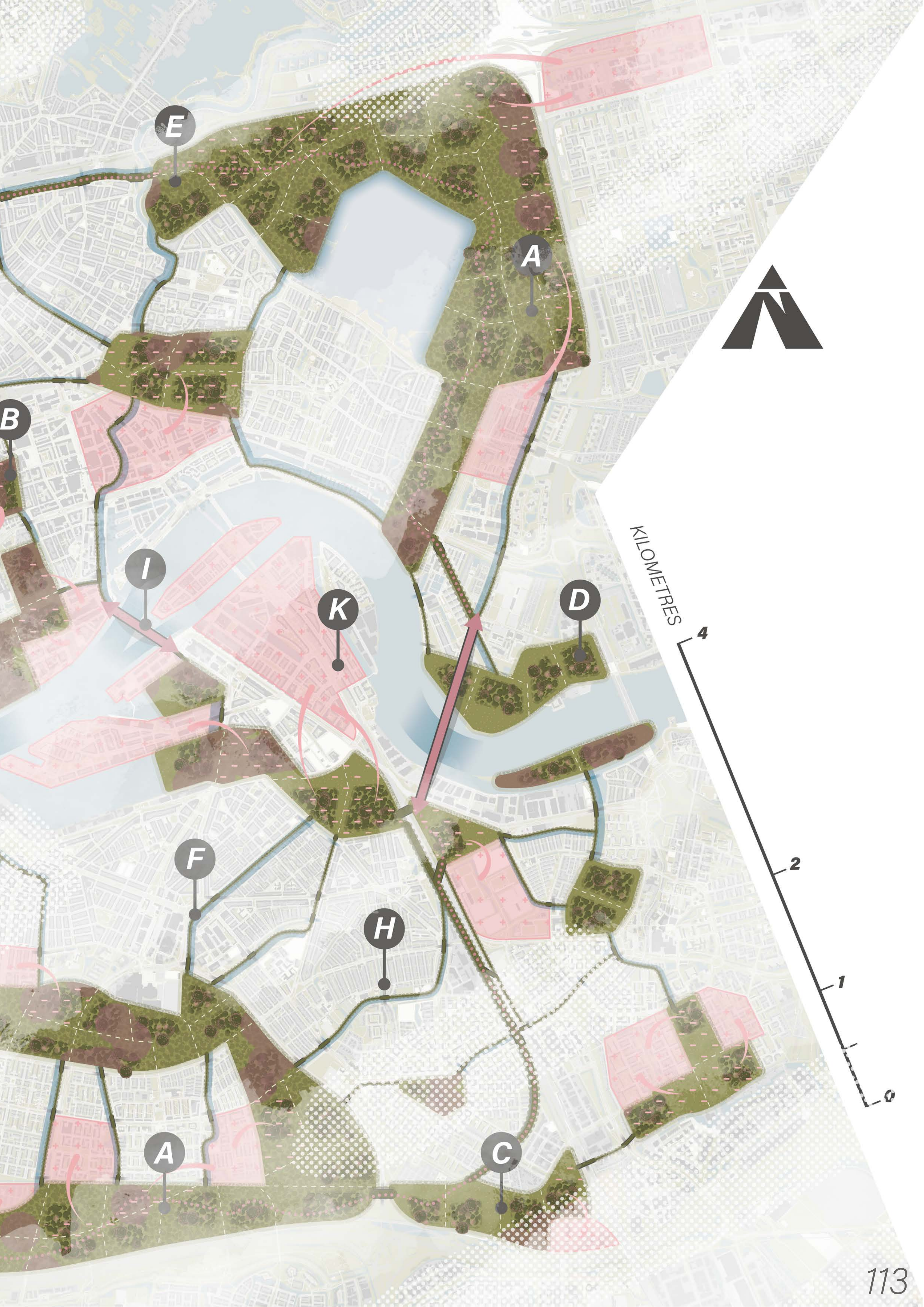

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Figure 100 *Visualizer design alternative 2 made using adobe firefly.*

5.2.b NATIONAL PARK ROTTERDAM

Design alternative 2 embodies freedom in the adaptation of the research and focusses on creating a more robust ecological network for stone martens and other urban wildlife, in favour of a set restructuring of urban open space in Rotterdam. Natural landscapes that once flowed through the area are reintroduced, interconnected through a network of green veins with transitional vegetation between the proposed nature types. The urban tissue becomes part of the marten's habitat. Heavy inspiration is taken from the Nationaal Park Rotterdam exhibition.

HABITAT PATCH

The northside, southside and centre of the project site have three developed nature types that connect to the regional green network (figure 101, next page), similar to the 'Rotterdam as national park' vision [***12***]. The Kralingen reserve (A) provides a forest with dense understory layer, plenty of berry bushes and ample dead foliage in which to hide. The Biesbosch reserve (B) provides a riparian woodland with periodical flooding where dead driftwood can be used to move about, and nesting birds can provide possbile food sources. The Zuiderlijk reserve (C) provides a wetland with large variety in vegetation, food sources and plenty of nesting materials.

These source patches provide edge-to-edge high habitat quality and therefore does not differentiate core areas and edges are only defined though patchy forestry (D). A natural landscape with biodiversity in plant and animal species thus arises [***14***]. A balanced ecosystem with urban food webs uninfluenced by humans is expected to occur, baring similarity to the symbiosis discussed in the 'Rotterdam as national park' vision [***15***]. To ensure this, only slow recreation is allowed in the reserves [***16***]. This alternative aims at decreasing marten nuisance to humans by providing such a qualitative natural habitat that building denning and car damaging less rewarding. The densely vegetated reserves and lack of edge habitat decrease the barrier function of infrastructure within. Territorial divides are thus created in a natural way, which possibly further stimulates male-female encounters [***1*** / ***4***]. Suitable denning and nesting sites are not provided, but can be found within the natural landscape elements within the reserves themselves. Examples are dead wood, shrubs, tree hollow and leave piles [***2*** / ***5***]. In similar vein do natural growing fruiting plants provide possible food resources [***7***]. A rapidly developed succession and naturalization of the marten habitat makes the traversability of the area diverse [***6***].

DISPERSAL CORRIDOR

The different landscapes are connected via green veins (E) through the city [***10***]. These can also be seen in the future map in the 'Rotterdam as national park' vision. The corridor system is more elaborate than in alternative 1 as both smaller and larger corridors connect through urban areas. They are undefined by certain UGI typologies as long as their planting transitions the vegetation of the nature reserves. Where space is limited, linear urban green infrastructure provide traversal within neighbourhood (F) adjacent to the green veins. In line with 'Rotterdam as national park,' traffic density is low in the appointed corridors but human usage is not excluded [***16***]. The different possible wildlife crossings are similarly undefined as the greenified city provides safer traversal possibilities and few roadkills are expected to not form a threat on a population that could be established [***13***]. Blue infrastructural barriers, such as the Nieuwe Maas, are made crossable by making the banks greener (G) and easier to traverse with a gentle slope.

ECOLOGICAL NETWORK

On a larger scale it is visible how urban green space is developed throughout the urban fabric (I). A coexistence of humans and martens is aimed at. To account for human recreation, existing "green pearls" (H), small green spaces scattered throughout the city, are appointed as recreational parks [***16***]. Similarly, existing urban areas and planned urban development are integrated at the fringes of nature reserves, providing a form of nature-inclusive densified housing (I), equally important within the 'Rotterdam as national park' vision. Brown rat predation is tackled by increasing the predation pressure through creating a highly ecological urban space that houses more predators of this mammal. Plus, the integration of wet nature types brings together the stone marten and brown rat habitat (J) [***8***].

Figure 101 *Reference image Kralingen (top), Biesbosch (middle) and Zuiderlijk (below) reserve (Gemeente Rotterdam, 2014)*

Figure 102 City-scale design alternative 2.

NATIONAL PARK ROTTERDAM

City-scale alternative 2

A Kralingen reserve forest
B Biesbosch reserve wetland
C Zuiderlijk reserve riperian woodland
D Patchy forestry natural
E Green veins transitional vegetation
F Green veins l-ugi
G Natural bank green slopy quays
H Green pearls parks and gardens
I Neighboorhoud densification / greenification
J Increased wildlife provision predation pressure


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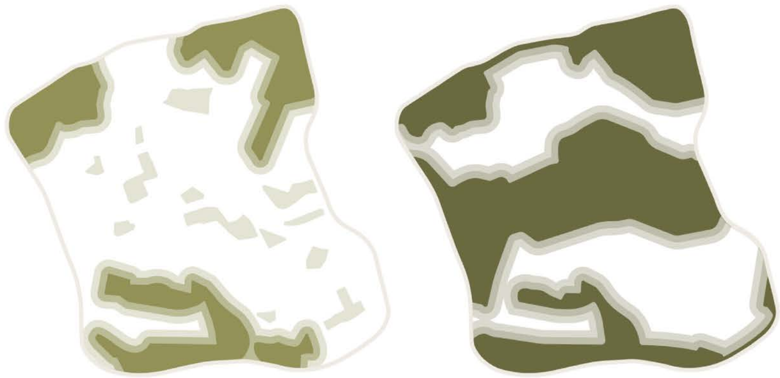
alt 1 **alt 2**

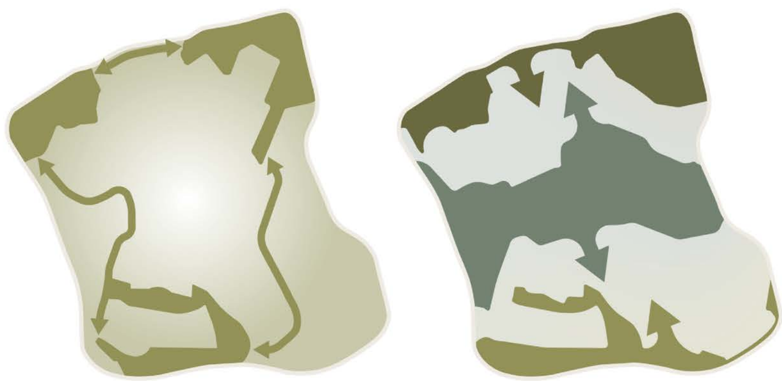
Parks / Nature

Park city focusses on the expansion and ecological improvement of existing urban parks, relocating urban areas towards the edges of these green spaces. National park highlights the natural landscapes that are reintroduced within the city, greenifying the urban areas that are currently situated within these landscapes.



Source-sink landscapes

The first alternative determines the Blijdorp, Kralingse bos and Zuiderpark green spaces, combined with multple smaller parks, as source patches for the distribution of martens. The second alternative highlights the forested landscapes as the source patches for the marten´s ecological network.



Population dispersal

Park city creates large, high-quality corridors to connect the design's source patches and ensure sufficient dispersal possiblity for the whole site. Overall, corridor quality and density is better at the edges of the site. The national park strengthens pup dispersal on the edges between forest and urban tissue by using more fine-scale natural UGI's, creating more transition areas.

Corridor system

Corridors within the park city are few, but strong. They consist of multiple layers of L-UGI's that create multiple traversal possibilities and aim to elicit familiarity of the stone marten population with the used vegetation. The national park vision uses transitional vegetation within a system of green veins. The corridor sizes, locations and typologies are, in general, less strict.

***Figure 103** Concept sketches of the differences between both design alternatives.*

Design elements
In line with the Rotterdamse stijl, similar design elements are used within the design of open spaces in park city. Yet, there combination is different for every park. National park uses the identity of the three different landscape types to create a marten-friendly design. Elements such as shelter places and foraging sites are to be found within the natural landscape instead of being decided for the whole design.

Urbanisation
To account for urban sprawl, the first design focusses on densification of existing neigbourhoods with respect for the original neighbourhood typologies as determined by the Rotterdamse stijl. The second alternative integrates the vegetation of the different landscapes with the neighboorhouds to make them part of the marten network.

Wildlife crossings
Park City utilizes wildlife crossings in designated corridors, including large ecoducts over the Nieuwe Maas barrier and larger crossings for major dispersal corridors. The National Park, on the other hand, doesn't employ wildlife crossings but instead adapts the open space design around key barriers. Along the riverbank of the Nieuwe Maas, gradual slopes are created to aid martens crossing.

Brown rat predation
The park city design makes use of design elements unfavoured by brown rats in areas where the animal is sighted most often, such as evergreens, grasses, poisonous plants and a lack of shrubbery. Nationaal park aims to introduce overarching vegetation types that are lesser inhabited by brown rats, and more often inhabited by possible brown rat predators.

5.3 EXPERT ASSESSMENT

Upon completion of the design alternatives, the researcher has interviewed four experts to assess the performances of the designs alternatives in relation to the design guidelines and criteria. For a quantitative analysis on the suitability of the design alternatives to accountfor the topics researched, a questionnaire was used. The questionnaire and formulation of the used questions is visible in appendix 6 . As a reason of the quantitative analysis, values within the upcoming figures correspond to:

0 - 4
Very unsuitable ***(vu)***

5 - 8
Unsuitable ***(u)***

9 - 12
Neutral ***(n)***

13 - 16
Suitable ***(s)***

17 - 20
Very suitable ***(vs)***

The questionnaire was filled out by all four experts:

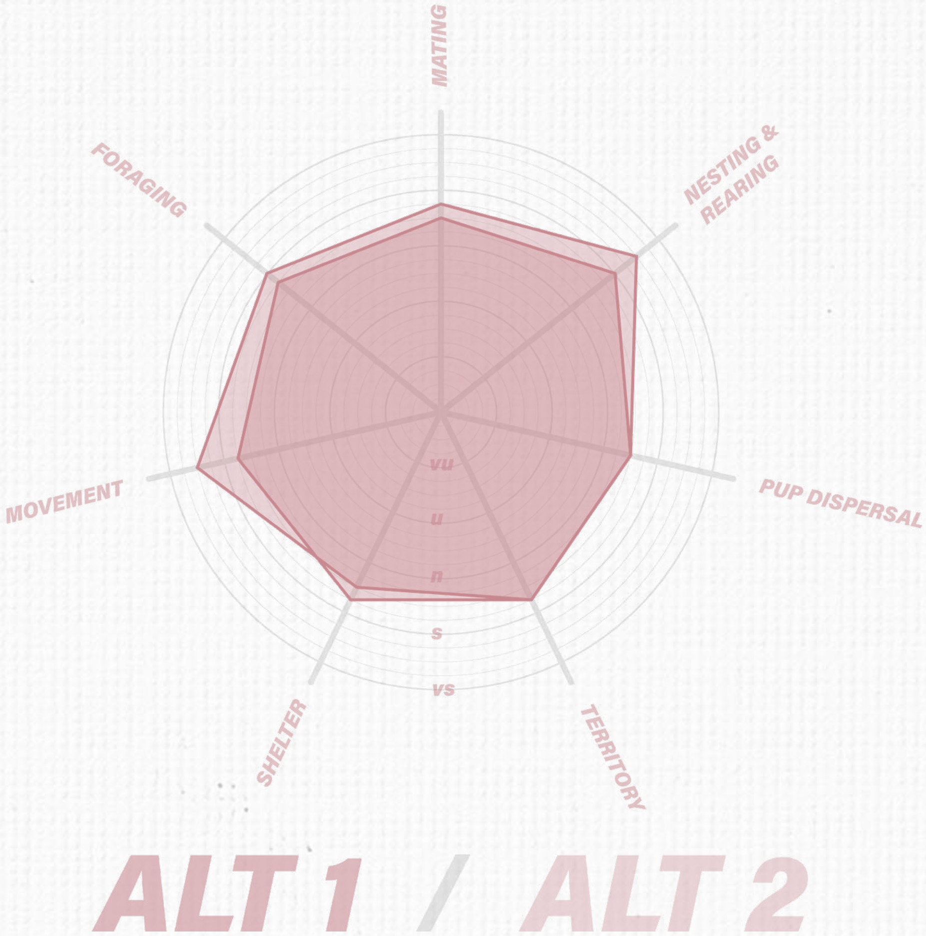
Name Garry Bakker
Profession Ecologist at Bureau Stadsnatuur.
Expertise Inventorying birds, bats, mice and mustelids, fish, amphibians, reptiles and dragonflies.

Name Yolanda Boekhoudt
Profession Senior Landscape architect at the municipality of Rotterdam.
Expertise Advocate for qualitative public green spaces for humans, animals and plants. Adapting research through design and participative processes.

Name Dolf van der Gaag
Profession Urban ecologist at the municipality of Rotterdam.
Expertise Advisor on urban developments and developer of ecological programs.

Name Zeger Dalenberg
Profession Strategic landscape architect at the municipality of Rotterdam
Expertise Nature-inclusive, animal-aided design

To complement these results, a qualitative analysis has been carried out about the proposed subjects. Both assessments take place in group sessions, therefore the results of both the quantitative and qualitative analysis are combined and elaborated within the next headings. All aspects of the thesis that have been confirmed within these assessments have not been incorporated into the next heading.



HABITAT REQUIREMENTS

Although the first design alternative scored better on individual habitat requirements, the second design alternative is thought to equally provide similar habitat qualities within the different natural landscape characteristics. A certain level of detailing within the park-scale is thought to be necessairy to substantiate that idea. The next main outtakes regarding favouring of alternative 1 (noted as 1) or 2 (noted as 2) in relation to SRQ1 can be identified:

2 The green spaces in the north of the project area, such as the Kralingse Bos, already have high quality, so low habitat quality is not the primary driver of limited population dispersal towards Rotterdam-Noord. Therefore the interconnectedness of alternative 2 is preferred.

1 2 The Nieuwe Maas is confirmed as significant barrier, to such a degree that any possible wildlife crossing should be taken. Here, one perspective favours the use of bridges and tunnels for crossing the Nieuwe Maas (alternative 1), as strong guiding vegetation is expected to secure actual usage and safe passage. Another perspective prefers the creation of natural banks (alternative 2), as the length of the area to be crossed is more ideal.

1 The idea of alternative 1 to transform the to-be-build bridge (13, figure 95) on the east side of the project area into a pup dispersal corridor is very much favoured by all experts. Polder de Esch (14) and Breijenoord (15) may lose ecological value if the new bridge is not properly designed, due to potential disturbances.

2 The contextualization of the second alternative is thought as especially important for colonization of the stone marten on a more regional context. Large canals, such as the Rotte (6) and the Schie (16) should therefore be highlighted within the network

Figure 104 *Results quantitative assessment design guidelines SRQ1*

ALT 1: 15/20
ALT 2: 14/20

BROWN RAT PREDATION

Brown rats are highly opportunistic, making it challenging to design effective predation strategies through direct interventions in both alternatives. Therefore most experts argue that all possible measures should be taken. The next main outtakes can be identified:

1 Minimal shrubbery and garbage concentration are thought to be guiding measures.

1 One expert sees great untapped potential in enhancing the Waalhaven (17) as large green corridor. This could most effectively connect the stone marten (south) and brown rat (north) population.

2 Another expert argues to consider the possibility that martens may not be suited for inhabiting the north side of the city, and for increased plague predation pressure other mammals should be designed for.

ALT 1: 13/20
ALT 2: 14/20

HUMAN-MARTEN CO-OCCURRENCE

The conversation often drifted toward the recreational value of the public green space. For the experts, a large part of the human acceptance is the provision of human usage to balance out improving the living environment against the negative effects of marten nuisance. Both alternatives can provide this in different ways. The next main outtakes can be identified:

2 Poorly designed parks, consisting of solely of grass and trees, are confirmed to be difficultly navigable due to poor shelter opportunities. Consequently, manmade landscape elements are preferably used. A drastic reimagining of park design is needed and therefore the design implementations of the second alternative are favoured.

1 The first design alternative is believed to be more easily adaptable as it minimally alters the existing urban fabric and green space usage, allowing more space for human activities.

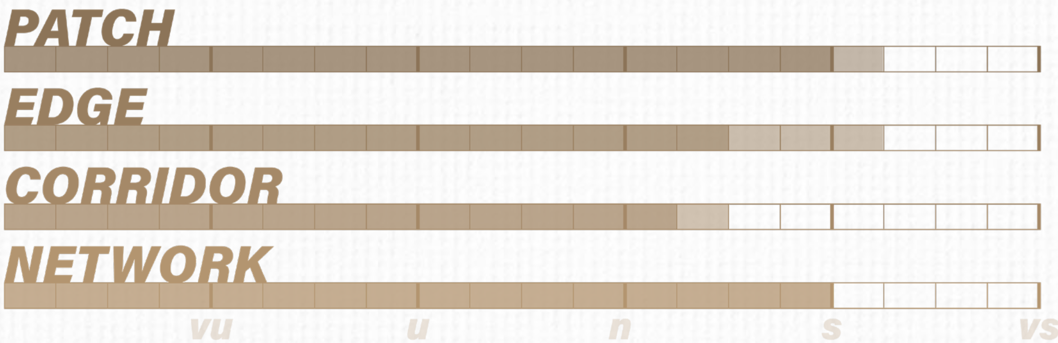


Figure 105 *Results quantitative assessment design guidelines SRQ2*

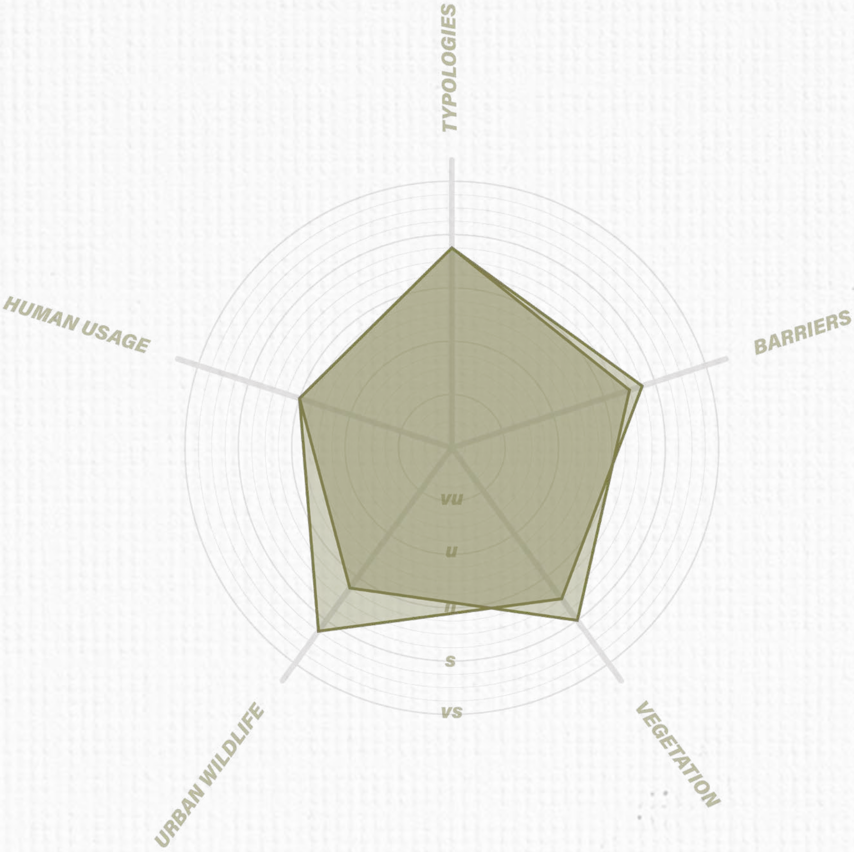
ALT 1 / ALT 2

OPEN SPACE SYSTEM

In comparison to the quantitative data it seems rather interesting that, although the first alternative most clearly adapts the design guidelines and criteria in the open space system, scores lower on all fronts. The more robust design of the different components in alternative 2 is favoured over a rigid system that ensures population dispersal and minimal nuisance. The next main outtakes can be identified:

2 The experts argue that southern-situated parks are capable of supporting a significant marten population. Habitats here are smaller than those documented in scientific literature, suggesting that territory size reduction is feasible if habitat quality is high. The exponential population growth is necessitating further distribution. Misuse of the proposed open space system in alternative 1 by stone marten is highly likely and the freedom in system adaptation of alternative 2 is therefore favoured.

2 Certain experts prefer the complementary usage of smaller corridors through urban areas as to destress the usage of the current critical human infrastructure. This is the case in alternative 2.



ALT 1 / ALT 2

URBAN GREEN INFRASTRUCTURE

The reimagining of UGI's within the second alternative is favoured as it is thought to create safer passageways, accounts for multiple species and introduces recreational possibilities. The next main outtakes can be identified:

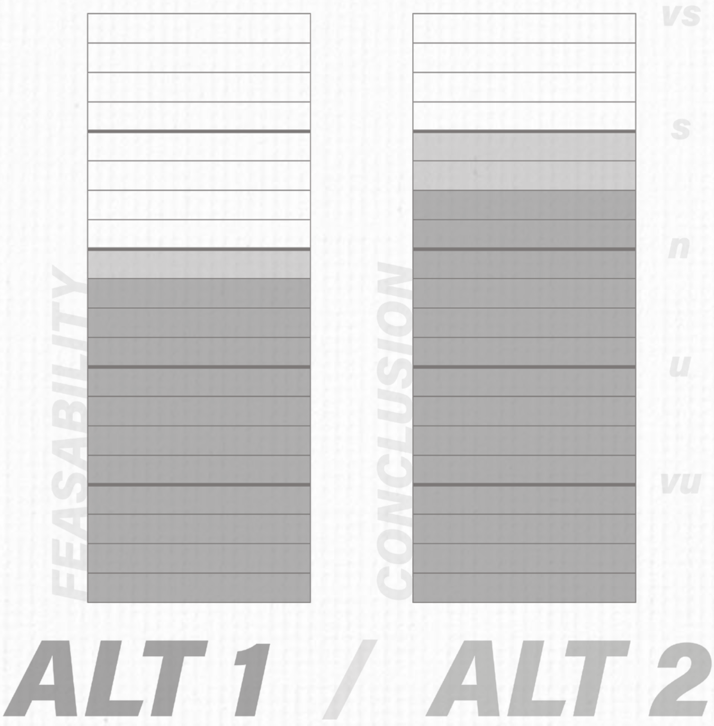
2 Instead of designing specific locations for safe wildlife crossings, implementing numerous simple, yet effective, small-scale crossings along major barrier axes might be preferred, such as in the second alternative.

1 Allotment gardens are thought, by the experts, to be vital for the dispersal of stone martens due to their easy food resources. This should be considered by addressing this potential issue for human acceptance of stone martens or leveraging it as an advantage, which is easier to achieve within the first alternative.

1 The experts stress to identify recreational activities that do not stress the animals. More general, both alternatives do not consider the current usage of urban spaces like sports fields, community gardens, and festival grounds, which are integral to Rotterdam's identity. Enhancing their ecological value would be beneficial for martens. The first alternative seems to give more space for this integration.

