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Planning Green Infrastructure Using Habitat Modelling. A Case Study of the Common Toad in Lomma Municipality

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William Walker

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Department of
Physical Geography and Ecosystem Science
Lund University
Sölvegatan 12
S-223 62 Lund
Sweden

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William Walker

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Supervisor: Karin Hall

Course coordinator: Jonas Ardö

Department of Physical Geography and Ecosystems Science

Lund University

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Abstract

For an ecosystem to be able to continue to provide important services to society, it must be able to adapt to change. As part of an ecosystem, the ability of a species to migrate in the landscape is vital for the adaption to change. A green infrastructure allows the movement of species in a landscape fragmented by human influenced land use. The importance of a green infrastructure is twofold in a changing climate. An increased frequency of extreme weather events will create changes in food availability, competition and the physical components of an ecosystem. A green infrastructure also provides services which are important for society's adaption to climate change such as water retention and shade.

This thesis looks at the composition of green infrastructure in Lomma municipality and the opportunities it provides for the common toad (*Bufo bufo*) to be able to migrate in the landscape. A habitat model was created for the common toad which was used to evaluate Lomma municipality's plan for extending existing green infrastructure. Lomma is located in a low lying landscape on the Öresund coast. In a changing climate the risk for flooding in Lomma is predicted to increase. Flooding was used as an example of a disturbance on the municipality's green infrastructure and the common toad's habitat with the aim of facilitating planning of green infrastructure in the future.

The result of the evaluation of Lomma municipality's green infrastructure was that, in general, the common toad's habitat followed the infrastructure. A number of locations in the landscape that lacked connectivity had been identified for new green corridors. The common toad is not representative of all species and so there were migration paths that did not conform to the green infrastructure plan. Using flooding as a disturbance resulted in a reduction in the toad's habitat area and also caused a break in migration connectivity in the landscape.

Key Words: *Green infrastructure, planning, habitat model, ecosystem services, adaption to climate change, common toad*

Sammanfattning

Om ett ekosystem ska fortsätta att förse samhället med viktiga tjänster måste det vara anpassningsbart. Som en del av ett ekosystem är arters förmåga att förflytta sig över landskapet vitalt för anpassningen. Grönstruktur underlättar förflyttningen av arter i ett landskap fragmenterat av bebyggelse och barriärer. Vid ett förändrat klimat är grönstruktur viktigt av två anledningar. Ökat antal extrema väder kommer att förändra tillgänglighet av föda, konkurrens mellan arter och fysiska komponenter i ett ekosystem. Grönstruktur tillhandahåller även tjänster som är viktiga för samhällets förmåga till klimatanpassning, så som vattenfördröjning och skugga.

Denna uppsats undersöker uppbyggnaden av grönstruktur i Lomma kommun och de möjligheter de skapar för vanlig padda (*Bufo bufo*) att förflytta sig över landskapet. En habitatmodell för den vanliga paddan har skapats vilken har använts för att undersöka Lomma kommuns plan för utvidgning av grönstruktur. Lomma ligger i lågt landskap vid Öresunds kust. Vid förändringar i klimatet är risken för översvämningar i Lomma därmed sagt att öka. Översvämning är således använt som ett exempel på störning på Lommas grönstruktur och vanlig paddas habitat med syfte att underlätta planeringen av grönstruktur i framtiden.

Resultatet av utvärderingen av Lomma kommuns grönstruktur var att den vanliga paddans habitat följde grönstrukturen. Flertalet platser i landskapet som saknade konnektivitet har identifierats i Översiktsplanen 2010 för att skapa nya gröna korridorer. Vanlig padda representerar inte alla arter, därför fanns spridningsvägar som inte stämde med planen för grönstruktur. Användandet av översvämning som störning resulterade i en minskning av paddans habitat och orsakade brytpunkter i konnektivitet i landskapet.

Nyckelord: Grönstruktur, planering, habitatmodellering, ekosystemtjänster, klimatanpassning, vanlig padda

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Contents

1. Introduction

The frequency of extreme weather events is likely to increase over the next century (Hartmann et al. 2013) causing changes in the physical and biological components of ecosystems (Blaustein et al. 2010). In a changing climate, the ability of an ecosystem to adapt and maintain its function is important for the continual provision of vital services to society. Ecosystem services such as the regulation of water and temperature are an important part of society's adaption to climate change (Boverket 2012a). Disturbances such as flooding or disease are a natural part in an ecosystem's functionality and in order for the ecosystem to be resilient, species need to be able to adapt. This involves having the ability to migrate in a landscape to find food, reproduce or avoid a disturbance. Land use transformation over hundreds of years has created a landscape of fragmented habitats. Barriers and human influenced land use type such as urban areas and agricultural land can make species migration difficult or impossible (Smith and Smith 2006). To facilitate species migration requires a green infrastructure, a network of connected aquatic and terrestrial habitats in a landscape that creates possibilities for adaptation to change.