2 The second alternative caters to possible new forms of nature recreation such as ecotourism.

Figure 106 *Results quantitative assessment design guidelines SRQ3*



CONCLUSION

The experts found it difficult to assess the design on SRQ1, especially SRQ1A/B, due to the scale size used. The park design was thought to be interesting to see how these proposed design guidelines and criteria can be implemented, with respect for the chosen site. Although the design guidelines and principles were deemed feasible by the experts, an integration of the ideas from the first alternative within the more robust city-scale design alternative 2 is deemed most interesting. Although more drastic, exciting new types of open space and its usage are expected. This also means a better habitat for other animals. In general, more additional values reason why design alternative 2 also scores better on feasibility. Therefore within the park-scale design, additional benefits to the adaptation of this research for human usage will be highlighted.

***Figure 107** Results quantitative assessment conclusion on design alternatives.*

Figure 108 *Exemplary evocative collage on what an urban open green space designed for stone martens within the 'marten city' final design could look like. Impression is taken during the night, when the stone marten is active. Location chosen near Rotterdam central station, photograph by (Bosch, 2017)*

5.4 FINAL DESIGN

Based on the expert assessment a final design has been created that combines both alternatives based on their respective strengths and weaknesses, adding additional design input advised by the experts, this map is visible in figure 109 . An elaborated legend with zoom-ins on the 3 subareas within this plan are visible on the pages thereafter. Given the complexity of the map, the writer encourages you to explore all its details. Although the final design is conceptual and large-scale, figure 108 (previous page) gives an impression of what such a design would look like.

Marten city envisions a drastic redesigning of urban green space in Rotterdam. Large urban parks and gardens, combined with recreational green spaces that are so characteristic for the city, are transformed into stone marten habitats. Ecological value is heightened by the integration of three natural landscapes, or sub-areas (figure 110, 111 and 112) that are bounded within the urban grid: The Biesbosch (A), Kralingen (B) and Zuiderlijk habitat (C). This urban wilderness promotes male-female encounters, creates safe nesting places, provides shelter and offers food resources. Yet their respective vegetation types are branched throughout the city, providing urban spaces promoting a degree of human-marten co-occurrence that are traversable for marten pups. Linear urban green infrastructures disperse marten pups throughout the whole city. A variety of wildlife crossings ensures safe passage. Pocket parks function as stepping stones for population dispersal through species-specific design implementations, whilst providing intimate green spaces for the city's inhabitants. Marten City leaves minimal space for plague species as predation pressure increases due to the rich biodiversity that is envisioned. Yet, this green urban transformation seamlessly accommodates a rapidly growing population, boosting liveability and creating a vibrant, sustainable community.

HABITAT PATCH

As stated by the experts, the proposed urban open green spaces already exhibit sufficient habitat quality. Therefore, existing recreational green spaces are greenified to be an active part of the martens' habitat. A selection here is made of UGI's that generally do not stress martens. For this reason the borders of the proposed network overlap with existing green space boundaries. As proposed by the experts, the second design alternative is consequently fitted within the space of the first alternative. Yet, smaller possibly occupied spaces within this network are more strictly designed through the usage of small-scale design implementations from the research. By ensuring the sustenance and improvement of existing social significance in UOS (believed by the experts) the human-marten co-occurrence is improved as a possible level of nuisance acceptance is hypothesized.

DISPERSAL CORRIDOR

The importance of habitat connectivity, frequently underpinned by the expert, is facilitated through using both important infrastructural connections and smaller corridors that also extensively connect through habitat patches. In this way a robust network for dispersal can be found throughout the city. As advised by the experts, naturalization of the water network is highlighted. Crossing the Nieuwe Maas is made easier by ensuring habitats and safe passageways along the whole river (figure 110). Other important barriers are crossed via multiple wildlife corridors that are placed along the whole verges of set structures that could potentially endanger crossing individuals.

The Waalhaven (figure 112) and other spacious linear areas are designated as landscape corridors that aid quick distribution of marten to the north. Based on expert advice, landscape bridges over key rail lines have been included in the plan (Figure 110, 111).

ECOLOGICAL NETWORK

To improve habitat provision outside of city boundaries (thought essential by the experts), large ecoducts connect with the nature areas outside on the urban-rural fringes (figure 111 and 112) In general, the appointed subareas and their respective nature type invite other urban and non-urban wildlife from in- and outside city borders. Although not part of this thesis' scope. The writer agrees with the experts that this could boasts the quality of Marten City over that of design alternative 1. As told by the experts, inviting possible predators is coincidentally essential for effective predation on brown rats and similar pest species.

MARTEN CITY

Figure 109 City-scale final design

MARTEN CITY

Final city-scale design

A Biesbosch habitat *wetland*
B Kralingen habitat *forest*
C Zuiderlijk habitat *riperian woodland*
D Recreational space *greenified*
E Landscape corridors *transitional vegetation*
F Green veins *L-UGI*
G Green pearls *parks and gardens*
H Building *replacement & densification*
I Neighboorhoud *greening*
J Vegetational difference *brown rat occupation*
K Dual-purpose crossings *dispersal*

D
G
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Figure 110
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Figure 110 Zoom-in Biesbosch habitat (wetland) with legend.

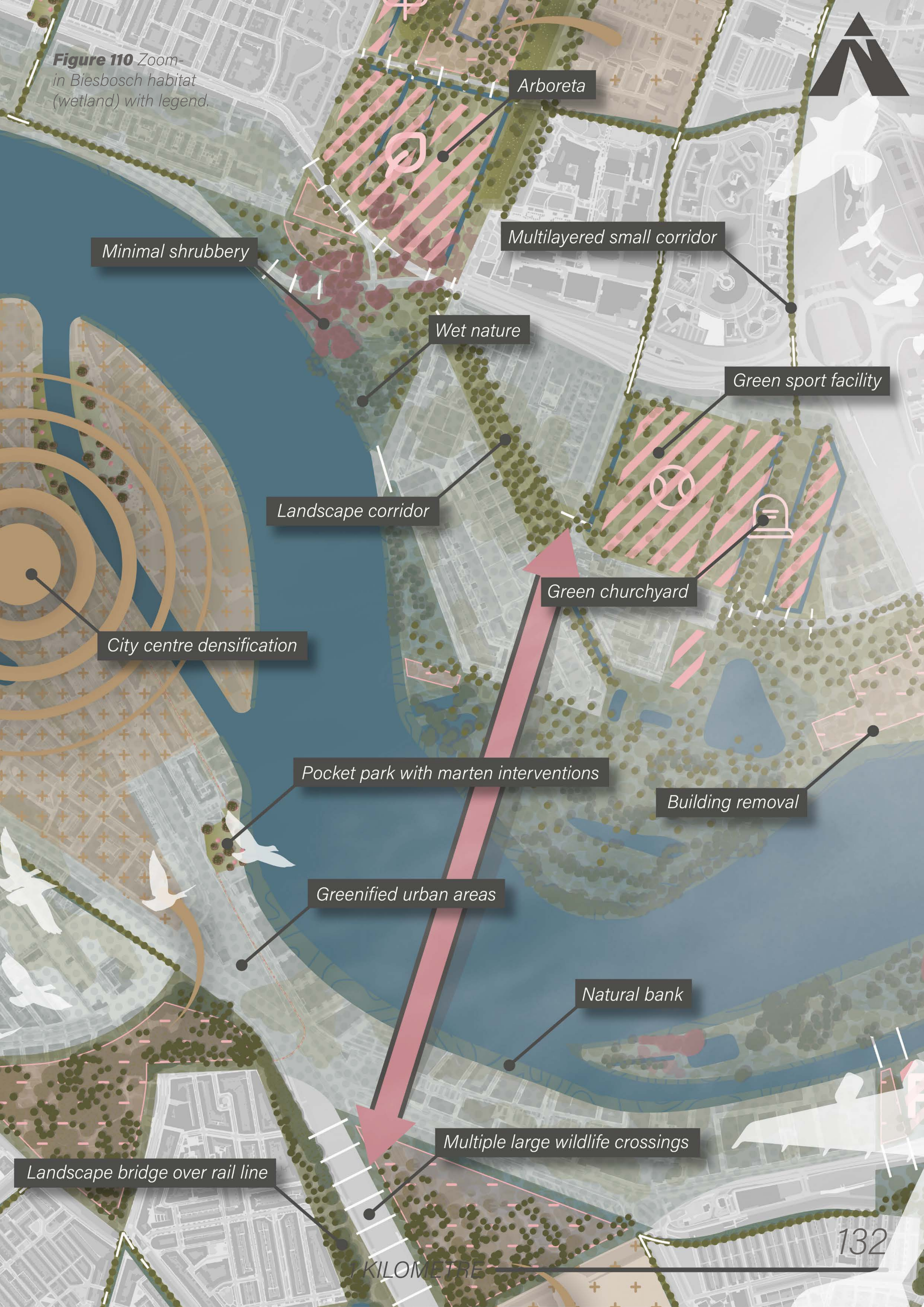


Figure 111 Zoom-in Kralingen habitat (forest) with legend.

Figure 112 : Zoom-in Zuiderlijk habitat (Riperian woodland) with legend.

DESIGN FLAWS

Although qualities of two design explorations are combined, certain critical design criteria are not met within the final design:

- In Marten City, the separation between potential habitats and environmental hazards, particularly roads, is minimal [***14c***]. Many green spaces are located along major infrastructural routes, and wildlife crossings are, despite being present in abundance, limited to specific locations. Consequently, the design cannot effectively reduce roadkill-related population declines.
- The design does not adequately emphasize habitat familiarity [***5d***]. The integration of various UGI's to accommodate diverse open space usage by humans in Rotterdam results in a range of different areas. Combined with incomplete implementation of specific marten design features, this increases the likelihood of marten venturing into urban areas to meet their needs.
- The differentiation between core areas and habitat edges is minimally addressed [***4h***]. A wide distribution of shelters and food resources may complicate the marten's socio-spatial organization and affect human-marten coexistence.
- The design lacks assurance regarding habitat requirements. The absence of clear guidelines for nesting sites and vegetation-based food resources especially means we cannot confirm that the proposed vegetation will provide adequate warm nesting locations or fruiting plants, even though this is highly likely [***2g*** / ***13d***].
- Large inhabitable areas for martens are created within Rotterdam, the size and shape of the designed habitat patches regards sufficient marten territories for the marten population [***8b*** / ***9d***]. Still, drastic changes to the grey-green integration (built areas and green space) in certain locations are designed, troubling the desired usage of dispersal corridors by martens [***10a***]. The wilding of greenery in general troubles the proposed open space systems design measurements. Elevated succession, for example, can reduce the presence of patchy vegetation that enables guided traversal through open space in the proposed coordinated manner [***3d***].
- Due to the large scale of the design, it lacks adaptation of detailed, small-scale design guidelines and criteria that. Although an individual's territory is large, are essential for creating a suitable habitat. The following chapter will address such issues on a smaller scale to improve the validity of the proposed principles, guidelines and criteria through designing

Figure 113 *Areal of the Dokhavenpark (Aerophoto-Schiphol, 2017).*

PAR

6

K-SCALE DESIGN

INTRODUCTION

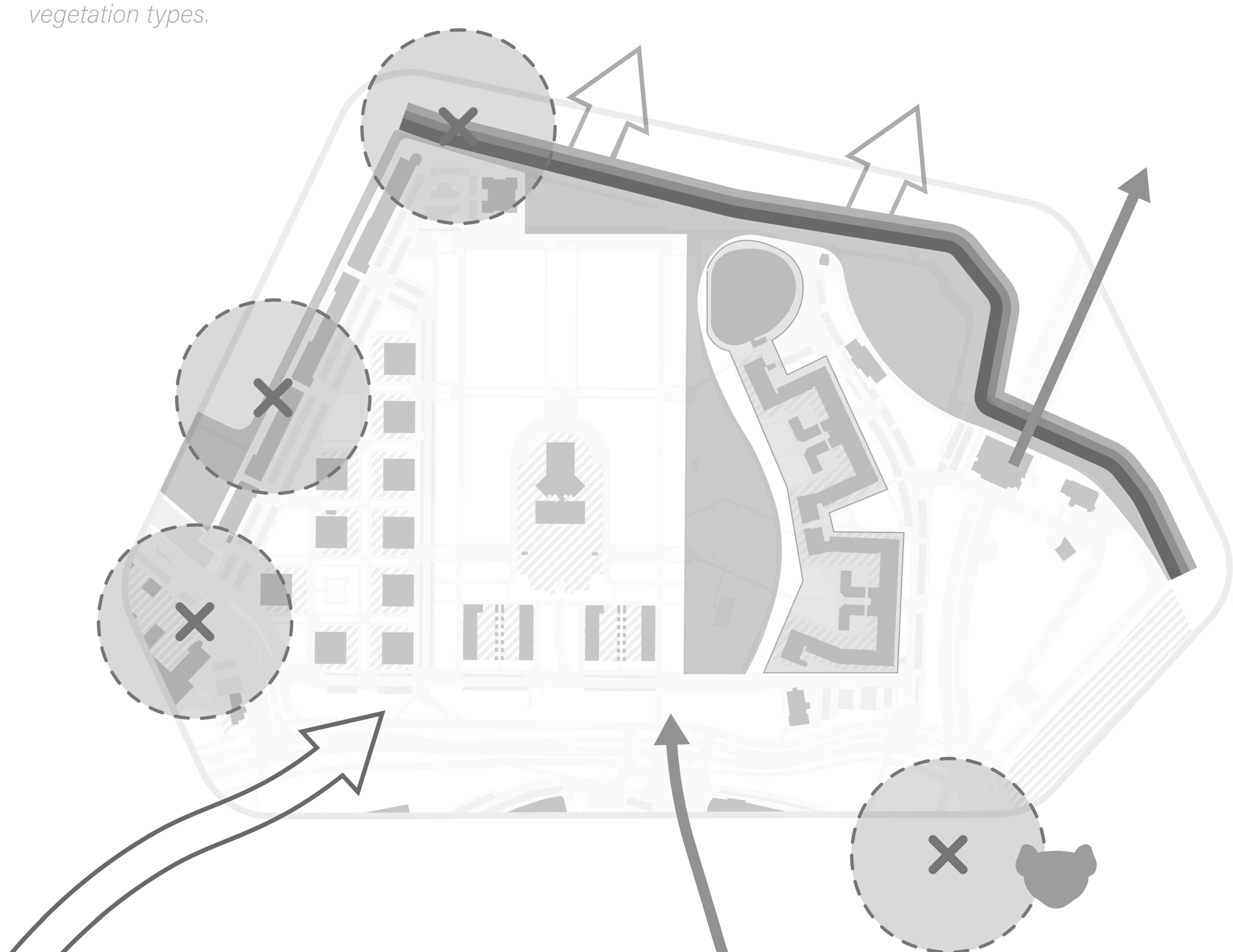
To explore a possible design for a marten habitat within urban green space, we zoom-in at an important part of Marten City: the Dokhavenpark (figure 113/114).

Dokhavenpark is a waterfront park positioned along the Nieuwe maas. Within Marten City the park is connected via the large Waalhaven corridor and narrow Wolphaertsbocht (figure 95, both 17's) corridor and the dual-purpose Nieuwe Maas tunnel crossing (11). It consequently functions as the last link between the urban areas north and east of the Nieuwe Maas and therefore is an important bottleneck for the marten pup dispersal. The north bank has been designated to have long embankments and both the Biesbosch (wetland) and Zuiderpark (riparian woodland) habitat reach the site. One marten has been sighted, but current inhabitation of the park is unlikely. Brown rats have been sighted west of the site in the industrial area, the designs will take this into account.

6.1 SITE COMPOSITION

A short site analysis of the different landscape layers (numbered according to figure 117 on page 140/141, as I, II, III, ...) has been conducted. During the expert assessment some first design sketch ideas on the marten-friendly redesign were produced. Here the experts, mainly the landscape architects, stressed the importance of analysing the original park design. This has therefore been given extra attention. The analytical layers depend where possible design opportunities arise for the different alternatives, or limitations that should be considered within all design alternatives (the latter being shown in italics within this chapter). Documentation on this and other landscape layers has been sourced from "Het nieuwe stadspark : opvallende vormen en pakkende scenario's" (Boersma et al., 1991). A site visit further substantiates this analysis. Based on the analysis different design alternatives have been developed.

Figure 114 *Position of Dokhavenpark within Marten City, including stone marten/brown rat sightings, corridors, natural quays and to-be-developed vegetation types.*



HISTORY

The former Dokhaven, which was filled in 1983, is one of the "overflow locations" designated to accommodate housing losses caused by urban renewal projects. The housing development was supposed to be combined with an underground water treatment facility (from here on out referred to as AWZI: 'AfvalWaterZuiveringsInstallatie'). However, due to disagreements over the design between the residents of Oud-Charlois (the neighbourhood to the south of the site) and the designers, development on the existing peninsulas of the Dokhaven continued whilst the rest of the site remains unaltered (see figure 115) (Boersma et al., 1991). As a result, there was no longer any cohesion in the construction and layout of the surrounding area. *A cohesive park design thus is a must for the new park design.*

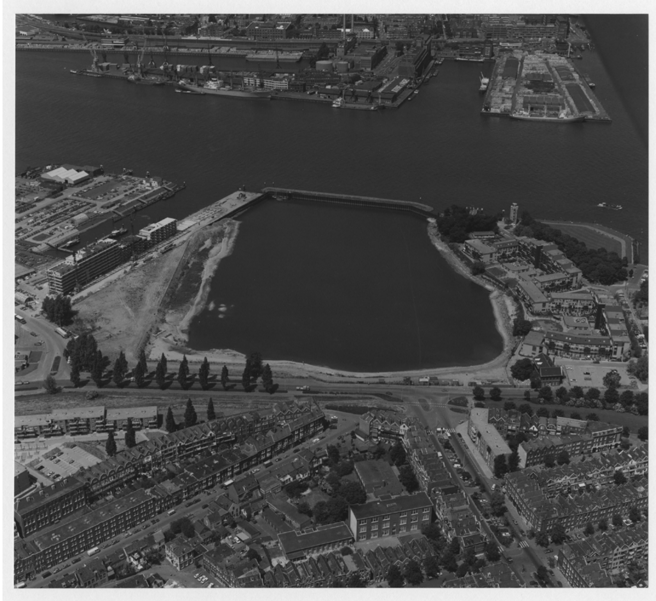


Figure 115 *Historical photograph of the Dokhaven before landfill (Stadsarchief Rotterdam, no date).*

ELEVATION (I)

Due to the presence of the wastewater treatment plant (figure 116), there is a soil layer with a thickness of 1 meter. This allows for one fully grown tree to be planted per 100 square meters in this area. *Alternatives should therefore aim at maintaining this ballast rule.*

WATER (II)

When comparing the elevation to the 60 mm precipitation map, lower areas with pooling can be distinguished. Certain infrastructures and the forest in the middle of the site are easily flooded. The embankment of the park remains completely dry. *Therefore, when choosing plants for different design options, they need to be considered and adjusted based on the groundwater levels of that area.*

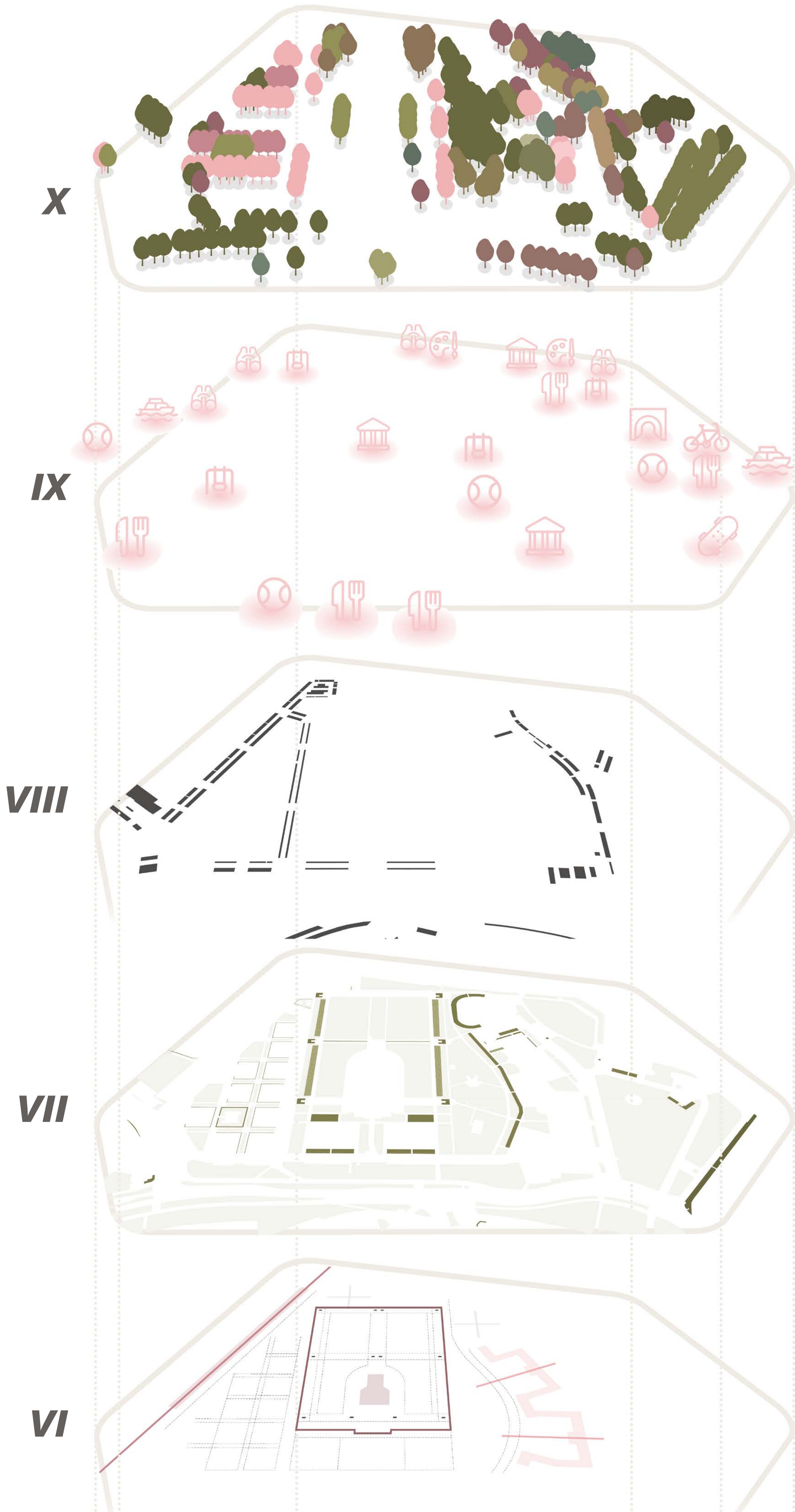
INFRASTRUCTURE (III)

When visiting the site, day-time trafficking was busiest at the Doklaan, the east-to-west road at the south of the site. In comparison to the night-time usage it seems that this road is the biggest threat to the marten dispersal. Other roads are mainly used for commuting and therefore in end-day rush hours can possibly form a threat due to overlap with starting marten activity. There is much local traffic. *Current mobility should not be diminished, especially commuting needs to be facilitated within each design. Other possible modes of transport can be suggested, as long as it is adequately offered.*

BUILDINGS (IV)

In the middle of the area, apartment blocks in a late 1970s style have emerged. Next to the gallery flat, three-story residential towers have been constructed. Two residential towers are situated along the river. Apart from the gallery flat en residential towers, all residences are equipped with a small (shared) private front or back garden. Given the number of residents in this area, there is still a lack of private green spaces. *The design will therefore focus on improving public green spaces for the residents. The relation between buildings and design should be carefully considered. Current housing availability and accessibility should not be diminished*

Figure 116 *Building of the AWZI (Hofmeester and Dijkstra, 1984).*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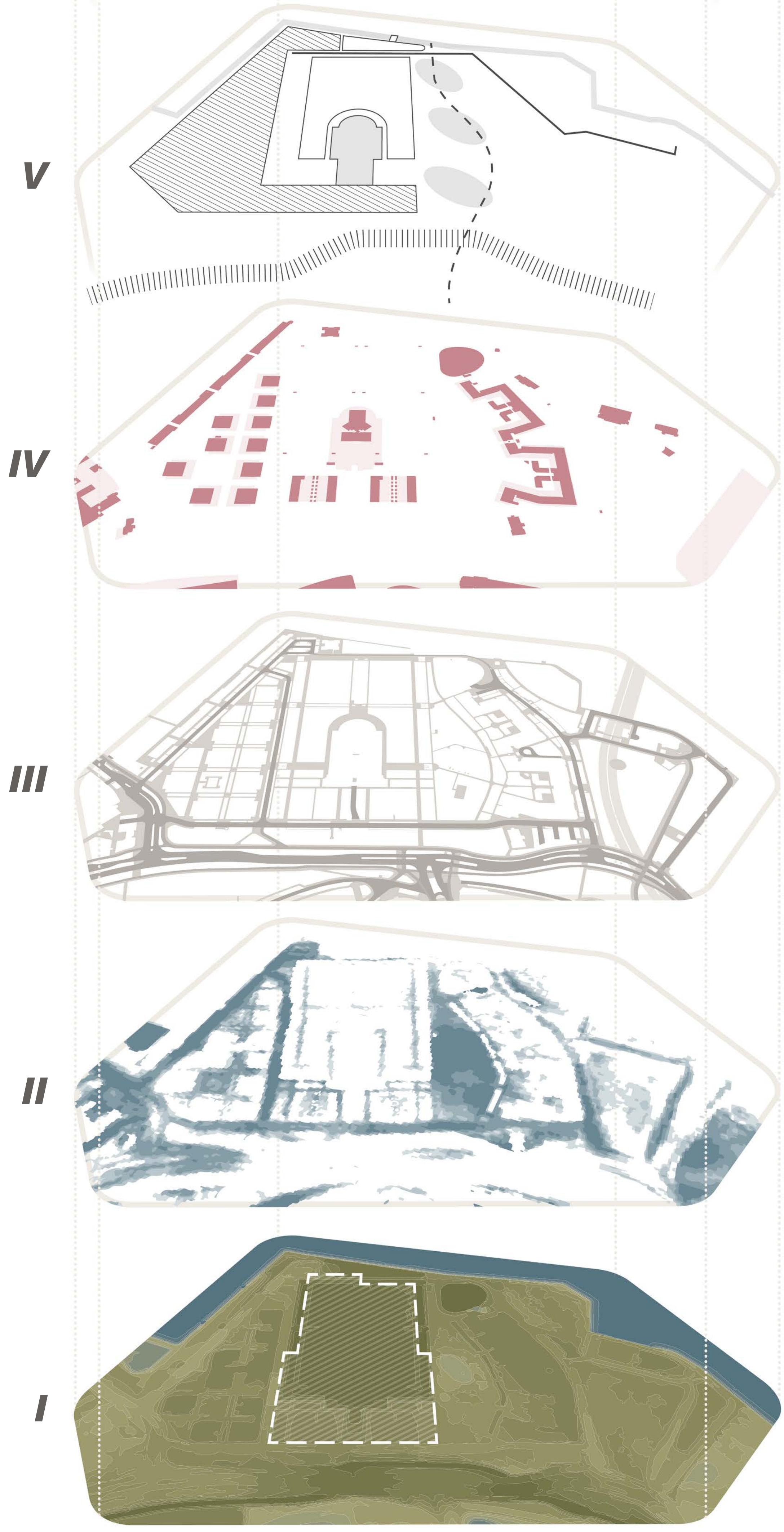


Figure 117 *Site composition of the Dokhavenpark*

ZONING (V)

Designer: Paul Achterberg (urban development department) / Client: Municipality of Rotterdam / Design surface: 5,5 ha / Design year: 1987 / Development year: 1987 – 1990

The original designers were given the assignment to design a park which strengthens the relationship between the neighbourhood of Oud-Charlois and the Nieuwe Maas, this happened along the curving path (figure 117) that is only partly realised, crossing through poplar groves. A powerful intervention was needed to create cohesion between the buildings in the area, the open play field was therefore added. The designers were also tasked with ensuring a view of the lively maritime traffic and the riverfront, this was aimed by creating a Nieuwe Maas balcony with a peer on the northside. New housing was to be centred to the south and west, to be connected with the Nieuwe Maas tunnel via a boulevard (Boersma et al., 1991). *Intentional zoning such as the view of the river and connection with the neighbourhood should be considered within all designs.*

LAYOUT (VI)

The shape of the AWZI was taken as the starting point to unify the residential areas with a strong layout. The rectangular rooftop garden forms the core of the park, with the large control building of the AWZI as a focal point. The author sees a resemblance to classical French baroque gardens. The symmetry of this ensemble is reinforced by 12 emergency exits, which must remain easily accessible within the design alternatives (Boersma et al., 1991). The symmetry is also visible in the arrangement of the new construction directly west of the AWZI. The design in the flanks follows its own lines. *The current lines within the park will be used as a basis and inspiration for the design alternatives. It is important that the emergency exits of the AWZI at least remain accessible.*

VEGETATION (VII)

Sparse planting has been used to accentuate the shape of the AWZI. Box hedges emphasize the equally important sightlines towards the water and create a sense of depth, which, according to the author, is a second parallel with Baroque gardens. Two groves of trees provide a backdrop that frames the view of the water. Groundcover vegetation is limited to green planting beds, hedges and rose bushes.

There are green roofs and many meadows, but to ensure a habitable green space much vegetation is thought to be needed. Existing vegetation should be integrated into the design wherever possible. *In general, vegetational coverage and density should increase to some degree.*

PARKING (VIII)

Parking spaces are mostly concentrated along thoroughfares within housing areas. Larger parking places are found southeast and northwest. *The existing amount of parking spaces should be retained, or other modes of transport need to be attractified and sufficiently facilitated.*

AMENITIES (IX)

A large lawn in the centre of the park has been designated as a play meadow, with space allocated for a football field. During the site visit, it appeared that this area was heavily used. In the rest of the site many different sport fields can be found. Another noticeable amenity within the city are its viewpoints. As many existing amenities and their respective location should be retained within the design. *If not, alternative recreational value should be created that reflect the current usage of the park.*

TREES (X)

A multitude of tree species can be found within the area that distinguish different spaces. For example between the three-story residential towers exotic prunus species can be found, and at the waterfront swamp cypresses are planted. Many non-native species can be found and there are large differences between tree ages and thus tree sizes. *Existing trees can be used for the habitat provision based on their location and characteristics.*

SOIL

Due to the phased filling of the area with land, there is a highly varied soil composition in various places. Soil surveys from municipal GIS data reveal a profile rich in peat and clay. Wetland natural habitats are therefore considered potentially developable there. *In general, when choosing plants for different design options, they need to be considered and adjusted based on soil conditions of that area.*

6.2 DESIGN ALTERNATIVES

Based on the level of detailing missing in the masterplan, a set of different design alternatives for the Dokhavenpark have been created, showcasing the variety in ways to adapt urban open spaces to make them more liveable for stone martens, adapting a different level of marten-adaptation and human-adaptation, as visualized in figure 118 below. After showing the respective design alternatives, the writer has made a design description of each alternative. This design description aims to clarify the design concept with the help of an inspiration map. This map shows how, apart from incorporating site-specific design requirements of 'site composition,' the analysis also provided a distinct inspirational basis for each design alternative. In doing so, site characteristics are connected with the specific design needs for martens. The plan drawings of the alternatives themselves, are meant to be explored. References to design elements for martens (and humans), including the selection of UGI's and wildlife crossing that differentiate and respectively answer SRQ3, are found within the maps.

After the design descriptions, a brief elaboration on the design characteristics follows, this is done according to the key concepts researched: habitat requirements; brown rat predation; human-marten co-occurrence; open space system; and Urban Green Infrastructure. This text is accompanied by a crossection that contextualizes the characteristics of each design, supported by direct references to the design criteria (appendix 1) important for that corresponding alternative. Appendix 7 and 8 map how the design guidelines regarding SRQ1/2 are applied within the area more specifically.

Further detailing of design differences, and coincidentally their respective strengths and weaknesses, are described within the self-assessment

The designs are based on native forest types as per Natura 2000 habitat classifications. By selecting indicator plant species for each forest type, the goal is to enhance biodiversity within the park. Indicator species specific to each forest type are also drawn to the area. Four key species, identified in the profiles for these habitats, are chosen for their potential to control brown rats and are featured at the end of each cross-section. Plant choices are based on flowering season and crown density, and include representatives from all vegetation layers discussed in this thesis. Additionally, two fruit-bearing plants are selected to match the vegetation and habitat type, promoting characteristics beneficial to the stone marten.

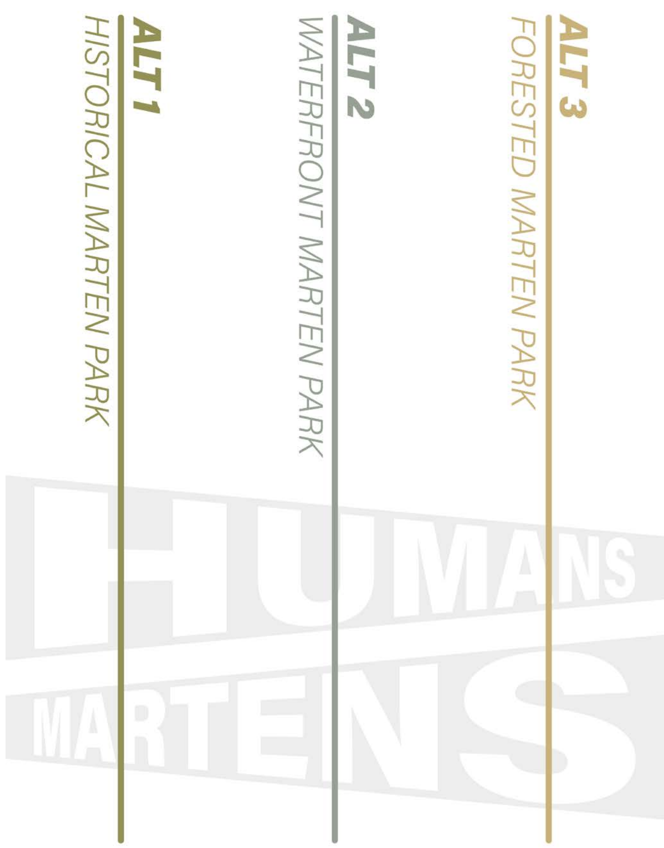


***Figure 118** Differences between the focus of the park-scale design alternatives.*

1

HISTORICAL
MARTEN PARK

The first park-scale design alternative respects the original park design by Paul Achterberg. This alternative incorporates the proposed zoning (V) of the site by strengthening and adding tree groves to create highly inhabitable areas for stone martens. The partly realised curvilinear connection between Oud-Charlois and the Nieuwe Maas is reconnected as marten corridor and infrastructural connection along these habitat edges and over the Doklaan by means of a fauna-friendly viaduct. The view of the lively riverfront is maintained through the open playfield that connects with a riverfront beach and boulevard, creating a more accessible quay for stone martens.
The layout (VI) of the original design is incorporated within the first alternative. The existing geometry and linearity within the layout of the parks design, mainly vegetation (VII), are solely strengthened via addition of a multitude of vegetational layers.

The north-west oriented hedgerows that were designed to direct the view towards the Maas, have been expanded with a tree lane and ground cover planting border to create two robust dispersal corridors throughout the site.

Another example is the addition of a large foraging site within the centre of the park by means of an orchard. The formal baroque-like layout of the Dokhavenpark can be maintained whilst improving the food availability for mammals both crossing and inhabiting the area.

Because of the parks geometry and minimal space availability mostly L-UGI's have been used such as green verges, hedgerows, tree lanes and other sparsely vegetated areas using grasses, shrubbery and ruderal vegetation. This alternative explores the usage of simple wildlife overpasses by integration of canopy bridges and hop-overs. These and other spaces aim at maintaining all existing amenities (IX) and adding more. The improved accessibility and parkability (VII) of this design alternative reflect the increased human usability. Recreational areas, housing blocks (IV), roads (III), parking spaces (VIII) and adjoined low habitat quality areas frequently create strong divisions between human and marten-occupied spaces within the Dokhavenpark. This alternative therefore aims at primarily providing an enhanced park experience for visitors whilst still creating liveable spaces for stone martens.

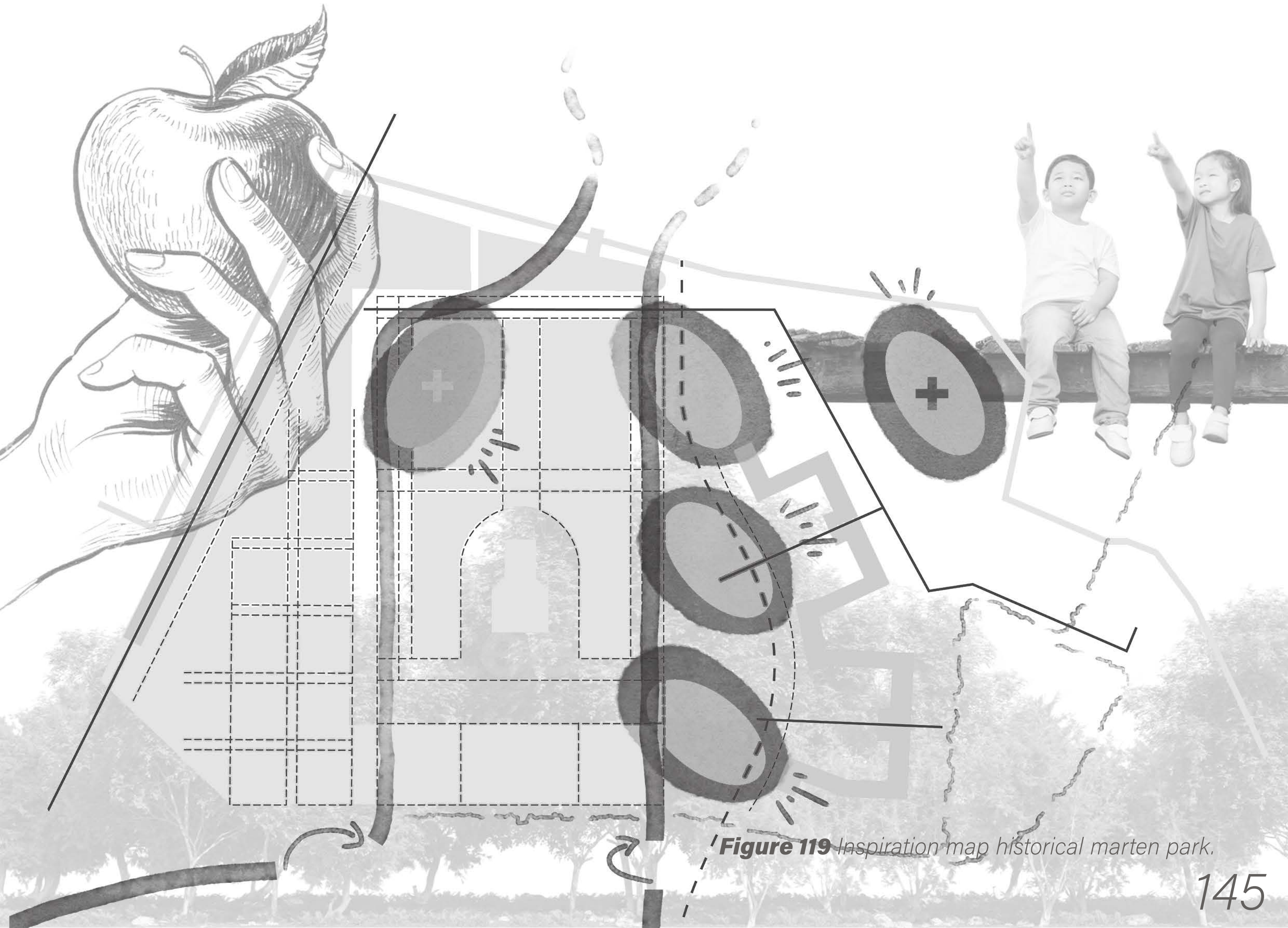


Figure 119 *Inspiration map historical marten park.*

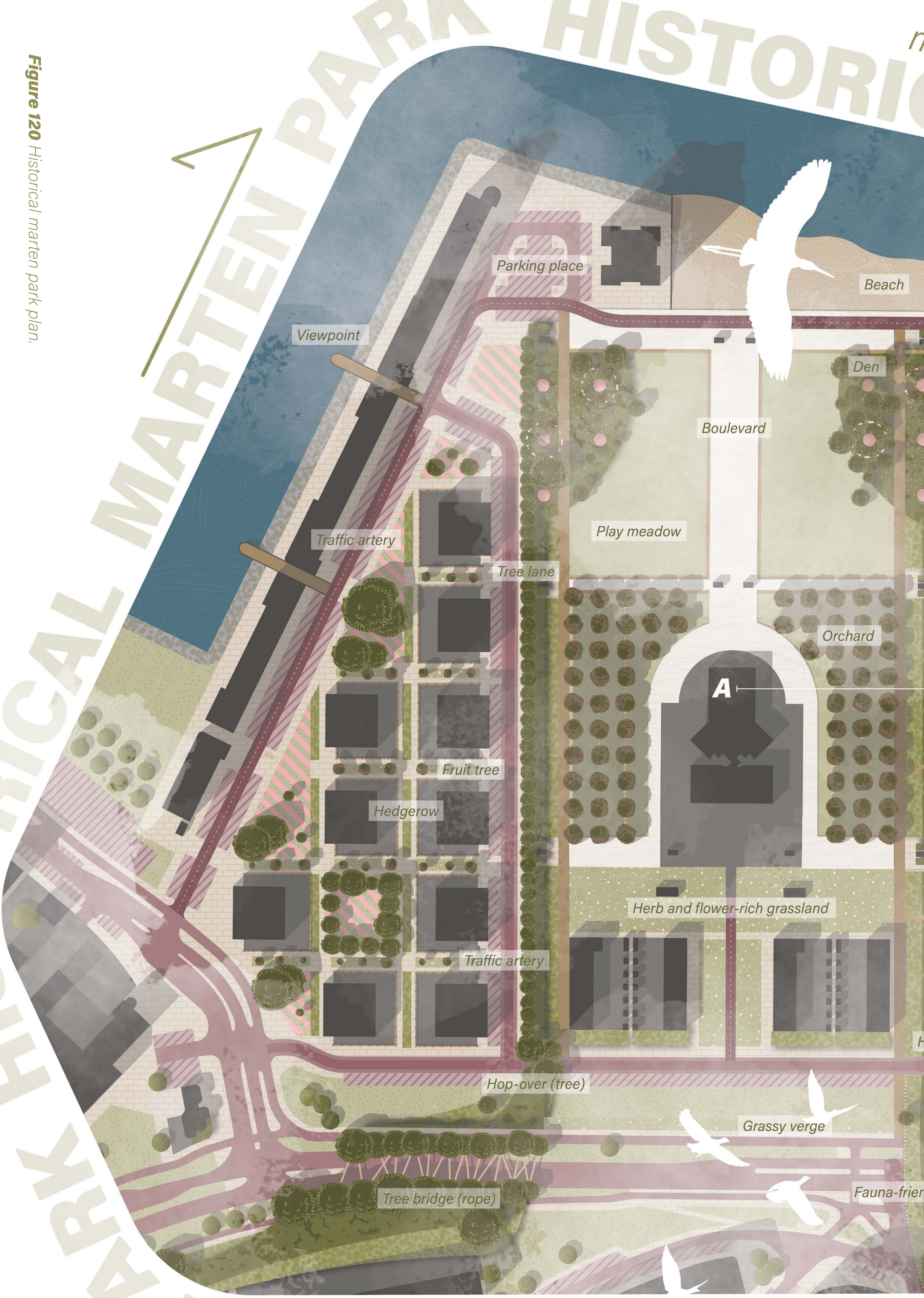


***Figure 120** Historical marten park plan.*


meters
0
50
100
200
CAL MARTEN PARK HISTORICAL MARTEN
Car routing
Riverside board
Berry bush
Tunnel with wildlife crossing
Nest
Existing trees
A
Green quay
New trees
Paved walkpaths
Private property
Recreational space
Tree grove
Flowery field
lop-over (shrub)
ndly viaduct

HABITAT REQUIREMENTS

As the most human-adapted design, the historical marten park incorporates a population density and male-to-female ratio consistent with research, which suggests a ratio of one male to two females within this 30-hectare park. Consequently, 20 marten heaps, 10 of which are suitable as nests, are distributed throughout the park's densely vegetated tree groves scattered throughout the park's open space. Within a small area, loose nesting material and food resources are available here. The extensive edge habitat is lined with foraging sites, such as 'plukfruit' (pick-your-own fruit), as shown in the cross-section. Despite the extensive recreational use and traffic, which borders various plausible marten habitats, a few year-round lush dispersal corridors connect most of these habitats along road verges and park edges.

BROWN RAT PREDATION

Dispersal corridors are lined with evergreen vegetation and plants toxic to rats. The minimal shrub and herb layers within edge habitats make the stone marten's core areas the most desirable for rats within the historical marten park (see cross-section). Therefore, the first alternative focuses on guiding the brown rat population distribution through vegetation characteristics to areas where the rats will encounter the highest predation pressure. Marten foraging sites feature fruiting plant species that are inaccessible to brown rats.

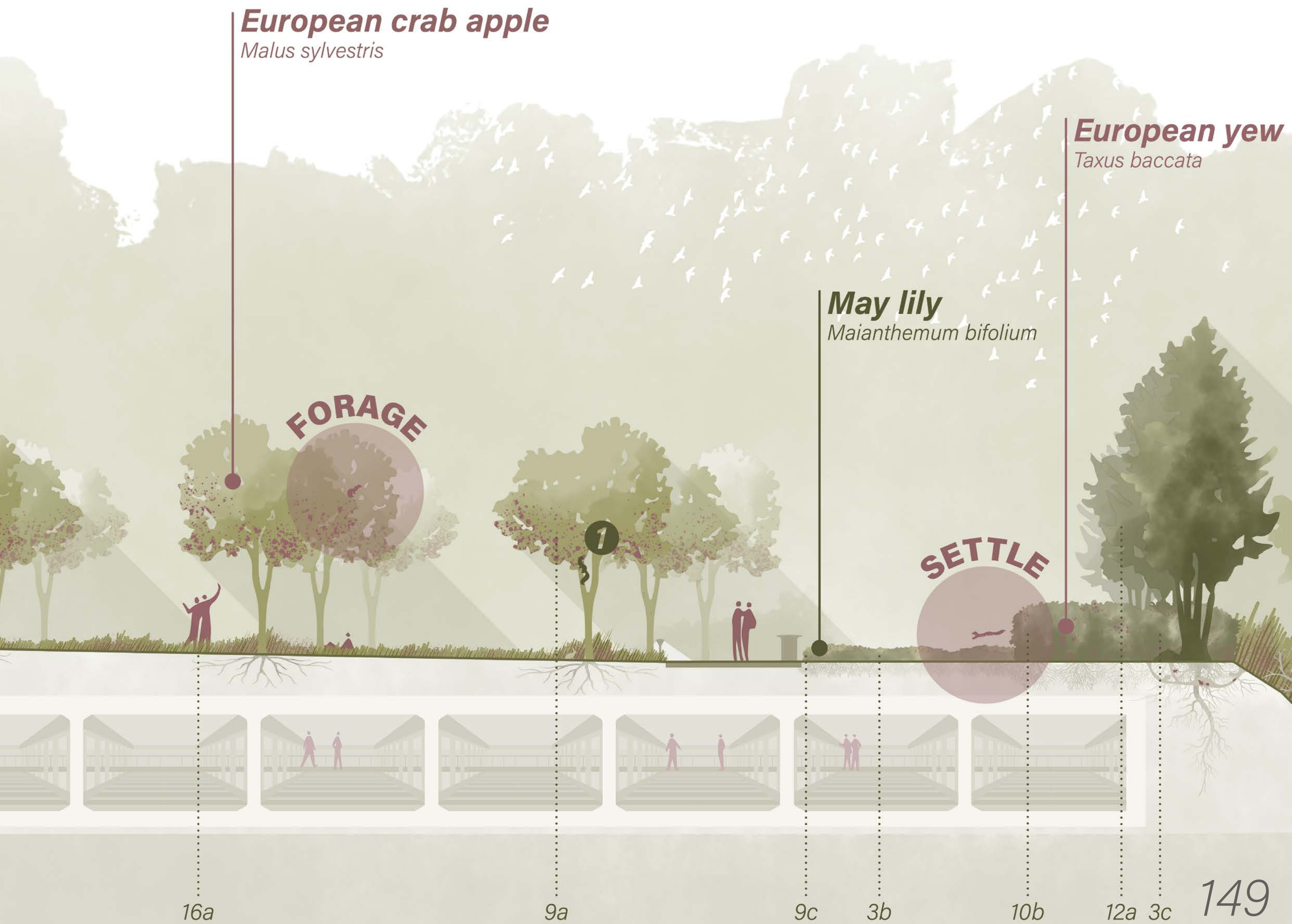
Figure 121 *Crossection historical marten park.*

HUMAN-MARTEN CO-OCCURRENCE

The first alternative significantly reduces the high-quality habitat area to five smaller zones and offers limited shelter opportunities within the edge habitat. Factors such as infrastructural connections, parking availability, building densities, and amenities restrict the areas with minimal stress levels for martens to the beforementioned tree groves that are minimally convoluted and abruptly shaped. Consequently, the attractiveness of denning or nesting sites and the limited accessibility of housing diminishes the likelihood of building denning.

OPEN SPACE SYSTEM

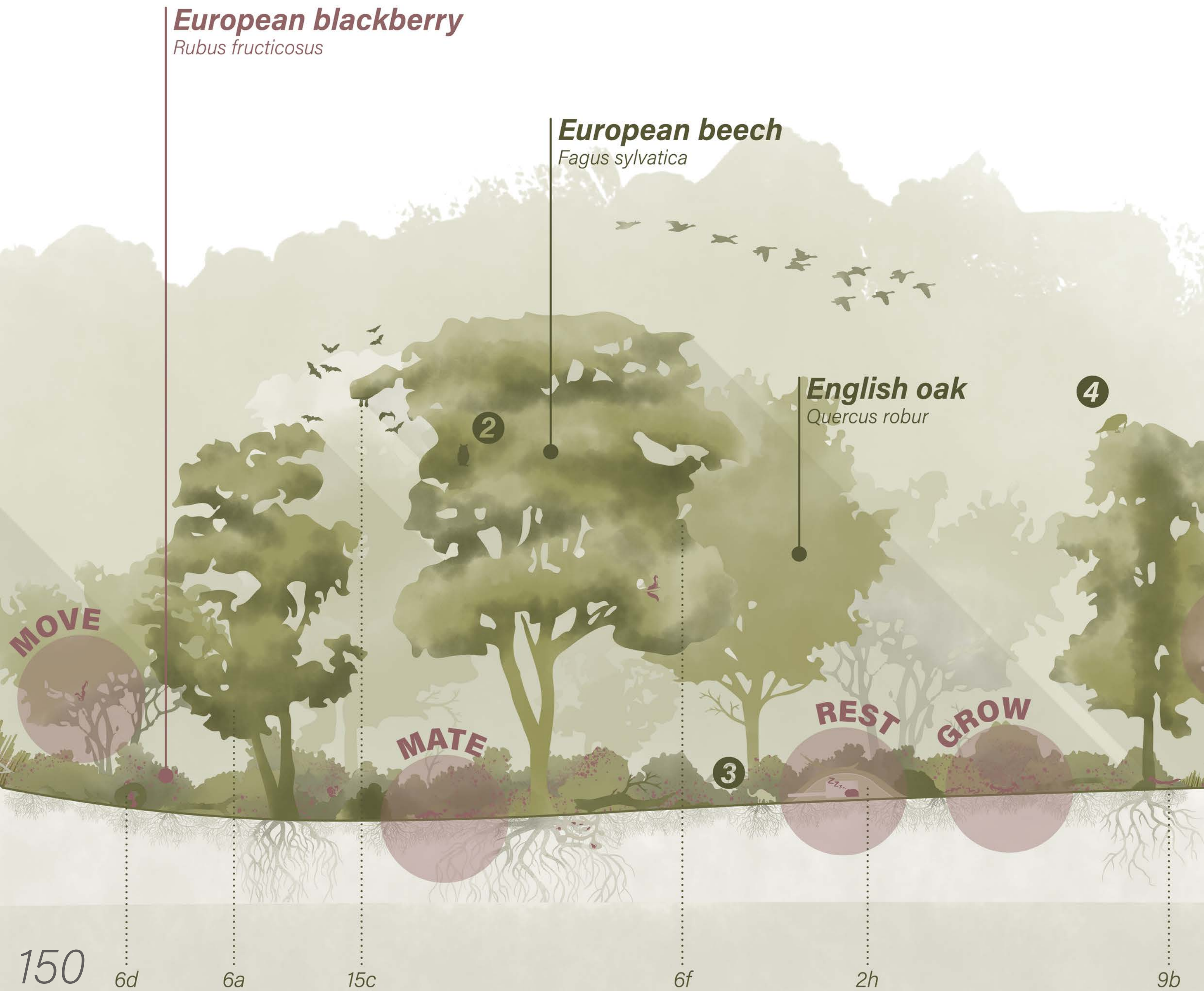
As mentioned, habitat edge design is well-represented. Although edge habitat partially meets habitat requirements, it is unclear how the existing habitat patch design divides female martens, particularly since five core areas are allocated for just two females. Access to these habitats is provided through wide, often multilayered corridors, as shown in the cross-section. The overall network density is low.