Sweden's Parliament adopted 15 national environmental quality objectives in April 1999 and a sixteenth in November 2005. A number of these objectives are related to green infrastructure, including the sixteenth objective, A Rich Diversity of Plant and Animal Life, which has the aim of safeguarding species habitats and ecosystem services. Local municipalities have a responsibility in trying to achieve the national objectives through their role in physical planning. (Naturvårdsverket 2012)

Lomma municipality is a low lying area on the Öresund coast characterised by an open agricultural landscape. The municipality has chosen to maintain the valuable small biotopes found amongst the agricultural land and expand existing green infrastructure in order to increase biological diversity and maintain ecosystem services (Backe et al. 2008). The existing plan for green infrastructure identifies areas in the landscape where green infrastructure is to be implemented with the aim of increasing the possibilities for species to migrate.

Habitat modelling is a method that uses a Geographical Information System (GIS) to calculate the extent of a habitat for a certain species and in doing so visualise areas in a landscape that lack connectivity for migration. A habitat model can be used for planning of green infrastructure, environmental conservation (Majka et al. 2007) and for identifying areas to avoid during the development of new buildings and roads in order to maintain migration connectivity in the landscape. The common toad (*Bufo bufo*) has experienced a decline in population following land use transformation due to the expansion of agriculture (Carrier and Beebee. 2003). The toad is a suitable species for habitat modelling as it requires both aquatic and terrestrial biotopes as part of its habitat and is sensitive to different land use types and barriers in the landscape when migrating.

1.1 Aim

The aim of this study is to facilitate the planning of green infrastructure in Lomma municipality by:

- Evaluating the existing plan for green infrastructure using a habitat model for the common toad (*Bufo bufo*)
- Using flooding as an example of a disturbance, calculate the effects on the municipality's green infrastructure and on the common toad's habitat

1.2 Assumptions and Limitations

The study area for the digitalisation of land use types and for creating a model of the common toad's habitat has been limited to Lomma municipality's administrative boundary. Where literature was lacking regarding effects of different land use types and barriers on the common toads migration, advice was sought from people with experience of amphibian studies. In reality, the effects of flooding on green infrastructure and on the common toad's migration would depend upon more factors than could be included in this study. The time of year at which flooding occurred, the length of time that flood water remained before draining away and the effects of an increased ground water level were not included due to restrictions in time or restrictions in data availability. There are also many recreational and spiritual benefits provided by green infrastructure, these aspects are not discussed in this report.

1.3 Outline of Report

This report includes a Background and Theory section, a Method, Results, a Discussion and a Conclusion. The Background presents underlying theory to the study and is based on published scientific literature, reports by local governments and authorities and expertise of others with experience in relevant matters. The Method describes the processes followed, the choices made and the motivation behind them to meet the aim of the study. The Results section presents the outcome of the habitat modelling process and includes suggestions for future work with green infrastructure in Lomma municipality. The Discussion includes limitations to the method and an evaluation of Lomma municipality's existing green infrastructure plan. The conclusion presents in short the main findings of the study.

2. Background and Theory

This section first presents the scientific theory behind what a green infrastructure is, how land use transformation has created the need for a green infrastructure and why it is important in a changing climate. Some of the laws and considerations behind the planning of a green infrastructure are presented before going on to present the characteristics of Lomma municipality, their work with a green infrastructure and their predicted problem with flooding in the future. An introduction to habitat modelling and the common toad are also presented here.

2.1 What is a Green Infrastructure?

Green infrastructure is a collective term for a network of areas of vegetation and water of different sizes, character and function. The term includes everything from mature forests and lakes to parks, grass road verges and gardens. Agricultural land is not classed as a part of green infrastructure (Blomberg et al. 2013). The term green infrastructure was first introduced to Sweden in 1992 by the Swedish National Board of Housing, Building and Planning (Boverket) in a report that aimed to promote a greener environment and greater biological diversity in urban areas. In 1996 when the Planning and Building Act SFS 2010:900 (PBL) was changed, a term was added to promote the purposeful planning of green areas with the aim of creating a connected network of green areas and corridors (Regionplane- och trafikkontoret 2008). A green corridor is a strip of habitat that connects other green areas in a landscape. A green corridor is often of similar habitat type to the areas it connects but differs from the surrounding landscape. Green corridors allow for the movement of species between habitat areas in a landscape where migration is made difficult or even impossible by other land use types (Smith and Smith 2006).