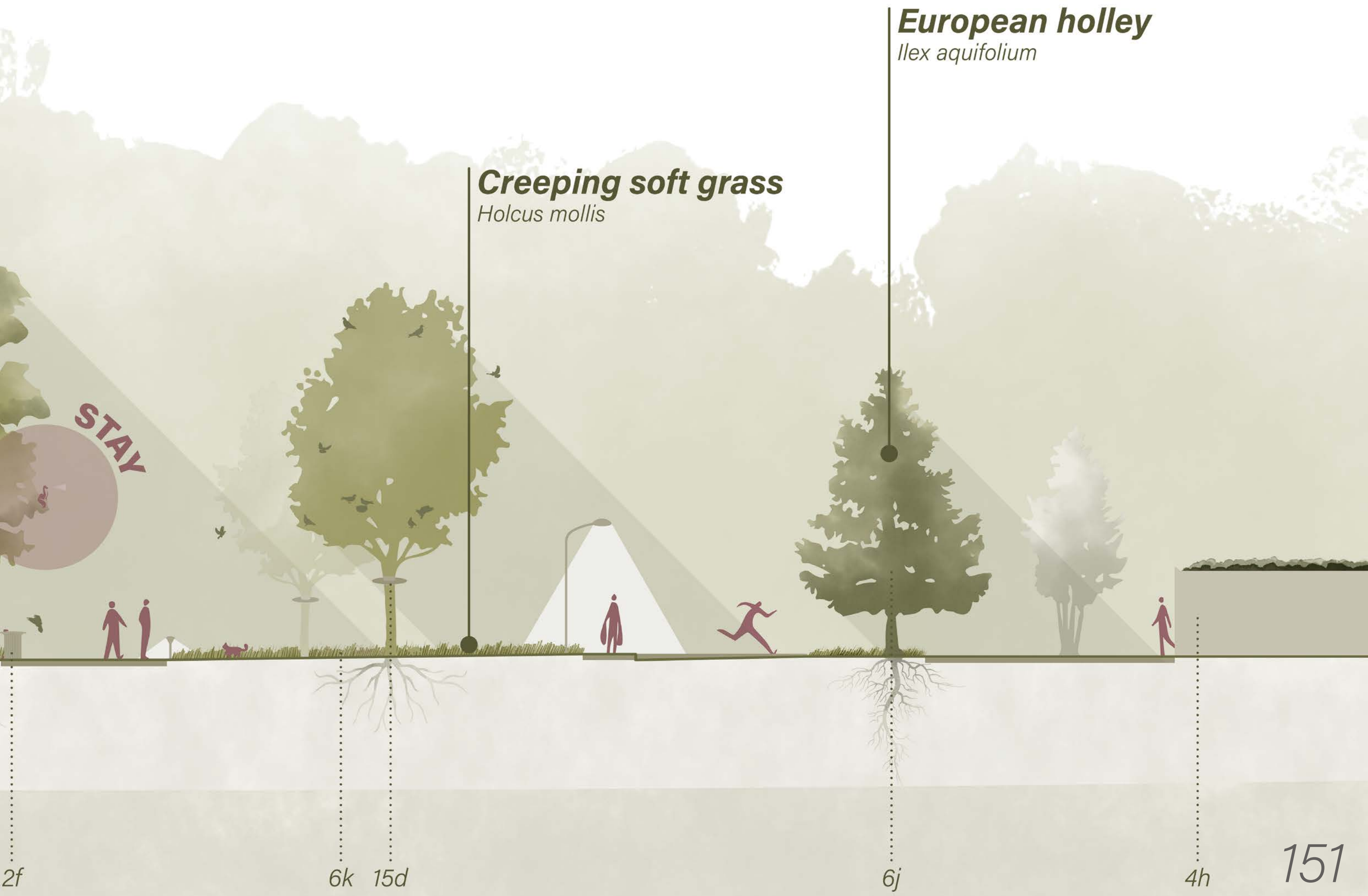
URBAN GREEN INFRASTRUCTURE

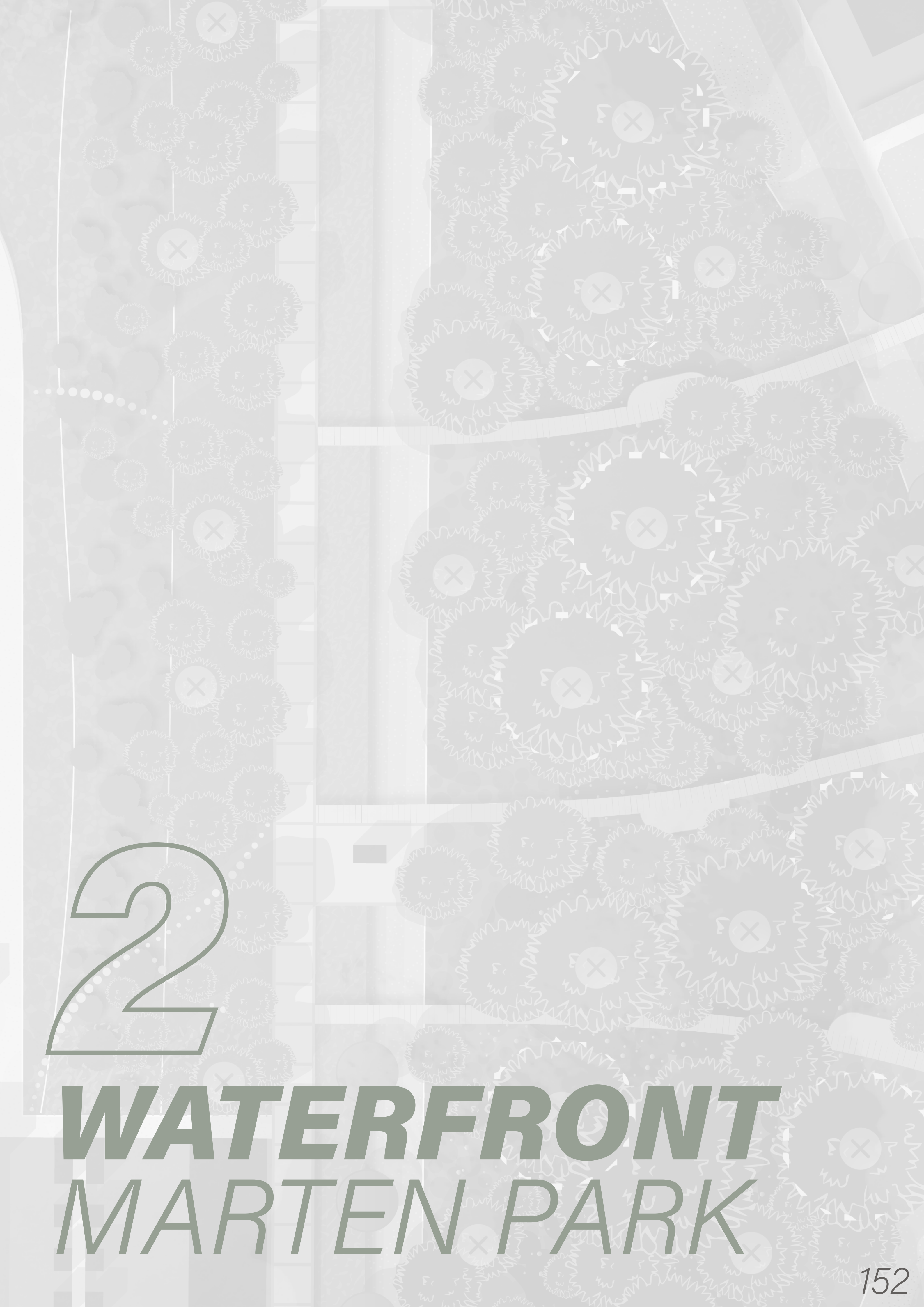
The historical marten park utilizes plant species characteristic of the 'beuk-eikenbos met hulst' forest type (Natura2000, 2008b), a widespread vegetation type in the Netherlands that adapts easily to various soil conditions and groundwater levels. The plant species include both deciduous and coniferous vegetation, providing excellent food and shelter year-round. Connecting the design's L-UGIs are simple wildlife overpasses that incorporate the designed vegetation. Solitary trees provide habitat for avian species, including birds of prey.

This human-occupied park design inadvertently attracts domestic animals such as house cats, but the core areas offer ample shelter for stone martens. Lighting within the park's design, as shown in the cross-section, is used to separate private human areas from marten-inhabited zones.



1. **European polecat** *Mustela putorius*
2. **Tawny owl** *Strix aluco*
3. **Domestic cat** *Felis catus*
4. **Common buzzard** *Buteo buteo*





2

WATERFRONT

MARTEN PARK

The second park-scale design alternative makes use of the site's relation with the Nieuwe Maas river. The soil typology, elevation level (I) and hydrodynamics (II) all aim at ideal conditions in certain parts of the site in which to develop wet nature. Even the tree species that are planted (X) along the waterfront or within the lower situated areas seem resistant to high groundwater levels (and periodical flooding).

Within the Dokhavenpark, space is created for the river water to influence natural development. A variety in ground elevation and water levels ensures the development of multiple vegetation types. Inspiration for this nature development is taken from the 'River as tidal park' future perspective (Strootman landschapsarchitecten, 2016) and Tidal park Keilehaven (De Urbanisten, 2018). As a result, suitable habitats for stone martens can develop at the edge of the area, making the dispersal of pups across the river more appealing.

To connect these BGI's and watercourses with each other and the surrounding corridors, wildlife underpasses are primarily used. Dual-purpose crossings enable safe, undisturbed dispersal of both martens and water underneath grey infrastructure.
The second alternative reduces the area available for human use, but it combines and concentrates the current amenities in the area around two traffic arteries. These two traffic arteries are the only car connections with the housing in the park, hence minimizing stress factors for stone martens on the northern flank of the area.

Although the area is strictly divided between marten and human-used places, slow recreation is realized within the rain gardens, attenuation ponds, and along the waterfront. Meandering boardwalks with numerous seating areas, viewpoints, fishing spots and stepstones accommodate nature tourism in this tidal park without disrupting stone marten's day rest.

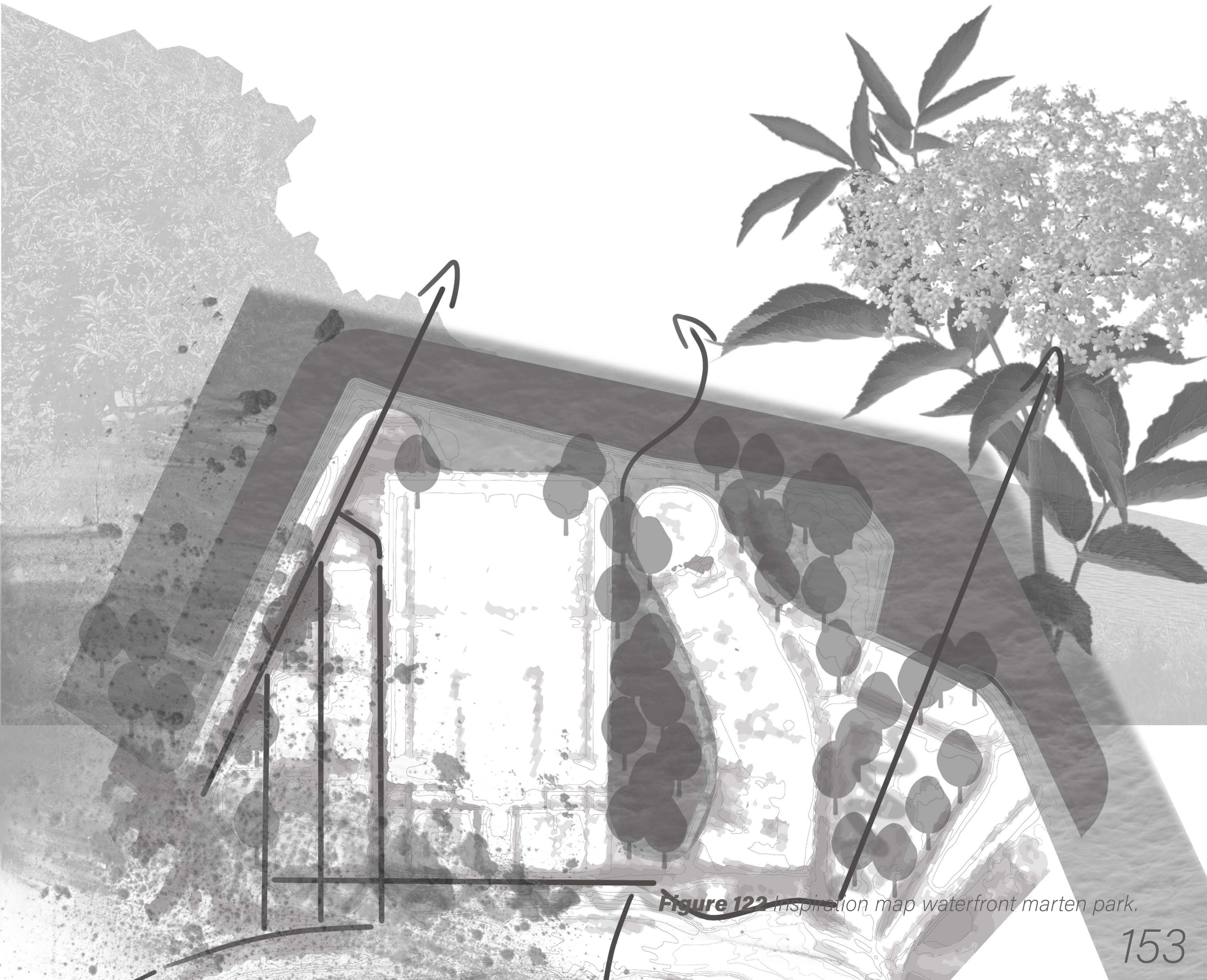


Figure 122 *Inspiration map waterfront marten park.*

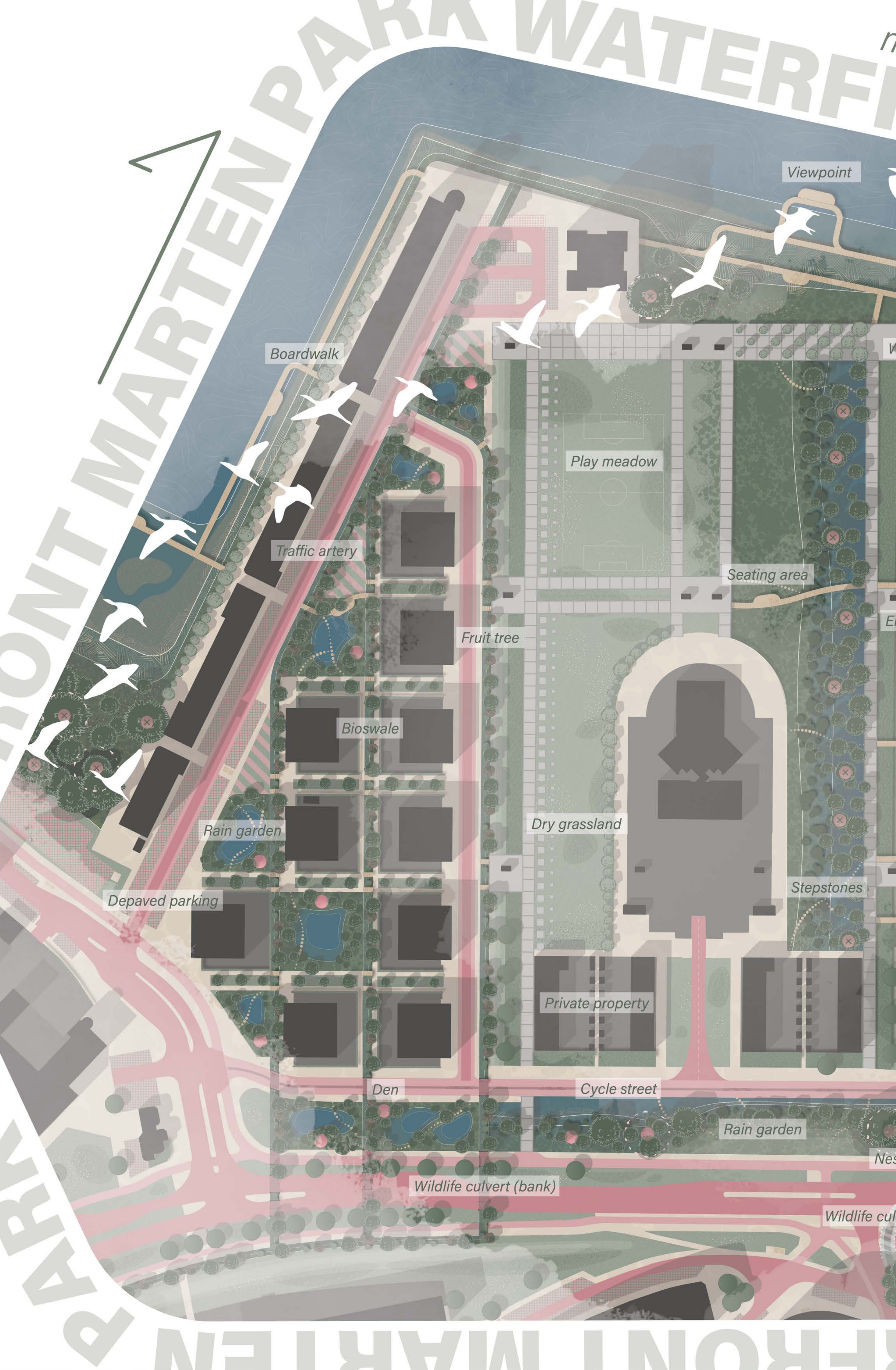


Figure 123 *Waterfront marten park plan.*

meters
0
50
100
200
RONT MARTEN PARK WATERF
NT MARTEN PARK
Reed vegetation
et grassland
Elevated nest
B′
B
Tunnel with wildlife crossing
levated den
Traffic artery
Berry bush
Wet understory layer
Fluvial forest
Existing trees
Fishing spot
New trees
Attenuation pond
vert (ledge)

HABITAT REQUIREMENTS

The waterfront marten park establishes four large core areas designed to house four female martens. The design includes 40 dens, 20 of which are suitable nests, and most of these territories connect to the river by integrating into a fluvial forest. The natural areas are divided by two major traffic arteries, adjacent housing blocks, and recreational spaces. Most permanent shelters are tree-bound (see cross-section) due to moist soil conditions. Despite this, liveability and traversability in these high-quality habitat areas (also extending to rainwater-fed green spaces within the park) are excellent, thanks to multilayered, patchy vegetation and sporadically placed marten heaps within the park's corridors.

BROWN RAT PREDATION

Heightened prey availability results from the extensive overlap of marten territories with favourable environmental conditions for brown rats. Most importantly, marten shelter and foraging sites are situated close to water bodies. This proximity is locally enhanced by designing small ponds near marten dens and nests (see cross-section). Direct predation on the riverfront is likely lower due to the tree-bound marten shelters.

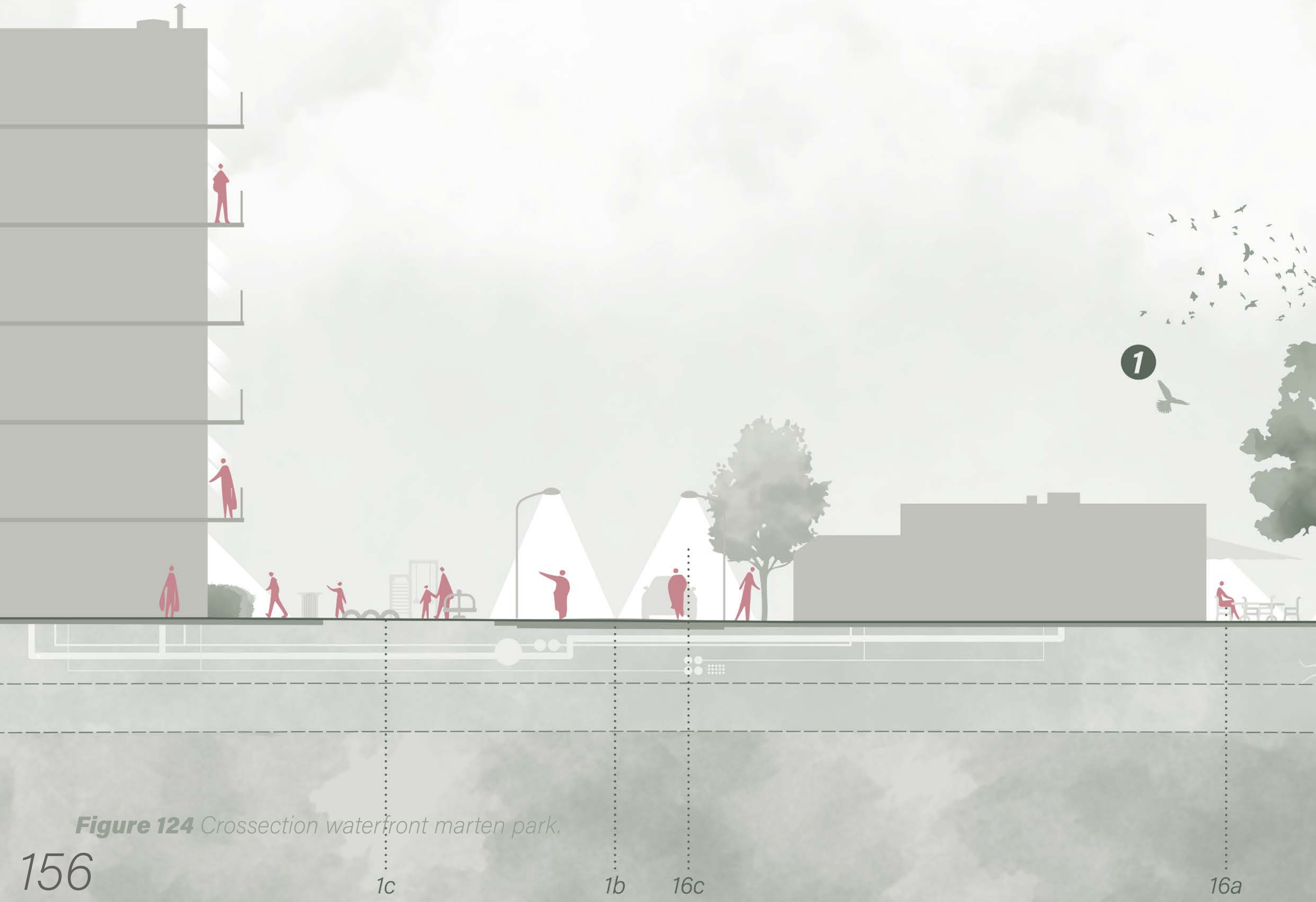


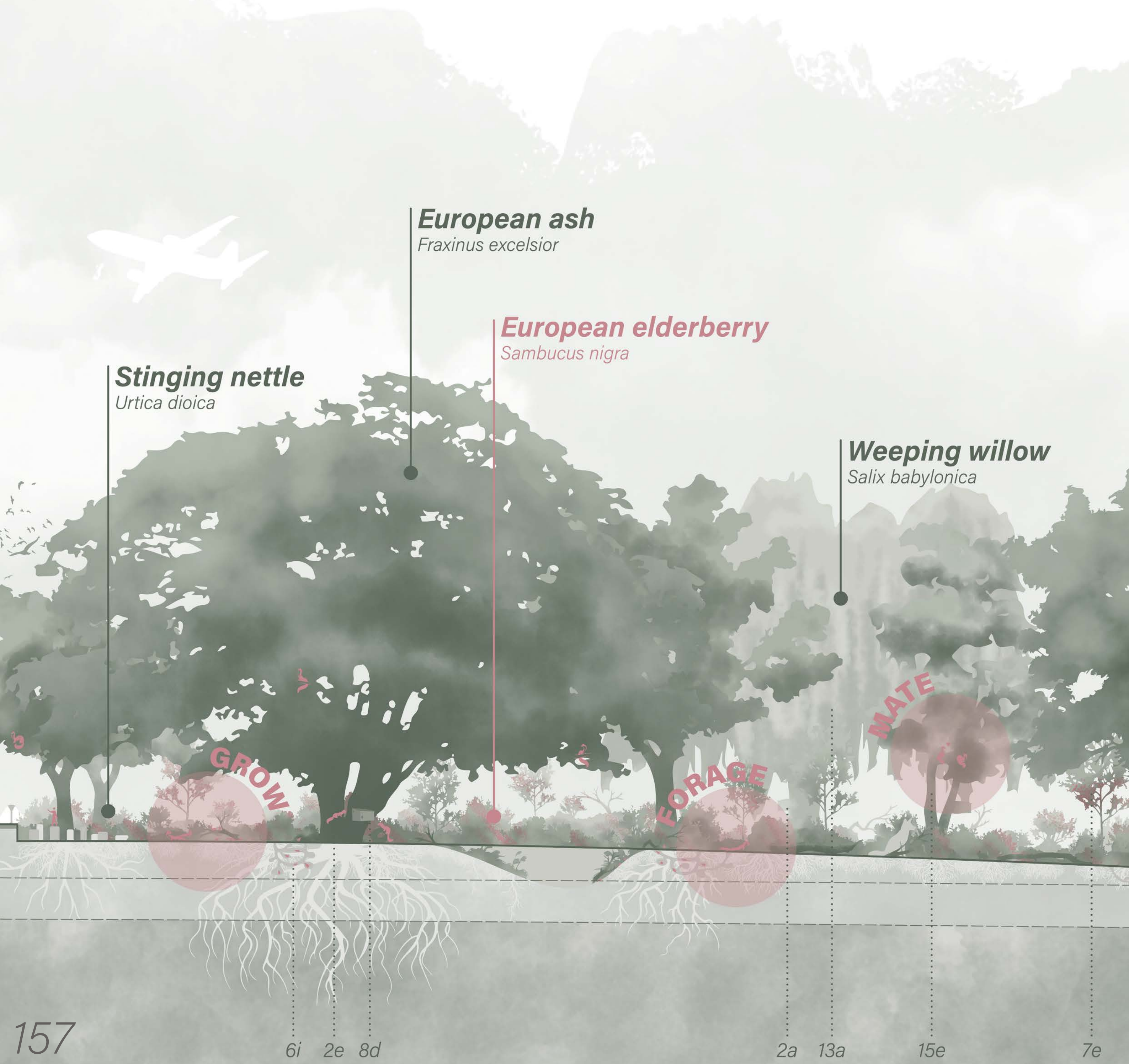
Figure 124 *Crossection waterfront marten park.*

HUMAN-MARTEN CO-OCCURRENCE

The second alternative aims to explore the edges of the proposed open space system by providing den and nesting sites, drinking spots, and additional food sources within the high-quality corridors and adjacent green spaces. Ground-based marten heaps in rain gardens and attenuation ponds offer habitat close to private properties, that strive to provide more isolated and insulated shelters than buildings. However, the concentration of high-quality areas along the riverbank allows for a significant differentiation between socially and ecologically important spaces, in respect to the larger core areas. This division is clearly visible in the cross-section.