In addition to providing habitats and the possibility for species to migrate in the landscape, green infrastructure has the role of providing ecosystem services. Ecosystem service is the term used to describe the utilities that humans gain from nature free of charge and is divided into three categories. Provisional Services describes resources harvested directly from nature by people such as food and water. Regulating services covers for example regulation of water quality and disease. Cultural services covers recreational and spiritual benefits gained from an ecosystem (Chapin et al. 2011). Species migration and the ability of ecosystems to provide services are closely linked as shown by the Swedish Environmental Protection Agency's definition of green infrastructure:

"*Structure in the landscape that ensures the long-term survival of habitats and species by ensuring the possibility to migrate and thereby maintaining the ability of ecosystems to provide important services*" (Naturvårdsverket 2011, p5)

This connection and the importance of green infrastructure in a changing climate are explained below.

2.2 Why Do We Need a Green Infrastructure?

Large continuous habitat areas such as forests or grasslands have been transformed over hundreds of years to meet of the needs of a growing human population (Smith and Smith 2006), resulting in a landscape of fragmented habitats separated by land use types that make species migration difficult or impossible. Land use transformation has created the need for a green infrastructure, to facilitate species migration between habitats. A habitat is defined as an area that has the resources and conditions to produce occupancy, survival and reproduction of a certain organism (Franklin et al. 2002). The habitat together with the species it sustains is known as an ecosystem, defined as the physical and biological components of an environment that interact to form a system (Smith and Smith 2006).

Historically the main reason for land use transformation has been the expansion of agricultural lands. Land use change causes the destruction of habitats and is currently the leading cause of species extinction (Smith and Smith 2006). The transformation of land use by, for example, clear cutting a forest in order to expand agricultural land has two effects, habitat destruction and habitat fragmentation. Habitat destruction is when a habitat is transformed to the extent that it can no longer support the species originally sustained. Fragmentation is defined as the 'breaking up' of large homogenous area of habitats into smaller scattered fragments (Laurance 2010). Fragmentation can result in a mosaic of small isolated habitat patches surrounded by other land use types (Smith and Smith 2006).

The consequences of habitat fragmentation for a species population are that it can become spatially divided into smaller populations creating a metapopulation structure (Mörtberg et al. 2006). The ability of a habitat patch to support a population of a certain species is dependent on the patch's size, shape, quality and isolation in the landscape. There is a correlation between habitat size and species diversity where in general larger patches contain a greater number of individuals and a greater number of species. If the patch size is reduced below a critical size, it may not be able to support the species and a local extinction can occur (Smith and Smith 2006).

Disturbances occur naturally and are an important part in the functioning of an ecosystem. Ecosystem resilience is the capacity of the system to maintain its function and structure during and after disturbances (Chapin et al. 2011). A larger disturbance on a patch such a flooding, fire or disease may cause a species population to die out. As long as the patch is not too isolated in the landscape it can be repopulated again by individuals from another population. If this is not possible, again a local extinction may occur. If enough populations are affected negatively it can have negative consequences for the whole metapopulation (Mörtberg et al. 2006). Another effect of habitat isolation on the ecosystem resilience is the risk of inbreeding due to the lack of interaction with other populations. Species diversity is important for ecosystem resilience (Mori et al. 2013); inbreeding can result in reduced genetic variation which can lead to reduced chance of species survival (Frankham et al. 2002).

2.3 Why is a Green Infrastructure Important in a Changing Climate?

According to the Intergovernmental Panel on Climate Change's report, the average global combined ocean and land temperature has increased during the period 1880-2012 and is predicted to continue (Collins et al. 2013). The occurrence of extreme weather events is also predicted to increase (Hartmann et al. 2013). The consequences of a climate related extremes such as drought, flooding and wildfire are, disruption of food and water supply, damage to infrastructure and the alteration of ecosystems. The predicted effect of a global temperature rise of between 1.5°C and 2.5°C is that between 20 and 30 percent of all species risk extinction (SwedBio 2014).

Even small changes in the physical components of an ecosystem such as soil acidity or moisture content can have significant effects on individual species. Each species may react differently to changes but the consequences can affect the whole ecosystem. Two types of impact of climate change on ecosystems have been observed, changes in the geographical range in which species can survive and the timing of biological activity (National Academies 2009). In 2007 the Department of Agriculture (Jordbruksverket) published a report entitled 'One Meter per Hour' which was a reference to the speed at which the vegetation zone in Sweden is moving northwards due to a rise in air temperature. The report was concerned with the change in climate over the next twenty-five years and pointed out that the rise in temperature was going to allow a longer growing season (Svensson et al. 2007). Another concern in a changing climate is that the competitive relationship between existing species which may allow invasive species to gain an advantage over native species (Naturvårdsverket 2011).