OPEN SPACE SYSTEM

Within the design, low habitat quality dividers separate recreational spaces, such as the play meadow, from dense forestry accessible only via boardwalks. This creates a significant distinction between human-centred and marten-centred spaces. There is also variation in patch-edge ratio and shape at certain locations. The network density of dispersal corridors largely responds to the urban grid, with bioswales placed in smaller areas and attenuation ponds in larger spaces, allowing for extensive overlap of dispersal corridors and marten habitats.



URBAN GREEN INFRASTRUCTURE

The poor drainage in the area makes it ideal for creating green rainwater collection and drainage spots where conditions such as soil depth and underground infrastructure preclude the development of fluvial nature. B-UGIs, such as rain gardens, bioswales, and attenuation ponds, can support a small number of individual martens due to their dense habitat provision. Additionally, as L-UGIs, these structures can effectively guide the animals through the area.

A moist alluvial forest, characteristic of the 'Essen-iepenbos' forest type (Natura2000, 2008a), lines the northern border of the waterfront park. This creates attractive areas for slow recreation that minimally disturb marten habitats due to reduced lighting and elevated infrastructure, as shown in the cross-section. The forest type provides space for riparian animals, such as migratory birds, to inhabit the waterfront park, benefiting from the biodiverse plant population and the availability of natural landscape elements like driftwood.

meters

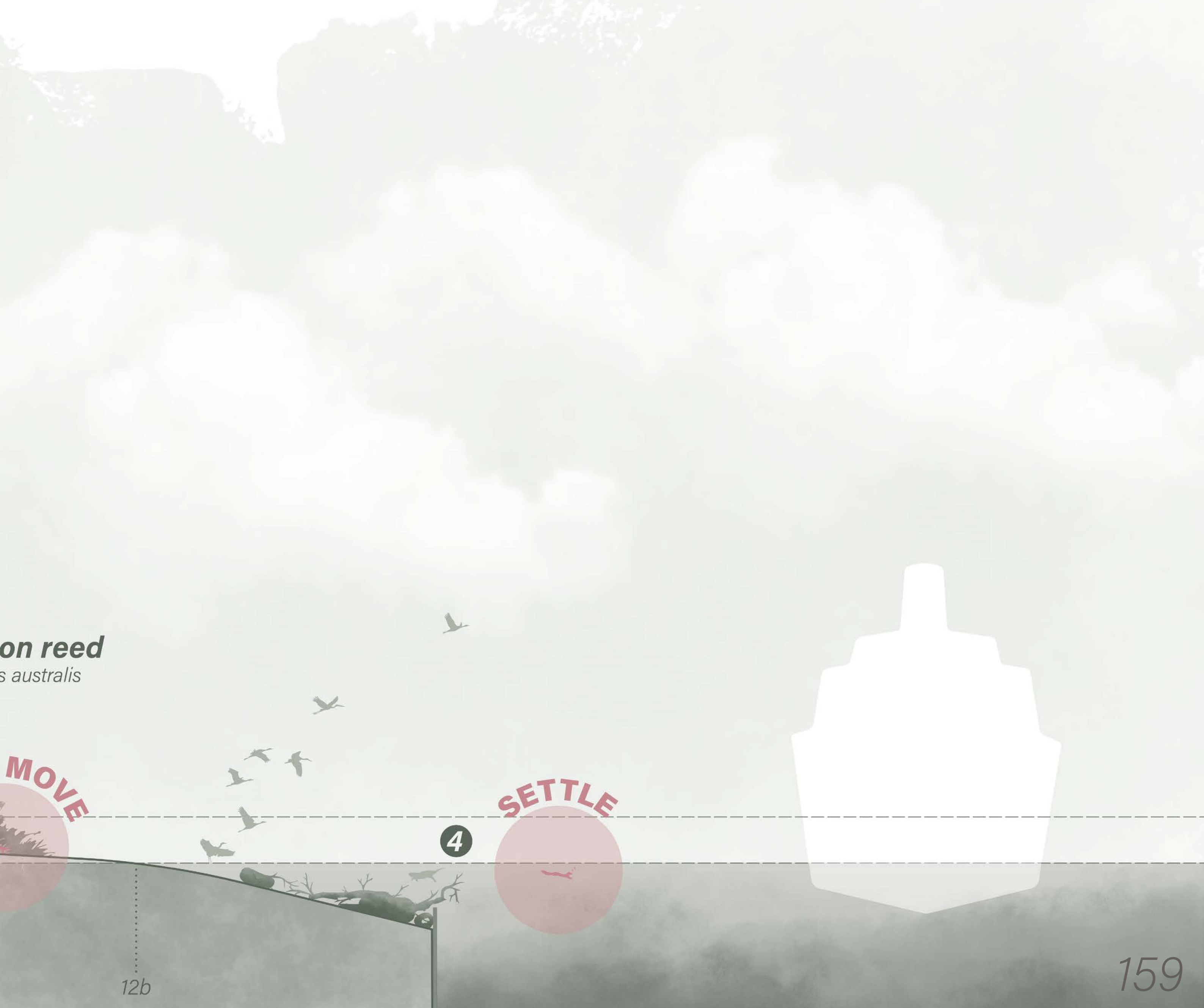
0 30

❶ ***Eurasian hobby*** *Falco subbuteo*

❷ ***Osprey*** *Pandion haliaetus*

❸ ***Barred grass snake*** *Natrix helvetica*

❹ ***Eurasian otter*** *Lutra lutra*



3

FORESTED

MARTEN PARK

The third and last alternative envisions a fully naturalized Dokhavenpark. With the RWZI building and location central within the parks design. A circular pattern with radii provides structure to the layout of the park. Nevertheless, these shapes simply serve as a guideline for developing a dense, wild forest vegetation with a succession that extends to the edges of the area. Habitat requirements for many martens will be abundantly present throughout the area. This plan aims to establish as much correlation as possible with the areas inhabited and/or used by stone martens in non-urban environments.

The above-ground and underground structures of the sewage treatment plant (I) must be removed to accomplish this. The main building (IV) and the house adjacent to the south will be vacated to allow stone martens to nest safely. The underground installation will be filled with soil necessary for the rooting of plant species appropriate to the forest type being developed.

The entire area will remain unmaintained, apart from the slow recreation facilities sporadically located within the park. These are connected by unpaved, meandering forest paths. The park is completely car-free (II); visitors and residents can park in the parking hubs (VIII) to the east and west of the park and then proceed on foot or by bicycle to their homes or, for example, their allotment gardens. A dedicated cycling and walking path is intended to guide traffic through the area as quickly and easily as possible.

A high variation in open and dense areas ensures a park-wide distribution of habitats and corridors. In both radial and concentric directions, there are nests, dens, foraging sites, drinking spots (II), and safe movement paths that frequently overlap with one another. All natural UGI's are found with this design alternative. Wildlife crossing is enhanced via speed limit reduction at the Doklaan and expansion of the street's profile with plant coverage for crossing martens. This alternative does not focus on providing a select number of safe wildlife crossings but rather on ensuring minimal barrier effects that can be safely traversed along its entire length.

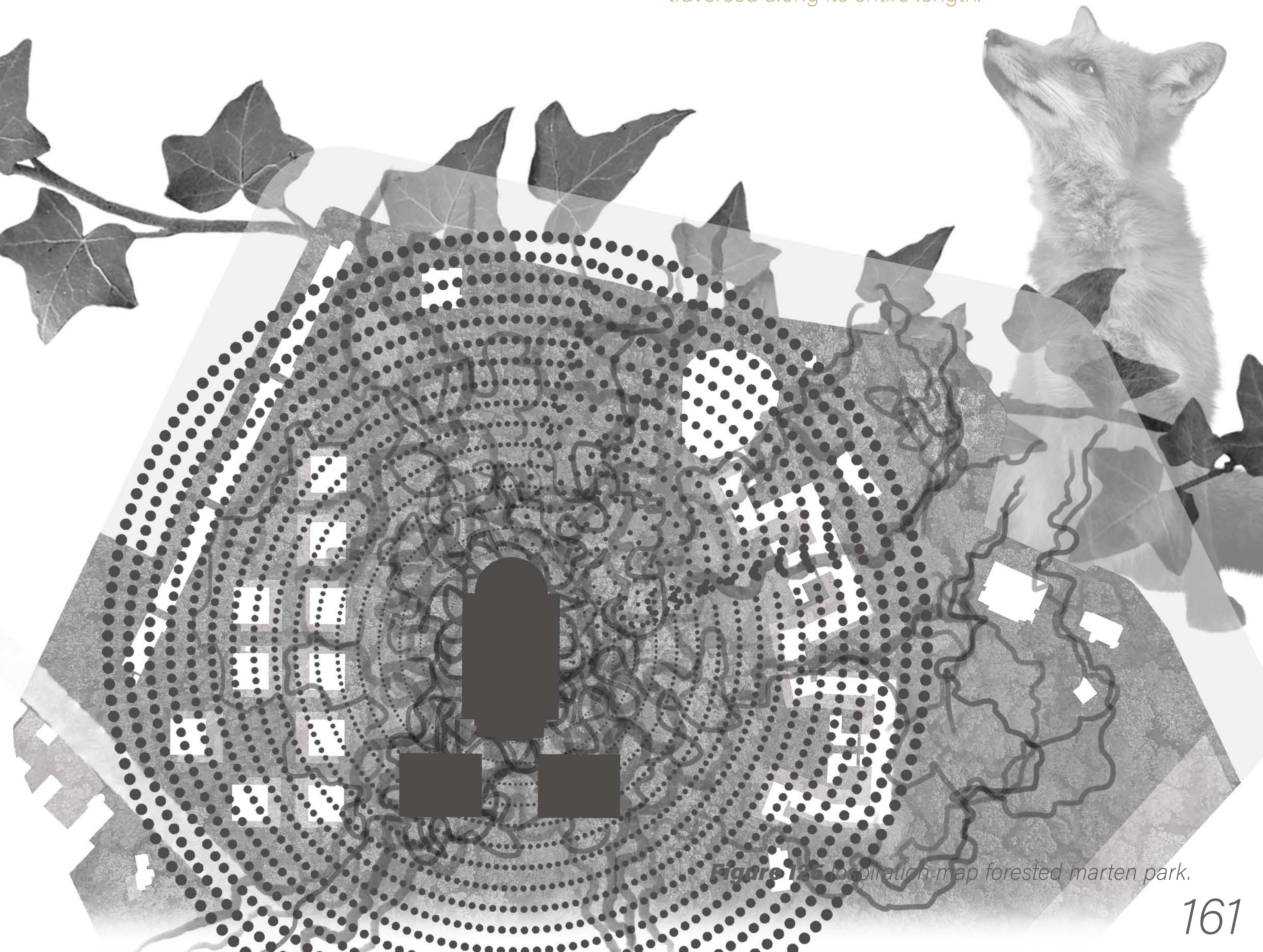


Figure 125 *Inspiration map forested marten park.*

Figure 126 *Forested marten park plan.*


meters
0
50
100
200
Walk bridge
Walking/cycling highway
Seating area
Stepstones
Ecoduct
Natural river bank
Private property
New trees
Bicycle parking
Herb and flower-rich grassland
Allotment garden
Existing trees
Parking hub
Hop-over (shrub)
Tree bridge (net)
MARTEN PARK
FOREST
MARTEN
PARK

HABITAT REQUIREMENTS

The forested marten park provides 60 marten heaps and 30 suitable nesting locations throughout Dokhavenpark. Although it is designed to house 8 females and 4 males, additional shelter locations are available within the untamed environment and abandoned buildings. A dense understory with patchy shrubbery both shelters the martens and facilitates safe traversal throughout the area. Berry bushes offer readily accessible food resources across the park. While borders between potential territories are minimally defined, the extensive habitat provision supports a self-organized socio-spatial structure. Drinking pools are readily available throughout the park.

BROWN RAT PREDATION

The third alternative prioritizes placing waste disposal dumps near marten shelters and foraging sites (as shown in the cross-section) to make the rats' primary food resource less accessible. Recreational pathways are equipped with waste bins adjacent to marten core areas. This alternative generally aims to increase predation pressure by providing habitat for various other predatory species, thereby extensively overlapping predator movement with brown rat foraging sites and paths.

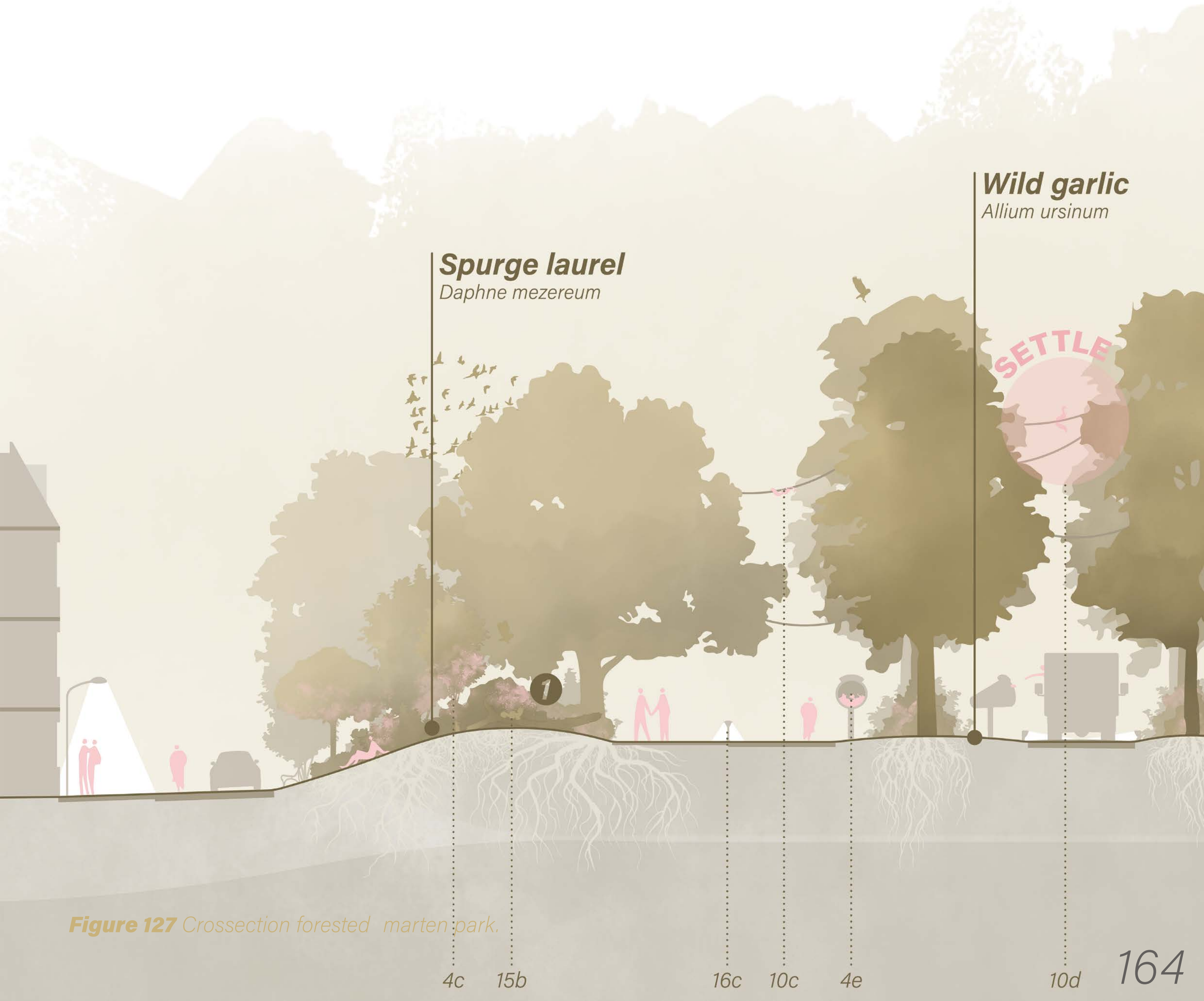


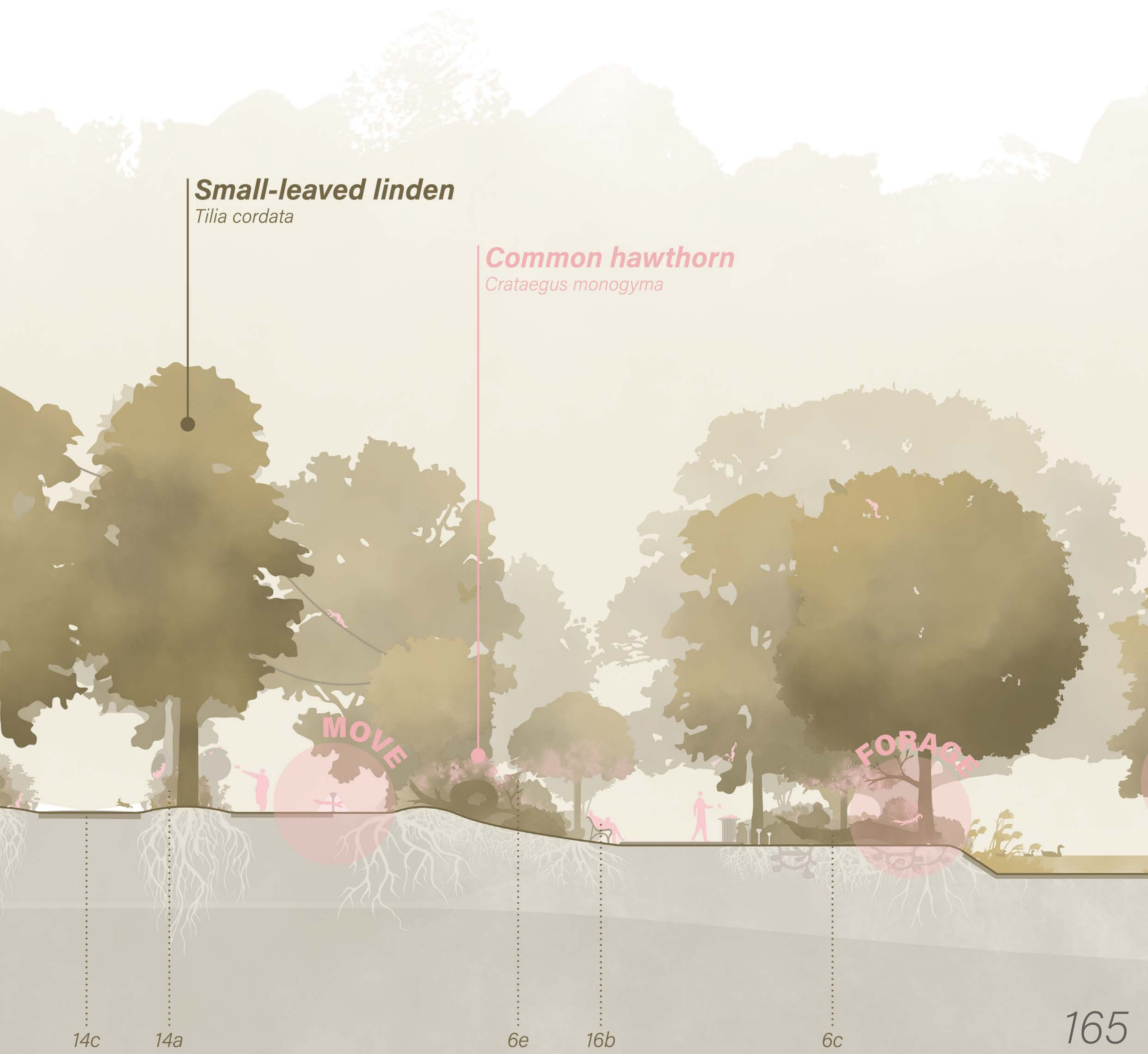
Figure 127 *Crossection forested marten park.*

HUMAN-MARTEN CO-OCCURRENCE

Minimal measures are taken to promote human-marten co-occurrence, resulting in vague divisions between social and ecological open spaces in order to maximize habitat conditions for stone martens. Consequently, vegetation often extends within one and a half meters from buildings, unlike in previous alternatives. Making the old building structures in the centre of the design more accessible also increases the likelihood of familiarity with house-bound nest/den sites, which this thesis repeatedly aims to avoid. By providing new recreational value though, the forested marten park design aims at provoking a level of human acceptance to marten nuisance.

OPEN SPACE SYSTEM

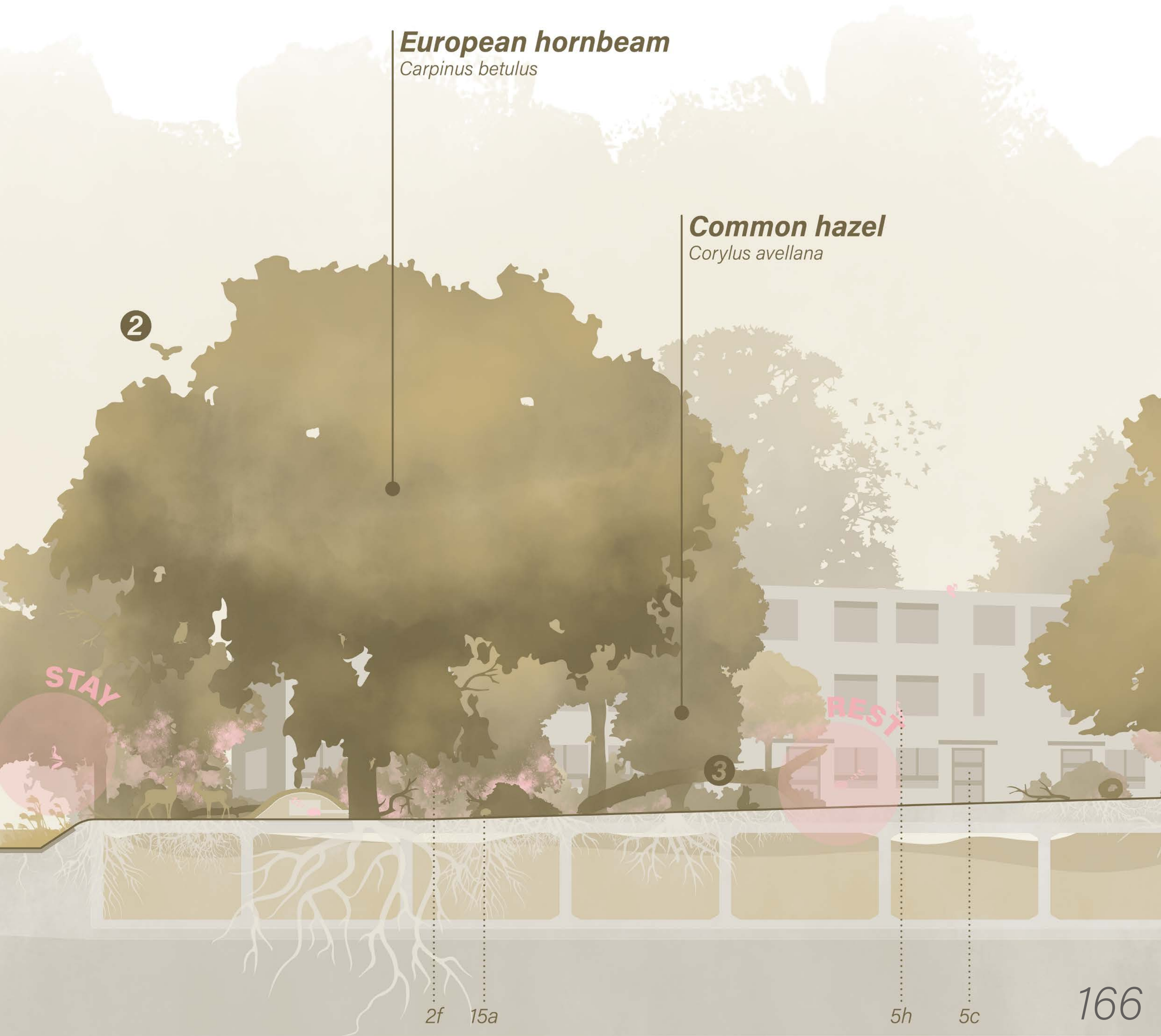
The forested marten park is designed as a source patch for population dispersal due to its high habitat quality. Consequently, network density is high, with minimal direction provided for dispersal movement, allowing marten pups to disperse in all directions. Habitat edges are defined solely by forest clearings amid patchy shrubbery. The minimal territorial division design promotes extensive overlap between male and female martens.



URBAN GREEN INFRASTRUCTURE

The 'eiken-haagbeukenbossen' forest type (Natura2000, 2008c) was chosen as it is common in the Dutch urban landscape, ensuring a correlation with many native indicator species and familiarity for stone martens with their rural habitats. The forest type provides ample shelter and food resources for both predators and prey.

Traversal to the park edges is enhanced by reducing traffic on key infrastructural connections, either by lining street profiles with patchy greenery (as seen in the cross-section) or by encouraging walking and cycling. Parking hubs provide car access for commuting and other destination traffic. Slow recreation facilities are dispersed throughout the park (see master plan), potentially even meeting habitat needs, such as the allotment garden offering easily obtainable food resources.



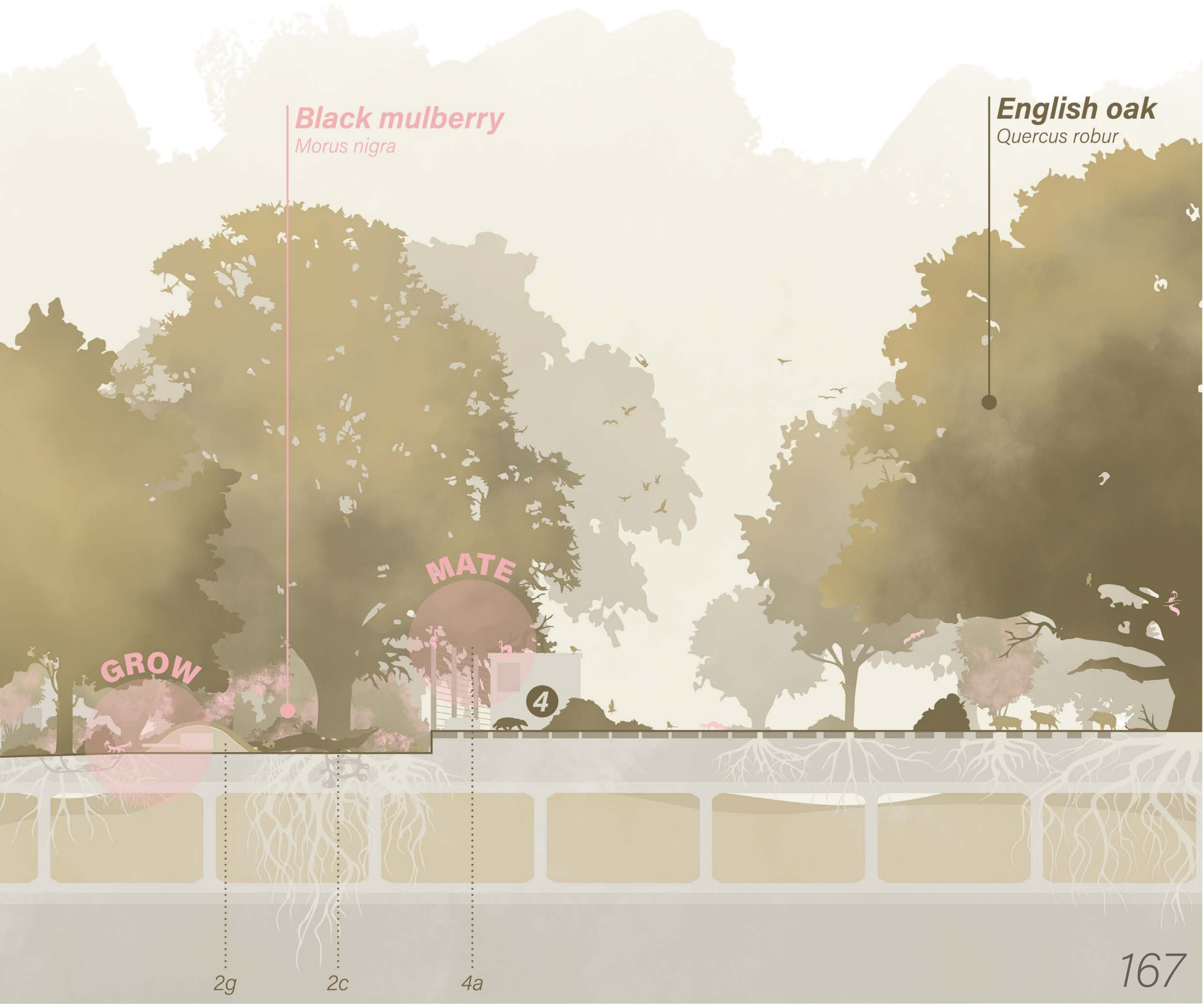
meters

0 — 30

15

19

1. **Pine marten** *Martes martes*
2. **Eurasian eagle-owl** *Bubo bubo*
3. **Red fox** *Vulpes vulpes*
4. **European badger** *Meles meles*



6.3 SELF-ASSESSMENT

The park-scale design alternatives function as proof of concepts, exploring the feasibility and viability in adapting the design guidelines and criteria derived from the research. Because they are presented as possible future trajectories for the marten-friendly redevelopment of the Dokhavenpark, no final design has been created. It is hypothesized that there is no 'perfect' final design that resolves the proposed design question without any shortcomings. A self-assessment of the historical, waterfront and forested park is done to investigate strengths and weaknesses within the individual designs. For this assessment the expertise of Jasja Dekker is used. Mr. Dekker is an animal ecologist currently working as freelancer undertaking assignments in the field of applied ecological research and management consulting. He has undertaken extensive research on stone marten behaviour and population dynamics (Dekker, 2024).

Appendix 9 presents the results of this assessment by scoring the suitability of the design alternatives with respect to the design criteria and overarching design guidelines. This is further elaborated with notes based on the qualitative analysis conducted with Mr. Dekker. Notes are given to highlight the differences between the alternatives. Next, a short conclusion is given on the main outtakes of this self-assessment.

DESIGN ALTERNATIVE 1

By significantly limiting the high-quality habitat area of Dokhavenpark, the first alternative is hypothesized to be the most successful in adapting the open space design to support human-marten co-occurrence. A key issue that arises due to the emphasis on edge habitats in the park design is the limited space available for the stone marten's occupational areas. The primary challenge in adapting the open space system framework within Dokhavenpark is the lack of space. The park itself encompasses approximately 30 hectares, including private properties and parking areas.

According to the design criteria [***8b*** / ***8c***], this necessitates that, as demonstrated in the third alternative, almost all available space must be of high habitat quality. There is insufficient knowledge about how future inhabiting martens will perceive and utilize their territory, which complicates the design criteria related to habitat patches and edges [***8*** / ***9***]. A discrepancy between proposed and actual usage can also be observed when considering potential stress factors. Increased traffic congestion and recreational activities in the first alternative could discourage martens from inhabiting or crossing the park.

Despite the historical marten park's inflexibility, this alternative effectively integrates the site's existing qualities with enhanced greenery. If multiple female martens were to inhabit the area, territorial divides would be ample, and the small core areas would still provide excellent spaces for nesting, resting, mating, and moving. The availability of plant-based food is excellent due to the abundant fruit supply in street plantings outside the core areas. More beneficial; brown rat occupation is largely confined to core areas since edge habitats and corridors are designed with evergreens, minimal shrubbery, and toxic plants. Additionally, the first alternative offers the best possibilities for interspecies co-occurrence with avian species due to the presence of solitary trees and marten-proof measures (see cross-section).

DESIGN ALTERNATIVE 2

The second alternative is believed to most effectively and safely guide martens through Dokhavenpark. The interconnected system of rain gardens and bioswales provides sheltered ground-level pathways that are undisturbed by traffic. The design of these features, along with the inhabitable BGI's, offers the largest variety of vegetation types and layers. According to Dekker (2024), this facilitates the best traversal possibilities for stone martens. Even crossing the Nieuwe Maas is likely, as marten habitats are linked to and familiar with the waterfront crossing. Similarly, the fauna-friendly Nieuwe Maas tunnel is considered by Dekker (2024) to be highly usable due to effective movement-guiding planting, which directs the animals to the entrance of the wildlife crossing.

The biggest challenge in ensuring the inhabitation of the waterfront area and B-UGI's is the moist soil conditions and fluctuating surface water levels. The accessibility of certain areas will deteriorate during specific seasons; however, more problematic is the necessity for tree-mounted marten boxes. The designed ground-based marten heaps offer much better-insulated nesting sites that are easier to find and access, with more direct food resources available. Still, inhabitable areas near built environments adapt marten heaps, based on Dekker's (2024) recommendation, to decrease the chance of building dens.

In the writer's opinion, the waterfront marten park creates the most exciting redesign of Dokhavenpark, as it not only meets the habitat requirements of stone martens but also adds new recreational value and introduces urban wildlife. This aligns with existing green visions for developing the Nieuwe Maas banks (Strootman landschapsarchitecten, 2016). In relation to the stated problem and with a marten-friendly redesign, a high degree of land sparing between humans and martens is achieved. However, the divisions are harsh, and the lack of edge habitat cannot ensure inhabitation of or foraging on private properties. The opportunity discussed in the research is leveraged by improving denning provisions for brown rats, ensuring a significant overlap between marten habitats and brown rat denning and foraging sites.

DESIGN ALTERNATIVE 3

The third design alternative offers the most robust space for habitation by multiple female and male martens. The high-quality habitat, edge-to-edge, makes the forested marten park more of a source patch than a stepping stone for stone marten population dispersal. However, the fragmented layout of the proposed site is poorly suited for guiding pup dispersal along a north-south axis.

While the patchy vegetation and reduced traffic congestion across all road profiles in the park create a safe overground crossing, they also contribute to the radial dispersion of stone martens.

In addition to the scattered traversal, the proximity of vegetation and built areas, coupled with minimal separation between human and marten-occupied spaces, increases the likelihood of marten nuisance on private properties. The uncertainty in animal behavior makes it difficult to determine whether the habitat quality will be sufficient for the future marten population or if a population increase might lead martens to use the built area around Dokhavenpark as part of their territory. Consequently, the socio-spatial organization within this alternative lacks guidance, potentially leading to intra- or interspecies conflicts.

The focus on naturalizing Dokhavenpark provides ample space for a wildlife community to settle. Observed urban wildlife within city boundaries can foster robust biodiversity, including improved predation on brown rats due to the introduction of other species. Overall, despite numerous habitat conditions, this alternative, due to minimal design guidance, has the least positive effects on maintaining a stable stone marten population that ensures a healthy balance between humans and martens.

7 DISCUSSION

This chapter concisely reviews the research approach and corresponding design process on the basis of multiple subjects that include limitations to the thesis and recommendations for further research.

LAND SHARING VS. SPARING

This thesis explores measures to ensure human-marten co-occurrence on a small scale rather than full coexistence. This approach parallels the broader debate on conservation strategies: land sparing versus land sharing. Land sparing advocates for creating protected areas, such as urban green spaces and parks, to minimize human impact and effectively support species conservation (Pearce, 2018). In this research, it involves enhancing the recreational value of socially significant green spaces while keeping ecologically important areas fully secluded. Evidence suggests that separating conservation areas from human land uses is effective in protecting species, and this thesis supports this approach to reduce the impact of stone martens on people. However, it becomes evident that such separation may require significant measures, raising the question of whether land sharing could offer a simpler and more effective solution for conserving marten populations in urban settings.

Land sharing integrates biodiversity protection within human-modified landscapes. This approach could improve habitat availability for martens and enhance connectivity between potential habitats. In contrast, land sparing often results in species loss in surrounding landscapes due to the isolation of conservation areas (Pearce, 2018), a risk that could arise if the proposed corridor system in the design alternatives is deemed inadequate.

INTEGRATED WILDLIFE MANAGEMENT

Even with a land sparing approach, managing martens effectively extends beyond landscape design to minimize human disturbances. An integrated strategy is necessary, combining multi-level wildlife management with public space maintenance and household interventions (Nyhus, 2016).

- Public space maintenance: For urban adaptors like martens, it is essential not only to redesign open spaces but also to maintain them. Regular pruning of dense vegetation near building facades for example, is crucial to prevent the establishment of high-quality marten habitats close to private properties. Such aspects are not covered in the thesis.
- Household Interventions: Addressing the impact of stone martens also requires measures at the household level. Martens' tendency to prey on bird eggs for example, particularly in spring, presents challenges. Homeowners need to secure chicken coops to prevent martens from accessing eggs and harming chickens. Such issues cannot be resolved through landscape architecture of urban open spaces alone, so this thesis focuses on discouraging martens from denning in buildings by making entry less appealing.

By integrating these strategies, human-marten interactions can be managed more effectively. Integration of the role of private properties for marten habitats is recommended for further research.

REGULATING ANIMAL BEHAVIOUR

The challenge of regulating animal behaviour, particularly with opportunistic species like the stone marten, is a significant concern for this research. Stone martens often respond unpredictably to conservation interventions, highlighting the need for flexible and adaptive design strategies to accommodate such variability. By presenting a variety of possible trajectories within design alternatives such is aimed at.

As previously discussed, managing human-marten interactions requires careful consideration of the animal's behavioural ecology. The socio-spatial organization of stone martens complicate efforts to design effective habitats with specific territorial and sex-dependent requirements. Securing exclusive access for females or identifying optimal nesting sites are just parts of a broader array of factors influencing territorial density and habitat use.

To enhance the effectiveness of conservation strategies, further research into the behavioural ecology of stone martens is essential. Understanding these details will help refine design directives and improve the validity of a marten-friendly design.

NEW PEST SPECIES

The opportunistic behaviour of the stone marten adds complexity to predicting how the species will respond to habitat changes. While the proposed designs aim to meet various habitat requirements, there is a potential risk of creating an overpopulation, which could transform martens into a pest species. This risk is elevated if new habitats provide sufficient quality, leading to increased population density as pups may occupy parts of the male marten's territory according to the beforementioned 'fitting model' (Broekhuizen, Müskens and Klees, 2010). Although design criteria on habitat edges aim to mitigate this risk, it cannot be entirely ruled out.

In contrast, the stone marten's k-selected traits (such as small litter sizes, large parental investment, and slow maturation rates) help prevent rapid population growth and possible overpopulation (Think Wildlife foundation, 2023). Additionally, urban martens do not exhibit drastic reductions in territory size compared to other urban-living mammals (Dudus et al., 2014). Their relatively large territories and solitary behaviour contribute to a more widespread population distribution.

This issue is closely linked to the potential for habitat provision to benefit brown rats. Which is the case if the designed areas are unsuitable for martens (or other plausible brown rat predators), or simply hard to access. Enhanced habitat for brown rats might result from increased marten populations and reduced predation pressure. This concern highlights the need for careful consideration of habitat design to avoid unintended ecological consequences.

SPECIES SPECIFICITY

The animal-aided design approach concentrates on specific target species, in this case the stone marten. The design effectiveness is assessed based on the success of these species (Weisser and Hauck, 2017). As a keystone species in urban ecosystems, the stone marten's presence can benefit a wider array of species due to the design's emphasis on their needs. This includes species essential for the marten's survival, such as the brown rat, and potentially facilitates indirect mutualistic relationships through interactions with other mammals:

Insects for example, may benefit from the presence of stone martens as the remnants of prey and waste left behind provide a possible food source. Similarly, while not a direct mutualistic relationship, stone martens can aid in seed dispersal through their waste, supporting plant growth in their habitat. Additionally, other predatory mammals, especially mustelids, may thrive in the designed spaces or rely on these areas for urban habitation (Balestrieri et al., no date).

Thus, AAD has the potential to enhance habitat quality for a broader range of species, even if initially focused on just a few target species. However, further research is recommended to develop a more holistic approach to biodiversity. The designs have sometimes been too narrowly focused on the stone marten, potentially overlooking broader biodiversity goals. A more comprehensive strategy is needed to ensure that supporting the stone marten does not inadvertently harm other species' populations either important for ecosystems in urban areas or generally endangered.

DESIGN FEASABILITY

The research outlined various design principles, guidelines, and criteria for habitat creation. However, applying these directives precisely, proved challenging due to the complex nature of the chosen project area where multiple factors must be considered. The detailed nature of the proposed design criteria often complicates their application, especially across different scales, and can trouble their conceptual usage. This weakens the usability of this body of work for further usage.

Moreso, integrating human usage as an important part of urban open space of public space is crucial for the feasibility of design application. Successful urban design must harmonize wildlife needs with human activities, creating environments that are both ecologically beneficial and functional for people (Buijs and Jacobs, 2021). Unfortunately, this balance is sometimes lost in the design, as the emphasis on wildlife habitat can overshadow the needs of human users.

Adapting existing urban areas to accommodate the stone marten can be more challenging than developing new habitats. Existing networks that facilitate human movement often act as barriers to wildlife (Dramstad, Olson, and Forman, 1996). Transforming urban landscapes to meet specific species' needs can restrict human use and significantly alter the existing environment. Therefore, urban areas require careful consideration to enhance both human functionality and biodiversity. Effective design must integrate naturalization with urban needs, ensuring that both human and wildlife requirements are addressed (Dramstad et al., 1996). A feasible design approach would need to draw inspiration from the research whilst also addressing other, arguably more important challenges.

In conclusion, while the research provides valuable insights and guidelines for marten habitat design, practical urban application demands careful consideration of various factors. Balancing human and wildlife needs, managing animal behaviour unpredictability, and adopting a broader perspective on biodiversity are essential for successful implementation.

Figure 128 *Marten peaking out of rubble (Natuurpunt, no date).*

8 CONCLUSION

This research aims to investigate how landscape architecture can contribute to stone marten populations in urban open spaces through the adaptation of urban green infrastructures. By using a 'Research through Design' approach, research questions in accordance with this research objective were answered by developing design principles, guidelines and criteria. These were tested through an iterative design process on two applicable scale-levels within the chosen site. Based on their implementation within 'proof of concept' designs, and their assessment, design directives were changed, added or removed. This continuous process is integrated within thesis itself. A definitive list of design principles, guidelines and criteria, aimed at concluding the answer to this research' objective, is found within appendix 1.

To summarize, responses to the research questions, and how they are shaped through the design process, are presented below:

SRQ1: What are habitat requirements needed to facilitate a stone marten population in urban areas?

Within urban areas, a stone marten population is in need of spaces for mating; nesting & rearing; pup dispersal; territory; shelter; movement; and foraging. Life history dependant habitat requirements require permanent availability through discrepancy between and elongation of life stages between individuals. In general, it is important that all of an individual's life necessities are met within a single female habitat. Key is the year-round availability of food and shelter, which is largely seasonal dependant.

The opportunistic nature of the mammal makes it easy to adapt certain habitat requirements for a marten population within urban open space design. Suitable denning/nesting locations, herbivorous dietary needs, and safe traversal routes are easily adapted within urban open space. Territorial divisions and carnivorous dietary needs are more difficult to regulate due to the species' opportunistic character traits.

SRQ1A: How can habitat provisions for stone martens improve their predation pressure on brown rats in urban areas?

By extensively overlapping habitat provisions of stone martens with brown rat habitats, food availability and shelter opportunity of set species is induced through creating a 'landscape of fear.' The brown rat carrying capacity of marten-inhabited urban open space can be further reduced through utilization of the window of opportunity created by the small differences in habitat requirements between both mammals.

Relevant criteria were easily integrated within the designs, and deemed effective by experts as long as proposed designs are, in fact, inhabited by stone martens and brown rats. On a general note, the highly adaptive nature of the brown rat makes it difficult to address the problem at its source. Although outside the scope of this question, the design process highlighted the necessity of widespread habitat provision for marten and other plausible predators as necessity for effective natural pest predation.

SRQ1B: How can habitat provisions for stone martens be adapted to facilitate their co-occurrence with humans in urban areas?

The organization of marten habitat provisions within urban open space determines the spatial usage of the stone marten population; by differentiating human and marten occupied areas through the creation of low habitat quality dividers, the identified issue of property damage can be prevented. Essential for effective low/high quality division is the provision of shelter places and foraging sites in core areas that outcompete those found in the built environment.

When applying the accompanied design criteria, the problem of spatial constraint arises. Limiting areal usage of stone marten within urban open spaces, smaller than mean territory sizes, means that there potentially is an increased likelihood of building denning. A certain degree of human acceptance on marten nuisance could improve flexibility in adapting mentioned criteria.

SRQ2: How can open space system design be adapted to create an ecological network for a stable stone marten population in urban areas?

An open space system for a marten population consists of habitat patches and pup dispersal corridors creating an ecological marten network. Population distribution is aided through the creation of continuous, densely vegetated connections between habitat patches, responsive in amount and size according to urban tissue density and proximity to source patches. The latter being essential for population growth. Population density is stabilized through the adaptation of edge habitat, limiting the amount of habitat provision and considering the marten's socio-spatial organisation.

Designing an ecological network in compliance with the question's design directives reveals the shape and size of open space needed. If overpopulation and, relating to SRQ1b, marten nuisance must be completely excluded, a rethinking of open space configuration is necessairy that drastically impacts urban development. Nonetheless, design criteria of SRQ2 can be used to imply space usage for martens, even on a smaller scale.

SRQ3: How can Urban Green Infrastructures be used or modified to support a stone marten population?

Adapting UGI's that prioritize the naturalization of urban open spaces, most effectively integrates stone marten habitats and plays a crucial role in balancing interspecies relationships by attracting other urban wildlife. Differentiating ecologically and socially significant green spaces can offer strategies for stabilizing marten populations while simultaneously accommodating human preferences, in a marten-friendly redesign, by considering recreational value. L-UGI's and BGI's are essential components for enhancing habitat connectivity, as are effective wildlife crossings.

The rewilding of urban areas through the development of large, undisturbed forested areas within the design alternatives, proved most effective in housing martens and benefitting biodiversity and other ecosystem services are biggest. In general, many UGI's are deemed suitable for stone martens, but their placement and design are crucial for use.

MRQ: How could landscape architects (re)design urban open green space in order to safely adopt a stone marten population?

To effectively integrate a stone marten population into urban open green spaces, it is essential to concentrate undisturbed green spaces within large urban parks, focusing on providing critical resources for female martens through smart design interventions. These core habitats should be surrounded by edge environments designed to mitigate overpopulation and deter building denning. Within these spaces, recreational areas can be established, allowing for human enjoyment while martens safely forage here at night. A network of dispersal corridors will facilitate the dispersal of juvenile martens towards potential future territories, creating an ecological network that fosters robust natural environments within urban settings. Despite the independent nature of the stone marten, designed spaces can be inhabited by other urban wildlife. Consequently, integrating stone marten habitats into urban open green spaces promotes an ecologically rich urban environment that enhances biodiversity and contributes to a balanced ecosystem free from pest species.

9 GLOSSARY

Core area: Area in the centre of a marten's habitat with high habitat quality.

Den: A marten's night shelter.

Edge habitat: Area around a marten's core area with low habitat quality.

Home range: A marten's habitat, including core area and edge habitat.

Interior-edge species: species that make use of both edge and interior habitats.

Interspecies relation: Relation between animals of different species.

Intraspecies relation: Relation between animals of the same species.

Juvenile: An individual marten that has not yet reached its sexual maturity.

Keystone species: Species critical to the survival of other species within an ecosystem, playing a key role in maintaining a balanced and healthy ecosystem.

K-selected species: invest more time and resources in raising fewer offspring, often in stable or predictable environments. They prioritize quality over quantity, with longer lifespans and greater parental care. Examples include elephants and humans.

Latrine: places where wildlife animals habitually defecate and urinate.

Mesopredator: Predator that occupies a mid-ranking trophic level in a food web.

Mesopredator release: phenomenon in which a mesopredators population increases after removal of a top predator.

Metapopulation: Group of spatially separated populations of the same species which interact at some level.

Nest: A marten's night shelter suitable for nesting.

Pup: An individual marten still (somewhat) dependent from its mother/father.

Pest: Organism that harm human activities, health, or the environment by causing damage, spreading diseases, or competing with other beneficial species over resources.

R-selected species: focus on producing many offspring quickly with minimal parental investment. They thrive in unstable or unpredictable environments where early reproduction and high offspring numbers increase chances of survival. Examples include insects and weeds.

Shelter: A marten's temporary day shelter.

Sink landscapes: Spaces where a marten population declines because of insufficient suitable habitat requirements.

Socio-spatial organisation: Patterns and processes defining how animals arrange themselves socially and spatially within their environment.

Source landscapes: Spaces where a marten population grows because of sufficient suitable habitat requirements.

Species coexistence: The long-term presence of multiple species in the same habitat, involving interactions or adaptations that allow them to maintain stable populations and avoid competitive exclusion.

Species cooccurrence: The presence of two or more species in the same location or habitat at the same time, without implying any specific interaction or relationship.

Stepping stones: small patches of land, suitable for temporary inhabitation when traveling over long distances.

Synanthrope: Organisms that live close to humans and benefit from environmental modifications.

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11 APPENDIX

8.2 APPENDIX 1

DESIGN PRINCIPLES, GUIDLINES AND CRITERIA

SRQ1

SRQ1a

SRQ1b

SRQ2

SRQ3

DESIGN PRINCIPLES	DESIGN GUIDE
"The entirety of an individual marten's life history needs should be met within a single designated female territory"	Mat
	Nesting & Rear
"Decrease food availability andshelter opportunity of the brown rat through increased predation pressure."	Pup disper
"Utilize the small window of opportunity created by the differences in habitat requirements of both mammals."	Territ
"Seperate human and martenoccupied areas through low habitat quality dividers"	Shel
"Create more attractive naturalshelter places and foraging sites"	Movem
	Forag
"Create an ecological network in urban open space to facilitate a stably growing stone marten population"	Habitat patc
	Habitat ed
	Disper corrid
	Ecolog netw
"Urban open spacse should seperate ecologically and socially significant Urban green infrastructures"	Typolog
	Vegetat
	Barri
	Urban wild
	Human us

LINES			DESIGN CRITERIA	
ting	1	The design should facilitate mate-guarding and promote female encounters.	1a	Borders should be permanent or temporarily strong from june to december.
			1b	Borders should use existing infrastructural barriers where possible
			1c	Borders should be surrounded by edge habitat
ing	2	Design should provide isolated, insulated spaces for female martens to nest and pups to grow up.	2a	Nests should be designed to ensure a minimum of 5 suitable nests per female habitat.
			2b	Nests should have sufficient loose material easily available
			2c	Nests should be located in quiet, secluded areas
			2d	Nests should have a latrine
			2e	Nests location should be spacious
			2f	Nests should have easily obtainable food sources close-by
			2g	Nests should be well insulated
			2h	Nests should be mostly concentrated in core areas
rsal	3	Design should aid the safe dispersal of juveniles towards a future habitat by creation of a corridor network with easily-available habitat requirements	3a	Corridors should be temporarily strong during late summer
			3b	Corridors should consist of a multitude vegetation layers at different heights
			3c	Corridors should have fruiting plants easily be available
			3d	Corridors should be lined with patchy edge vegetation.
ory	4	Design should account for the rigid socio-spatial organization by using ample space and widely providing nesting places within intersexual territories.	4a	Territories (m/f) should have core areas between different sexes overlap*
			4b	Territories should have food resources for all martens concentrated in core areas (f)
			4c	Territories should have habitat requirements be evenly spread out over open space
			4d	Territories of the same sex should not overlap*
			4e	Teritories should concentrate marten foraging sites and shelters around waste disposal dumps
			4f	Teritories should concentrate marten foraging sites and shelters close to water
			4g	Territories should have core areas in the centre of open spaces
			4h	Territories should have habitat edges around buildings, private properties and parking spots
lter	5	Design provides permanent day shelters during all seasons, and creates flexible day shelters during summer plus flexible night shelter during winter through the provision of natural landscape elements.	5a	Dens should be designed to ensure a minimum of 10 permanent day shelters per female habitat.
			5b	Dens should be situated at high altitudes or have entrances five centimetres in width
			5c	Dens should provide overhead and side-coverage
			5d	Dens should have a similar typology to designed nests
			5e	Dens should be placed at surface level
			5f	Dens should be placed on bare soil
			5g	Dens should be well insulated
			5h	Dens should be located in quiet, secluded areas
			5i	Dens should be concentrated in core areas
ent	6	Design aids the safe movement of martens within their habitat through the provision of a multitude of green traversal routes that connect resting and foraging places.	6a	Natural landscape elements should bloom from march to august.
			6b	Natural landscape elements should have have organic debris available from september to february.
			6c	Natural landscape elements should connect foraging sites and shelters
			6d	Natural landscape elements should provide overhead coverage*
			6e	Natural landscape elements should be available at different heights*
			6f	Natural landscape elements (elevated) should maximally be spaced 1,5 meters of each other
			6g	Natural landscape elements should minimally be distanced 1,5 meters away from building facades
			6h	Natural landscape elements should connect marten movement to brown rat foraging sites/paths
			6i	Natural landscape elements in core areas should have characteristics desired by rats
			6j	Natural landscape elements in habitat edges should have characteristics undesired by rats
			6k	Natural landscape elements should be concentrated in core areas
ting	7	Design should provide carefully selected fruiting plants that fit within the seasonal needs of a marten's herbivorous diet.	7a	Fruiting plants should provide ripe/rotten fruit during summer/autumn
			7b	Fruiting plants should be chosen for their nativity and relevance to the marten's diet.
			7c	Fruiting plants (trees) should have high-hanging fruits
			7d	Fruiting plants (trees) should have fruits that are held for a long time
			7e	Fruiting plants (shrubs) should be toxic to rats
			7f	Fruiting plants plants should be concentrated in core areas
hes	8	Create habitat patches that meet female martens requirements.	8a	Patches should be divided into smaller habitat patches if areal can house multiple male martens
			8b	Patches should preferably be 15 ha for females and 30 ha for males
			8c	Patches with limited size should have respectively larger or qualitatively better core areas
			8d	Patches of all sizes will be designed for females
			8e	Patches (source) should be included within an ecological network
ges	9	Create rigid habitats edges that contain a selection of habitat necessities	9a	Edges should include more than half of the marten's food resources if necessary
			9b	Edges should be designed as abrupt as possible
			9c	Edges should be designed as straight as possible
			9d	Edges should create a minimally convoluted habitat patch
rsal ors	10	Create an interconnected network of pup dispersal corridors that respond to the available space	10a	Corridors should be uninterupted
			10b	Corridors should minimally be 3 metres wide
			10c	Corridors should be of high-habitat quality
			10d	Corridors should be able to connect through habitat patches
ical ork	11	Create an ecological marten network that enforces population distribution through effectively integrating source patches.	11a	Network should have high corridor densities near source patches
			11b	Network should account for higher corridor densities and smaller corridors when urban tissue is dense
gies	12	Select or implement UGI typologies and their placement to meet specific habitat requirements.	12a	Typologies of L-UGI should be used to guide marten movement
			12b	Typologies should be chosen based on their corresponding usage and position in figure 66
ion	13	Enhance vegetational diversity through naturalization and native planting.	13a	Vegetation should have large canopies with thick foliage
			13b	Vegetation should be provided at canopy, understory, shrub, herb and grass layer
			13c	Vegetation should be chosen that is native to the site
			13d	Vegetation should be fruit-holding
ers	14	Develop safe overpasses and underpasses across blue and grey infrastructure using the simplest possible methods.	14a	Barriers should be accompanied by patchy vegetation
			14b	Barriers should have wildlife corridor-accompanying vegetation
			14c	Barriers near habitat patches should have reduced traffic congestion
			14d	Barriers should choose corresponding wildlife corridors based on figure 73
life	15	Implement adaptive measures that create habitats for both predators and prey of the stone marten.	15a	Urban wildlife (preys) should be considered considered through naturalization of urban open green space
			15b	Urban wildlife (brown rat predators) should be considered through naturalization of urban open green space
			15c	Urban wildlife (mammals) should be considered by prioritizing brown rat predation in design
			15d	Urban wildlife (avian) should be considered by adapting marten-proof measurements.
			15e	Urban wildlife (predators) should be considered by providing sufficient traversal routes
			15f	Urban wildlife (predators) should be considered by designing denning/nesting sites with small entrances
age	16	Use human activities as a strategic tool to influence marten occupancy patterns.	16a	Human usage should be limited to edge habitats due to edge programming
			16b	Human usage during the day should limit recreational intensity close to core areas.
			16c	Human usage of artificial light should be strategically placed to shelter or aid martens.

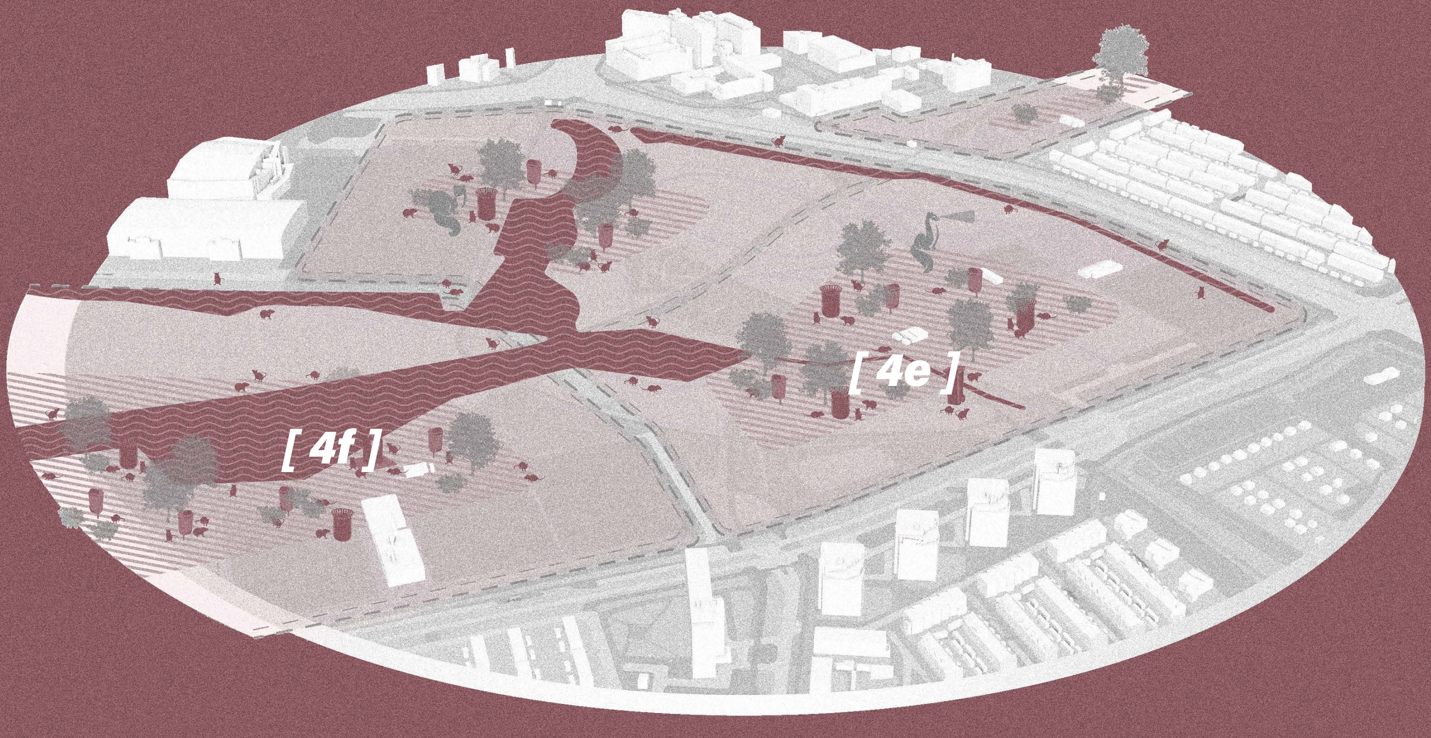
8.2 APPENDIX 2

FRUITING PLANT SELECTION DETAILS

#	Latin name	Name	Hanging height	Mentioned in research	Nativity	Toxicity	Summer/ Autumn	Seed hold time
1	*Fragaria vesca*	Wild strawberry	low	no	native		yes	x
2	*Prunus laurocerasus*	Cherry laurel	low	yes	native	toxic to rats	yes	x
3	*Ribes nigrum*	Blackcurrant	low	no	native	toxic to rats	yes	x
4	*Ribes ribrum*	Redcurrant	low	no	native		yes	x
5	*Rosa rubiginosa*	Sweet briar	low	no	native		no	x
6	*Rubus caesius*	European dewberry	low	yes	native		yes	x
7	*Rubus fruticosus*	European blackberry	low	yes	native		yes	x
8	*Solanum nigrum*	European black nightshade	low	yes	native	toxic to rats	yes	x
9	*Vaccinium myrtilles*	Eurpean blueberry	low	yes	native	toxic to rats	yes	x
10	*Juniperus communis*	Common juniper	low/high	no	native	toxic to rats	yes	x
11	*Prunus spinosa*	Blackthorn	low/high	yes	native	toxic to rats	yes	x
12	*Taxus baccata*	European yew	low/high	yes	native	toxic to rats	yes	x
13	*Cornus mas*	Cornelian cherry	high	no	native		yes	long
14	*Crataegus laevigata*	Midland hawthorn	high	yes	native	toxic to rats	yes	x
15	*Crataegus monogyna*	Common hawthorn	high	yes	native	toxic to rats	yes	x
16	*Ficus carica*	Common fig	high	yes			yes	long
17	*Malus sylvestris*	European crab apple	high	yes	native		yes	long
18	*Mespilus germanica*	Common medlar	high	no	native		yes	long
19	*Morus nigra*	Black mulberry	high	no			yes	long
20	*Prunus avium*	Wild cherry	high	yes	native		yes	long
21	*Prunus domestica*	European plum	high	yes	native		yes	long
22	*Prunus persica*	Peach	high	no			yes	long
23	*Prunus pradus*	Common bird cherry	high	yes	native		yes	long
24	*Pyrus pyraster*	European wild pear	high	yes	native		yes	long
25	*Sambucus nigra*	European elderberry	high	yes	native	toxic to rats	yes	x

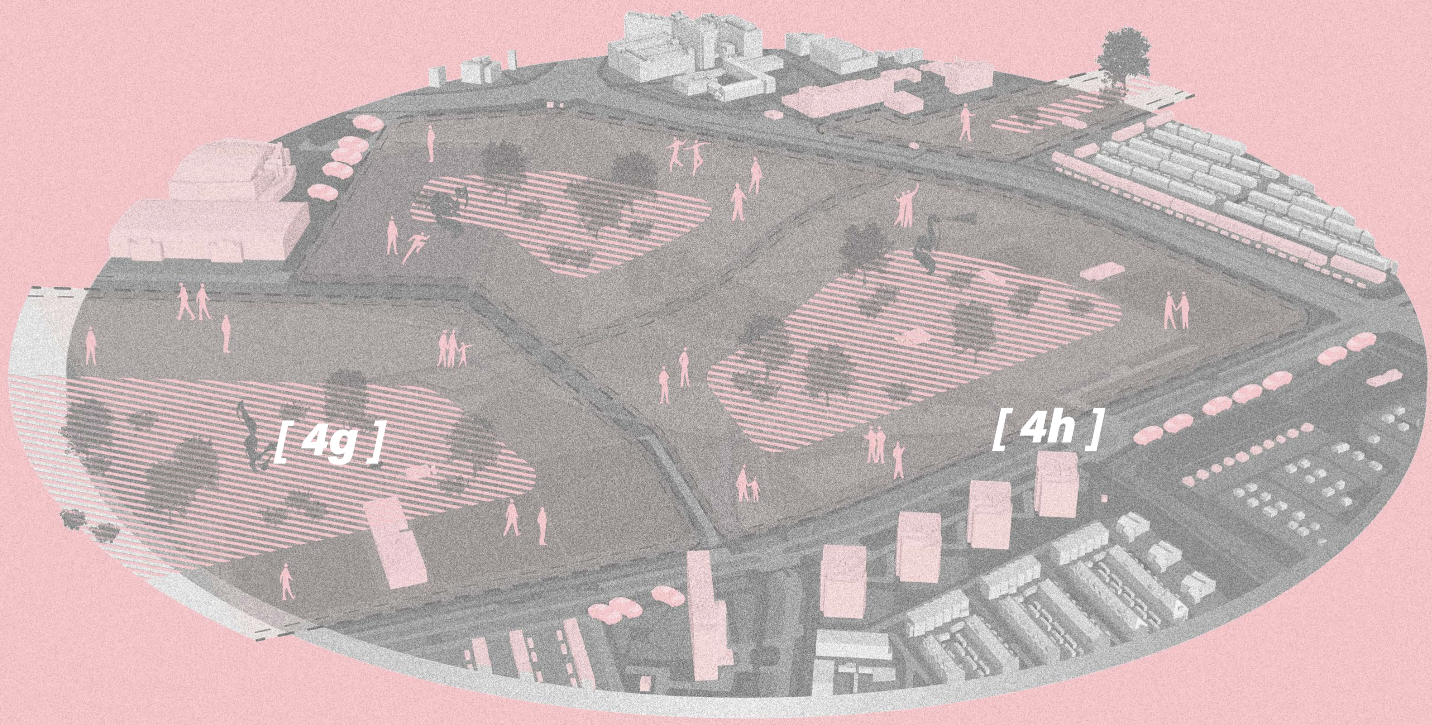
8.3 APPENDIX 3

ADAPTED HABITAT REQUIREMENTS DIAGRAMS
BROWN RAT PREDATION



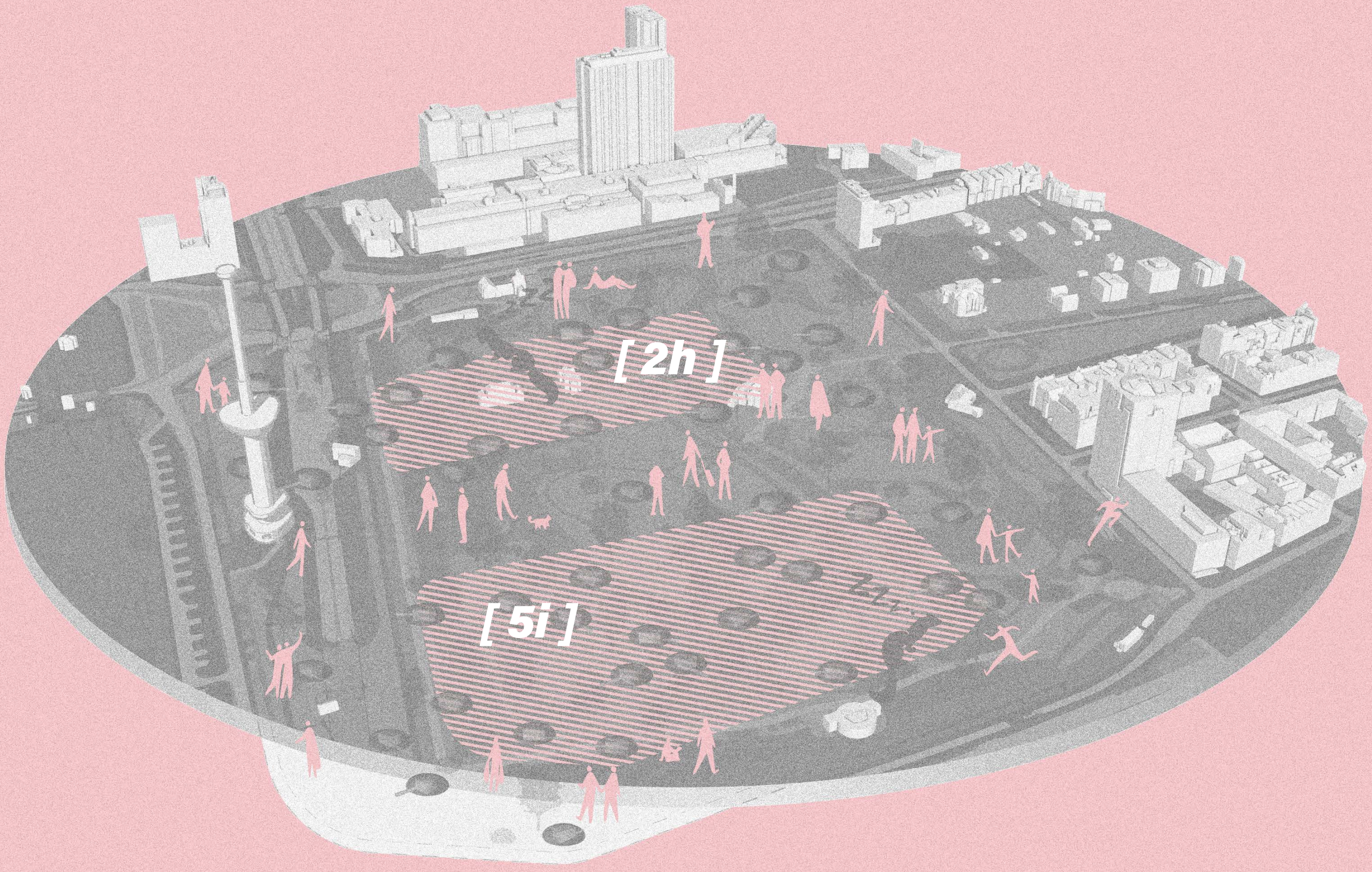
8.3 APPENDIX 3

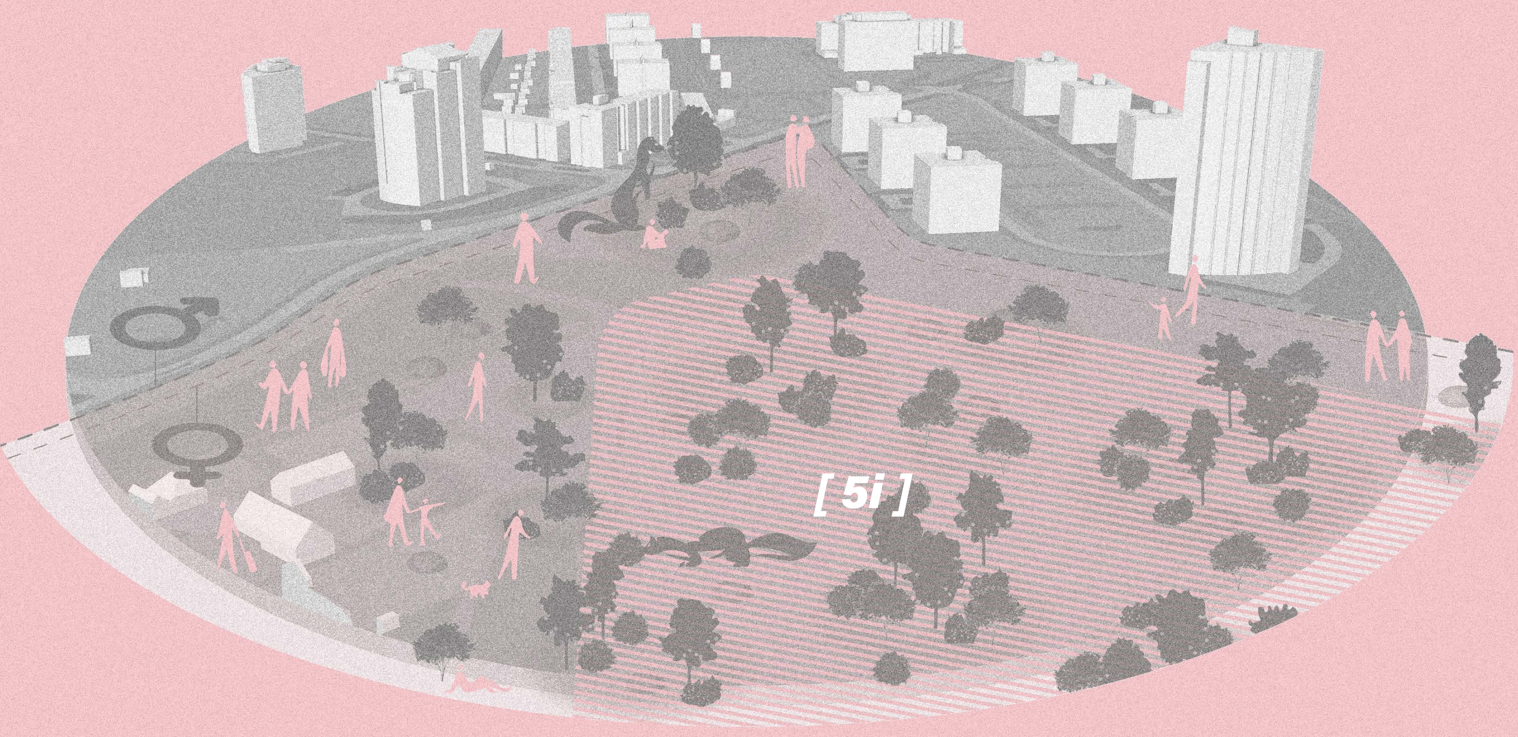
ADAPTED HABITAT REQUIREMENTS DIAGRAMS
HUMAN-MARTEN CO-OCCURRENCE



8.3 APPENDIX 3

ADAPTED HABITAT REQUIREMENTS DIAGRAMS
HUMAN-MARTEN CO-OCCURRENCE





8.4 APPENDIX 4

UGI TYPOLOGIES DESCRIPTION

Numbered according to visualizer of chapter 4

UGI category	*UGI type*	*Description/assumption*
Building greens	Ground-based green wall	Ground-based climbing plants intended for ornamental (and sometimes food production) purposes.
	Facade-bound green wall	Plants growing in facade-bound substrate, e.g. containers or textile-systems.
	Balcony green	Plants in balcony and terraces, planted mostly in pots.
	Green roof	Roof vegetation on thin or thick substrate with possible irrigation and management. Vegetation is established either artificially by seeding/planting or naturally.
	Roof garden	Public or private green roof with a mix of decking, paving and plants used for moslty recreational purposes.
	Atrium	Green area surrounded/enclosed in a building planted mostly with ornamental plants.
	Private frontyard	Area at the frontside of private houses cultivated mainly for ornamental purposes and/or non-commercial food production.
	Private backyard	Area at the backside of private houses cultivated mainly for ornamental purposes and/or non-commercial food production.
Constructed on grey infrastructure	1 Green pavement	Semi-permeable pavement often alternating between porous material and ground-cover plants.
	2 Green fence	Boundary structure composed of a framework coverd with climbing plants.
	3 Green pergola	Arched structure consisting of a framework covered with climbing plants.
	4 Green noise barrier	Large manmade structure designed to reduce noise pollution, overgrown by vegetation
Associated with grey infrastructure	5 Street tree	Trees planted along roads and paths either solitary or in rows.
	6 Hedgerow	Hedges along roads or paths often used as boundary structure.
	7 Green verge	Non-tree, mostly shrubby or grassy verges along roads or possibly other natural/manmade elements.
	8 Railroad bank	Green space along railroads, containing mostly ruderal vegetation.
	Green parking lots	Parking lot with increased sustainability due to measures such as permeable pavements, stormwater management and greenery.
	Parklet	Sidewalk extension, mostly on former roadside parking spaces, used as public amenity by creating seating areas and small green spaces.
Recreational green space	9 Neighbourhood green space	Semi-public green spaces in multi-story residential areas designed for communal usage. Vegetated by grass, shrubs and trees.
	10 Institutional green space	Formal green spaces surrounding public and private institutions and corporation buildings.
	11 Shared open space	Semi-green public spaces that are mostly paved and have a prominent recreational function (e.g. square, boulevard)
	12 Green playground	Green areas intended for playing or outdoor learning.
	13 Green sport facility	Intensively cultivated and fertilized grass turf tolerant to frequent trampling for sport activities (e.g., golf courses, football fields).
	14 Camping area	Green space reserved for camping, often lawns vegetated with sparse shrub and trees.
	15 Cemetery/churchyard	Burial ground often covered by lawns, trees and other ornamental plants.
Parks and gardens (UGI providing numerous environmental, social and recreational benefits to residents and wildlife alike)	16 Large urban park	Large green space within a city intended for recreational use by urban residents. It can include different features such as trees, lawns, playgrounds, water bodies, ornamental beds, etc.
	17 Pocket park	Small park-like area around and between buildings vegetated by ornamental trees and grass, publicly accessible.
	18 Historical park/garden	Similar to large urban parks, but with distinct management due to heritage status.
	19 Botenical garden/arboreta	Educational and ornamental areas planted with large diversity of (non-)native plant species.
	20 Nursery garden	Growing area for young (mostly native) plants, including few mature trees
	21 Zoological garden	Areas with animals kept in cages and enclosures often combined with planted trees, ornamental beds and cultivated grass.
(Semi-)natural areas (UGI which is either natural or manmade and has possible management)	22 Forest	A remnant woodland, managed forest or mixed form of area with dense tree vegetation and mostly different vegetational layers.
	23 Shrubland	Natural/manmade landscape characterized by dense growth of woody plants, typically smaller than trees (e.g., heath, macchia).
	24 Grassland	Pastures or meadows with possibly flowers and herbs.
	25 Ruderal area	Recently abandoned and/or derelict areas with spontaneously occurring ruderal vegetation or pioneer species.
	26 Wetland	Areas with soil permanently or periodically saturated with water and characteristic flora and fauna adapted to moist conditions.
	27 Riperian woodland	Ecosystem characterized by mature or mixed age trees and vegetation that thrive along the banks of rivers, streams or other water bodies where groundwater levels are high.
Urban agriculture (UGI focussed on serving community and food resources)	28 Allotment garden	Small garden parcels cultivated by different people, intended for non-commercial food production and recreation.
	29 Community garden	Areas, collectively gardened by a community for food and recreation.
	30 City farm*	Urban agricultural space cultivating crops and raising livestock, often serving as community resource for education, sustainability, and local food production.
	31 Arable land	Regularly ploughed land used for crop production.
	32 Orchard	Parcels with fruit and nut trees used for agricultural or biofuel production. Beside trees, the land is only sparsely vegetated.
Blue-green infrastructure (UGI including water bodies and their banks)	33 Lake/pond	Natural/artificial standing water bodies containing non-saline water with (semi)natural aquatic communities. Banks are either artificial/managed or natural.
	34 River/stream	Running waters including springs, streams and temporary water courses. Banks are either artificial/managed or natural.
	35 Dry riverbed	Dried up land depression formed by flowing water, (un)managed and usually rich in biodiversity. It is often used for recreation.
	36Canal	Artificial non-saline water courses with man-made substrate. Banks are mostly artificial.
	Estuary/delta	Downstream part of and landform at the mouth of a river, formed by sediment deposits and subjected to tidal effects.
	Sea coast	Contact areas (littoral) between sea and land of different characteristics (e.g. sand beaches, cliffs, coastal dunes).
Water management (Blue-green infrastructure focussed on managing water drainage)	37 Rain garden	Small constructed drainage areas near houses/roads to intercept runoff. Often planted with native shrubs, perennials, and flowers.
	38 Bioswales	Vegetated and gently sloped pit for filtering surface runoff.
	39 Flood control channel	Stomwater management channel usually constructed with earth/stone banks or concrete.
	40 Attenuation pond	Basin with managed drainage for storm events, consisting of mostly grass, reeds and some trees.

Sources: (Braquinho et al., 2015; Ecological Institute, 2020; Jones et al., 2022)

8.5 APPENDIX 5

WILDLIFE CORRIDOR DESCRIPTION

Numbered according to visualizer in chapter 4

** = dual-purpose crossing*

type	*description*	*variation*	*min. width (m)*	*min. heigth (m)*
1 Hop-over	Connection made through overlapping tree canopies on either side of the road. If the road is too wide for canopies to touch, a tree within a median strip can be used/added to bridge this gap. The hop-over preferably connects to existing linear landscape elements. Alternatively, shrubbery can be planted in road verges to create a passageway. However, the risk remains notably high, particularly with wide roads, as animals still need to traverse the road surface.	Shrub	x	6
		Tree	x	0
2 Canopy bridge	If the distance between trees on either side of a road is too wide for a wildlife crossing, a canopy bridge can be constructed. The gap between the tree canopies is bridged using a rope, net, or wooden construction. Existing road constructions can also be utilized. In general it applies that the wider the gap, the sturdier the structure needs to be.	Net	0,5	6
		Rope	0,04	6
		Construction	0,5	6
3 Wildlife ramp	Plank connecting the banks of small waterways. They can be made out of wood, steel or concrete and should incorporate and should include a barrier of sorts (such as a small fence) that prevents usage by people.		0,5	x
4 Fauna-friendly viaduct*	(Re-)designing part of a viaduct to incorporate a one- or two-sided green strip through which wildlife can traverse. The strip is vegetated with screening vegetation and a barrier should be created between the road and wildlife corridor. Aternatively, if space is limited, a gully can be designed next to the viaduct.		0,5	x
5 Eco-Aquaduct*	An aquaduct (structure connecting waterways over infrastructure) that reserved space in the waterway's bank that allows fauna to traverse the underlying road. This additional strip accomodates wet nature values and target species associated with banks and marshes. Shared usage with humans is likely (e.g. goods traffic, aquatics).		15	6
6 Ecoduct	Viaduct for animals. The design can be a simple green strip, it can have a bit more vegetational structure or it can mimick an entire ecosystem. Ecoducts take up a lot of space as they also need an approach zone. Shared usage with humans is possible, but in comparison to a fauna-friendly viaduct animals are its main users.		15	6
7 Landscape bridge	A very wide ecoduct that creates a landscape that seamingly transitions into the landscapes on either side of the road, mostly designed for multiple species.		60	6
8 Amphibian tunnel	Small wildlife tunnel directly underneath road surfaces mainly focussed on reducing barrier effects for amphibians as their roof consists out of perforated concrete or metal which reduces the climate difference in- and outside the tunnel. Shared usage by other small mammals (e.g. martens, mouses, squirrels) is possible. Corridor is small, easily adaptable but very fragile.		0,5	0,5
9 Transverse wildlife passage	Small wildlife tunnel mainly used for crossing railways, focussed on reducing barrier effects for amphibians, reptiles and small mammals. Two adjacent concrete sleepers are replaced with metal sleepers that create a small walk-through space filled with fine ballast and covered by a metal grille. Easily adaptable when underground space is limited, attractive approach zone is needed.		0,6	0,2
10 Wildlife culvert*	A culvert, mainly used for water drainage, has minimal space for animal passage. By creating a elevated ledge of hanging ramp along its sides, animals can still make use of the waterway to cross a road. These corridors can still be used during high water levels. They are regularly used by small mammals.	Ledge	0,5	1
		Ramp	0,5	1
11 Bridge/viaduct with wildlife crossing*	Passageways concerning bridges over wide waterways where, due to its size, the conditions under the bridge are suitable for the development of bank vegetation. If possible, a continuation of the waterways natural banks will be made. Otherwise, an artificial bank will be created. The amount of sunlight reaching the bank under the bridge must be carefully taken into account.		x	x
12 Small wildlife tunnel	Tubes or rectangular, dry culverts intended for usage by small to medium-sized land-based mammals. These tunnels can be pressed underneath existing roads if their diameter is no larger than 3 metres. An approaching slope is necessairy. If road verges are narrow, side entrances must be used. A thin soil-layer with possible vegetation can make the tunnel more attractive for animals.	Wide road verge	0,5	0,5
		Narrow road verge	0,5	0,5
13 Tunnel with wildlife crossing*	A redesign of existing tunnels with sufficient space to incorporate a green strip next to present infrastructure. The green strip is vegetated with screening vegetation that, in comparison to a fauna-friendly viaduct, should account for minimal sunlight. Artifical screening structures can also be created, such as a barrier between the paved and unpaved strip.		0,5	x
14 Big wildlife tunnel	Tunnel created when the construction of a bridge or viaduct is not feasible. A large fauna tunnel is similar in shape and dimensions to a traffic tunnel, but its ground layer consists of vegetated soil. Due to their size, they are moslty designed for large mammals (e.g. deer, wild boars, horses). In need of a wide road verge as the approaching slope is larger than that of a small wildlife tunnel.		0,5	0,5
15 Elevated infrastructure	In places where infrastructure crosses a depression or important linear natural landscape (such as a stream valley), a bridge or viaduct can be provised. Such facilities can leave the underlying landscape unhindered, preserving existing natural vegetation to pass under the road. Due to its size, daily/seasonal migration and dispersal of different species can be accomodated at the same time.		x	5

Source: (Ministerie van Infrastuctuur en Waterstaat, 2021)

8.6 APPENDIX 6

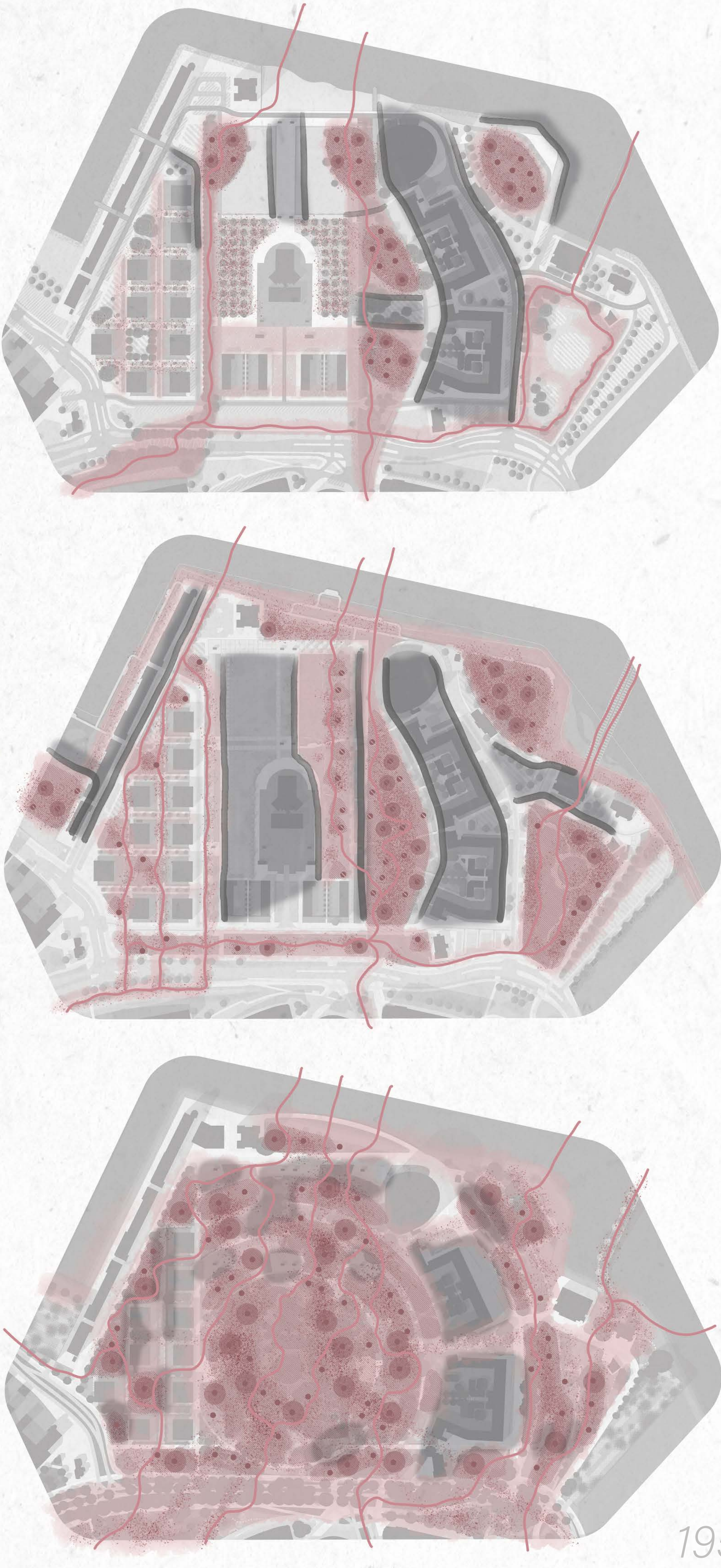
Expert assesment table with examplary fill Garry Bakker

Subject	Question	Alt. 1 vu	Alt. 1 u	Alt. 1 n	Alt. 1 s	Alt. 1 vs	Alt. 2 vu	Alt. 2 u	Alt. 2 n	Alt. 2 s	Alt. 2 vs
Mating	*Design facilitates mate garding and promote male-female encounters.*				■					■	
Growing	*Design provides isolated, insulated spaces for female martens to nest and pups to grow up.*				■						■
Settling	*Design aids aid the safe dispersal of juveniles towards a future habitat.*				■					■	
Staying	*Design effectively incorporates the socio-spatial organisation of martens.*				■						■
Resting	*Design provides permanent and flexible day shelters during all seasons.*				■					■	
Moving	*Design aids the safe traversal of martens within their habitat.*				■					■	
Foraging	*Design provides the needs of a marten's herbivoric diet.*				■					■	
Brown rat predation	*Design provokes brown rat predation by martens and decreases its food/shelter availability.*			■					■		
Human acceptance	*Design accounts for possible marten disturbance on humans*			■					■		
Patch	*Design creates high quality home ranges and core areas for stone martens.*					■					■
Edge	*Design provides low quality habitat edges, aimed at decreasing disturbances related to buildings/cars.*			■					■		
Corridor	*Design creates dispersal corridors that are attractive for juveniles to use.*			■						■	
Network	*Design lays the foundation to a ecological network for a stable stone marten population.*				■					■	
UGI typologies	*Design effectively uses and adds UGI typologies that suit the marten's habitat requirements.*			■							■
Barriers	*Design makes safe traversal over blue/grey infrastructural barriers possible.*				■				■		
Vegetation	*Design incorporates vegetation based on the habitat needs of stone martens.*				■				■		
Urban wildlife	*Design takes the safe interaction of and existence with other urban wildlife into consideration.*				■						■
Human usage	*Design adapts human usage of green space to the needs of stone martens.*				■				■		
Feasability	*Urban green space (re)design is possible in actuality.*		■				■				
Conclusion	*Urban green space is designed to adapt a stable stone marten population.*				■					■	

vu	Very unsuitable
u	Unsuitable
n	Neutral
s	Suitable
vs	Very suitable

8.7 APPENDIX 7

Habitat requirement diagrams park-scale alternatives



Mating

Nesting & rearing

Pup dispersal

Territory

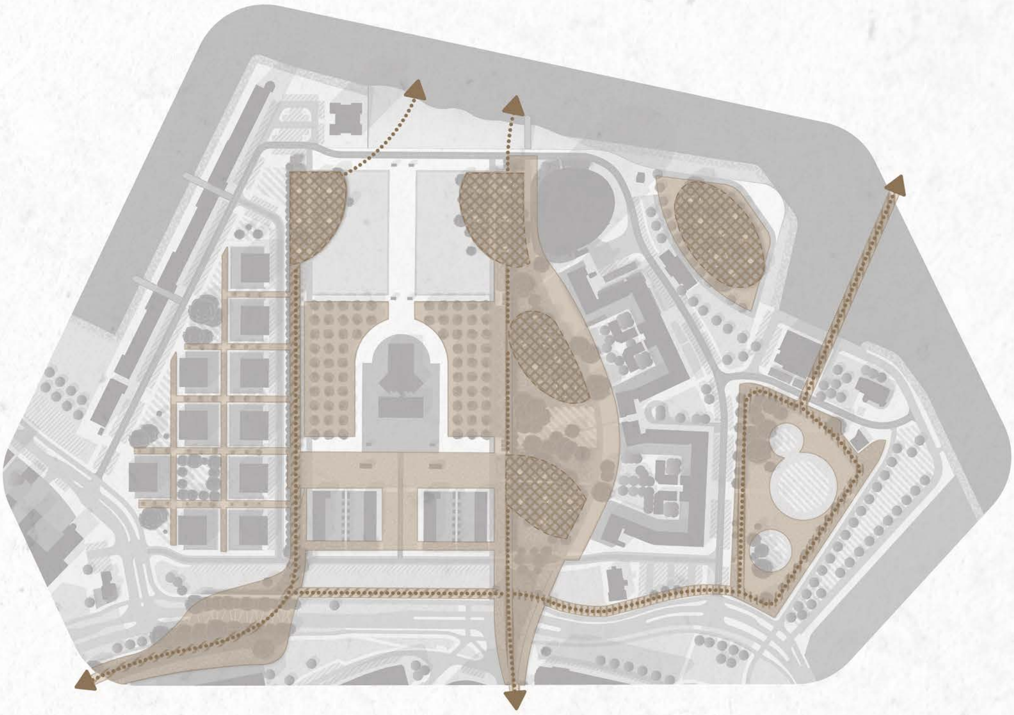
Shelter

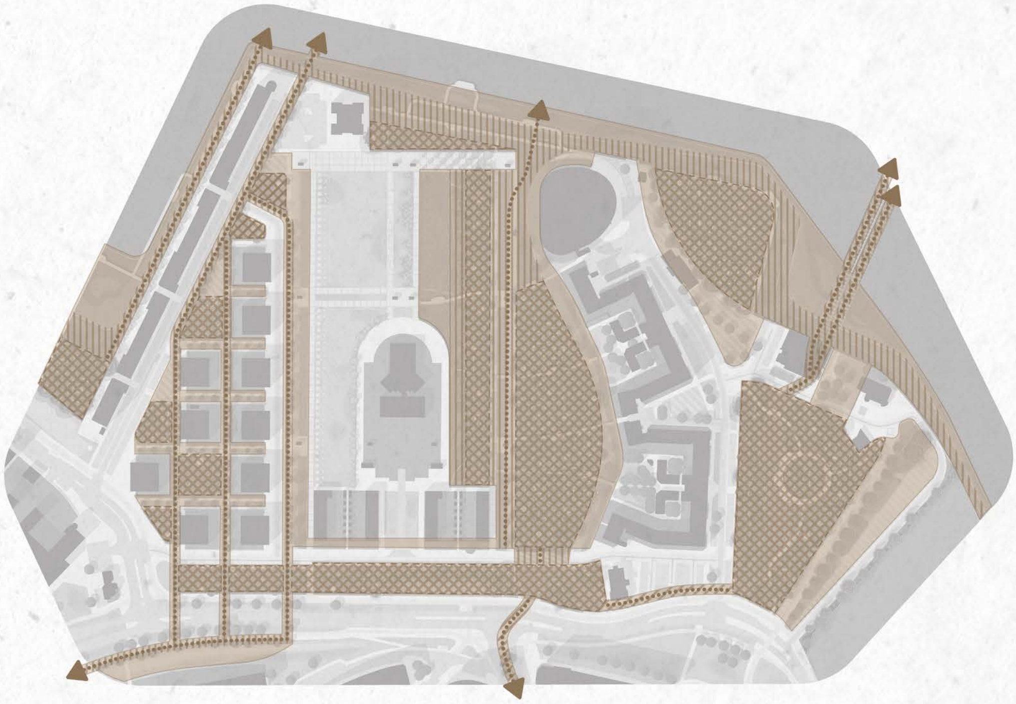
Movement

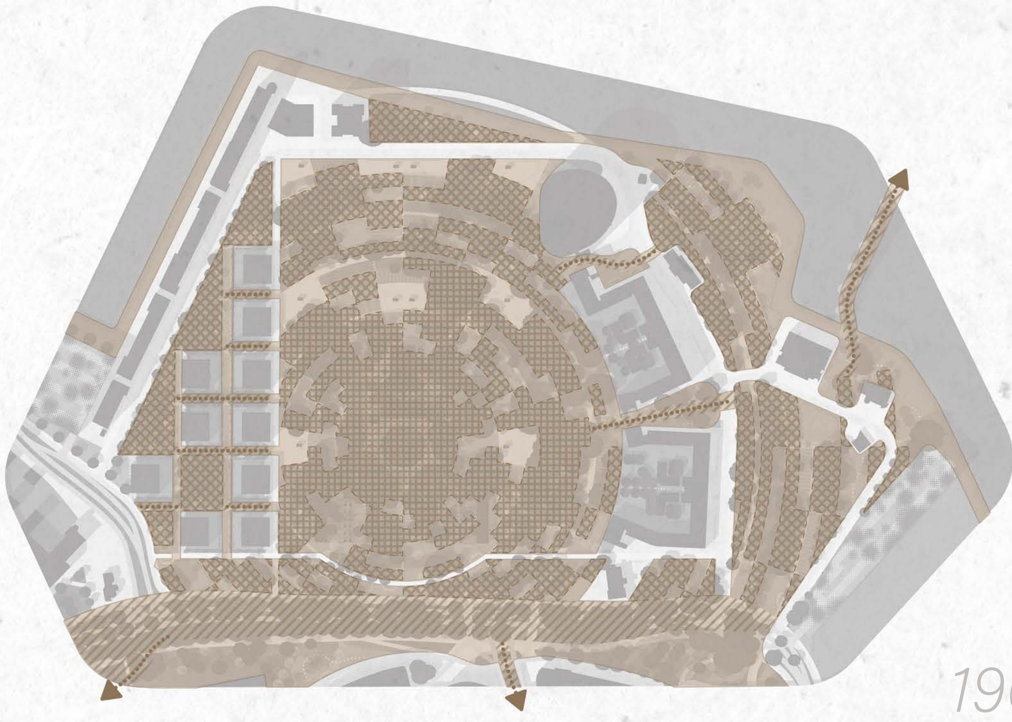
Foraging

8.8 APPENDIX 8

Open space system diagrams park-scale alternatives







Core area

High habitat quality

Edge habitat

Dispersal corridor

8.9 APPENDIX 9

Self-assesment table with notes Jasja Dekker

Part 1

D.G.	Alt. 1		Alt. 2		Alt. 3		D.C.	Alt. 1	Alt. 2	Alt. 3	Notes Jasja Dekker
1	++	Although aimed at 2f:1m, borders further divide possible marten habitats.	+	Larger habitats are strongly divided, but small habitat patches have minimal edge habitat.	--	No strong infrastructural barriers and little differentiation in possible male territories.	1a	++	+	--	Easy-to-patrol boundary areas (often open areas) serve as suitable habitat separations.
							1b	++	+	-	
							1c	++	o	--	
2	+	Uses solely marten heaps, small core areas and increased human usage could create nuisance for nesting females and pups.	+	Partly uses tree-bound marten boxes. Therefore pup traversability is possibly impacted and nests are badly insulated.	++	Uses solely marten heaps. Safest conditions for females to rear and marten pups to play and scavenge freely. Possibility of building nesting.	2a	++	++	++	Wide spread of nesting location decreases chance of building nesting for female individuals dwelling on the edges of the marten network.
							2b	++	-	++	
							2c	o	++	++	
							2d	+	+	++	
							2e	++	++	++	
							2f	+	+	++	
							2g	++	++	++	
							2h	++	o	-	
3	++	Corridors frequently crossed by foraging sites, strong continuity in vegetation layers.	++	Corridors lined with fruiting plants, dense grass/herblayer to constantly maintain overview whilst being sheltered.	-	Minimal direction in movement due to little planting continuity. Densely vegetated corridors, can be preceived disorienting.	3a	++	++	++	During dispersal, marten pups require lower edge vegetation to both move sheltered and maintain visibility; overly dense vegetation can be disorienting.
							3b	++	++	+	
							3c	+	++	+	
							3d	++	++	-	
4	+	Female/male-specified habitat requirements to be found within core areas, yet seperated in edge habitat. Smallest potential predation pressure, largest potential human marten co-occurance.	++	Female/male-specified habitat requirements to be found within core areas, decentralised in other park areas. Large potential predation pressure, large potential human marten co-occurance.	+	Female/male-specified habitat requirements to be found throughout the park, possible cause for territorial agression. Largest potential predation pressure, smallest potential human marten co-occurance.	4a	++	++	++	Although a 15ha (f) / 30ha (m) territory size is a realistic starting point for design, there are enough individuals monitored in similar environments living in even smaller densities. A small areal does not have to be a limiting factor for habitat provision densification. Based on the proposed design alternatives inhabitation of 2, 3 or 4 female martens is thought reasonable.
							4b	-	+	++	
							4c	++	+	--	
							4d	o	+	++	
							4e	o	++	+	
							4f	++	++	--	
							4g	++	+	-	
5	+	Secure denning locations concentrated in urban open space. Possible nuisance due to increased recreational value and less flexible day shelters due to a small vegetated areal with organic debris in comparison to the other alternatives.	O	Permanent day shelters partly consist of tree-bound marten boxes. Easy food availability and familiarity with marten heaps is partly lost. Predation pressure is lower in comparison to other alternatives. Permanent day shelters are badly insulated.	++	Overall excellent conditions for sheltering. Best provision of flexible day shelters due to abundance of natural landscape elements. Possibility of building denning.	5a	++	++	++	
							5b	++	++	++	
							5c	++	++	++	
							5d	++	--	++	
							5e	++	+	++	
							5f	++	++	++	
							5g	++	--	++	
							5h	++	--	++	
							5i	++	-	++	
							5j	o	++	++	
							5k	++	o	-	
6	++	Forest type and indicator species chosen based on their suitability of 6a/6b. Select species, unfavoured by rats, used to design edge habitats. Most effective in determining rat occupancy	+	Forest type and indicator species chosen based on their suitability of 6a/6b. Nature type unfortunately frequently inhabited by brown rats.	+	Forest type and indicator species chosen based on their suitability of 6a/6b. Best at connecting foraging and shelter sites of stone martens and brown rats. Highest chance of movement along private properties.	6a	++	++	++	Waste disposal dumps, wet areas and high shrub coverage are leading sources for rat infestations.
							6b	++	++	++	
							6c	-	+	++	
							6d	++	++	++	
							6e	++	--	--	
							6f	o	o	++	
							6g	++	+	--	

							6h	++	+	--	
7	++	Indicator species chosen based on suitability of 7a/7b/7c.	++	Indicator species chosen based on suitability of 7a/7b/7c.	+	Indicator species chosen partly suitable of 7a/7b/7c. Alternative with most uncontrollable succession.	7a	++	++	++	
							7b	++	++	+	
							7c	++	++	+	
							7d	o	o	--	
8	-	Patch size not conform the amount of martens (f/m) designed for.	-	Patch size not conform the amount of martens (f/m) designed for.	O	Patch size not conform the amount of martens (f/m) designed for. Only alternative with core areal suitable for 1f/1m according to the research.	8a	x	x	x	See note 'territory'
							8b	--	--	--	
							8c	--	-	++	
							8d	++	++	++	
							8e	x	x	x	
9	++	Largest share of low quality habitat, needed for food provision. Distinct borders between core, edge and built area.	-	Little edge habitat, often abrupt transition from habitat to built area.	--	No distinct edge habitat defined.	9a	++	-	--	
							9b	++	o	--	
							9c	++	-	--	
							9d	++	o	--	
10	+	Few dispersal routes interrupted by the need of overground road crossing.	++	Strong corridor system: completely uninterupted and lined with multiple places to rest, hide, shelter and forage.	+	Although plenty dispersal possibilities, routes are poorly defined. This can disrupt crossing martens.	10a	o	++	-	Safe road crossings for martens are important for marten dispersal, surface passages are most likely to be used. Despite excellent climbing ability, martens prefer to traverse continuously over ground surfaces. This is mostly because airborne crossings, such as tree bridges, will initially be more difficult for stone martens to locate.
							10b	++	++	++	
							10c	+	++	++	
							10d	+	++	++	
11	+	Cleary defined habitat patches and corridors.	++	Cleary defined habitat patches and corridors. Corridor density adapted to different urban densities.	O	No definition of ecological network in relation to urban tissue.	11a	x	x	x	
							11b	+	++	o	
							11c	x	x	x	
12	+	UGI typolgies clearly aid dispersal movement to appropriate living areas.	++	Highest landscape variety, clear usage of openly vegetated green structures.	+	Minimal L-UGI's. Monotony in forest vegetation non- favourable of diverse necessities.	12a	+	++	--	Vegetation type diversity naturally supports the marten's needs, while uninterrupted linear plantings of herb-rich grasslands improve their traversability.
							12b	++	++	++	
13	+	Most limited in safe crossing possibilities, enhanced by possibly increased traffic congestion	++	Corridors provide continuous same-level crossing that are uncrossed nor undisturbed by roads.	++	Infrastructural barriers have reduced traffic congestion, combined with patchy vegetation along the length of all roads make traversal throughout the whole park safe.	14a	-	x	+	Provision of road-accompanying vegetation is important and often sufficient to facilitate a safe road crossing on quiet roads. By providing fragmentary vegetation, an overview of the presence of dangers for both road users and martens is better and also ensures that the barrier will be crossed instead of parallelly followed. Also see note 'corridors'
							14b	++	x	++	
							14c	++	++	++	
							14d	--	+	++	
14	++	Nature type and according indicator species chosen based on suitability of 13a/13b/13c/13d. Most unnatural structuring and positioning of vegetational layers.	++	Nature type and according indicator species chosen based on suitability of 13a/13b/13c/13d. Most variety in vegtation types.	++	Nature type and according indicator species chosen based on suitability of 13a/13b/13c/13d. Most flexible den location, shelter opportunities and vegetal food resources.	13a	++	++	++	
							13b	++	++	++	
							13c	+	+	+	
							13d	+	+	+	
15	+	Alternative provides the most space to separate habitat areas for martens and birds using marten-proof measures.	+	Possible introduction of riperian and aquatic fauna not or minimally observed in Rotterdam.	++	Alternative has the highest chance of inhabitation by other urban wildlife existing occuring within Rotterdam. Prey availability is potentially large and inhabitation by other predators of the brown rat is highly likely.	15a	+	+	+	Despite fruit being a major part of the stone marten's omnivorous diet, its distribution in natural habitats is often influenced by the presence of potential prey. The more inviting the urban green space is for other animals, the easier it is for the stone marten to meet its dietary needs.
							15b	+	o	-	
							15c	+	++	++	
							15d	++	++	++	
							15e	+	+	++	
							15f	+	+	++	
16	-	Marten habitats are built around and seperated by existing amenities which possibly stresses day resting martens.	++	Fast recreation concentrated in built areas intended as inhabitable by marten. Routing is rerouted and boardwalks encourage nature tourism.	++	Minimal disruption due to sporadically distributed small areas with slow recreation possibilites in greenery, unpaved routing an	16a	+	++	+	
							16b	--	++	++	
							16c	-	+	++	
	16/32		20/32		12/ 21		Overall score				

Part 2