In a changing climate a functioning green infrastructure has a dual purpose. It provides a network that allows different species to migrate between habitats and adapt to disturbances and changes, thereby allowing ecosystems to adapt and maintain their structure and function. The second function is that the services provided by ecosystems play an important part in society's adaption to climate change (Naturvårdsverket 2011). Examples of this are that the urban heat island effect can be reduced by evapo-transpiration and creation of shade and the risk of flooding can be reduced through the interception, infiltration and storage of excess water.

2.4 Physical Planning

Planning and creating a green infrastructure in Sweden involves stakeholders on many levels. In 1999 the Swedish parliament adopted fifteen environmental quality objectives and in 2005 a sixteenth. Several of these objectives relate to work with green infrastructure with the aim of promoting either biodiversity or ecosystem services. (Naturvårdsverket 2012) The national government works to create possibilities for the implementation of measures that can create or protect green areas. These measures are adapted by fishing, agricultural and forest industries, county administrations, municipalities and local stakeholders to meet regional requirements. Local municipalities hold a central role in physical planning and therefore have an opportunity to create or protect green areas (Naturvårdsverket 2011); they also have a responsibility to implement the environmental quality objectives (Naturvårdsverket 2012).

A municipality's Development Plan (Översiktsplan) aims to give guidance and support to decision makers about the use of land and the development of urban areas within the municipality boundary (Boverket 2011). As part of their role in physical planning, municipalities have a responsibility to take adaption to climate change into account in the planning process (PBL 2 Kap 3§), including taking measures to reduce the risk for accidents, flooding and erosion (PBL 4 Kap 3§). Green infrastructure can be included in a Development Plan as part of the process of adapting to climate change (Boverket 2012a).

A Development Plan is a balance between different interests (Boverket 2012b) as physical planning and construction of new infrastructure such as roads, railways and buildings can cause conflicts between the needs of industry, preservation of cultural heritage, recreational interests and environmental protection. Any land use change has an effect on the surrounding landscape and often, a small negative effect can be accepted if the benefits outweigh the negatives. Over a long period of time this can cause degradation to ecosystem services and to the structure and character of a landscape (Naturvårdsverket 2011). In order to prevent degradation, areas of value can be protected by law. Areas of national interest may be protected under the third and fourth chapters of the Swedish Environmental Code SFS 1998:808 (MB 3-4 Kap) as can other areas of natural value under the seventh chapter (MB 7 Kap). For those areas that are lost during development, environmental compensation can be used as a method of replacing the loss of or damage to environmental resources. The method aims to create new areas of natural value or increase the value of other existing areas to compensate for the loss of a green area. The area created does not necessarily need to be of the same type or in the same location as the one damaged or lost (Persson 2011).

For these areas to be as beneficial as possible as part of a green infrastructure there are certain factors that must be considered during the planning process. The type of area created and its location can depend on what is missing from the landscape, the properties of the landscape and the period of time over which the area will reach full potential. Certain areas of environmental value are impossible to recreate over a short period of time such as an old deciduous forest. The type of area chosen and its location can also depend upon the aim of creating the new area. With good planning it is possible to create areas with a multitude of functions that meet several aims at once[1]. The Environmental Protection Agency gives the example of a newly created wetland. If located correctly in the landscape it can reduce the risk of flooding by storing water, increase biodiversity and migration possibilities for a number of species and create recreational opportunities such as bird watching (Naturvårdsverket 2011).

There can also be conflicts of interest when creating areas of environmental value. Increase in forest, meadow or wetland area often happens at the expense of agricultural land which reduces the capacity for production of food. The transformation does not mean that the lands properties for food production are lost, the area can be transformed back should the need arise. A green infrastructure is required in both urban areas and rural areas, in urban areas there can be a conflict over the need for land to build on and the land used by a green infrastructure. Another conflict in the planning process is land ownership as this can limit the number of areas available for the creation of new green areas. By having a strategic plan for the development of green infrastructure over a longer time period, land can be bought or exchanged by a municipality in order to develop a functional green infrastructure. (Bengtsson 2013)

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[1] Movium Partnerskarp. Environmental Compensation Seminar. Habo Gård, Lomma. Muntlig communication. 6th March 2014.

2.5 Study Area - Lomma Municipality

Lomma municipality is located in western Scania on the Öresund Coast and has a land area of $56km^2$. Lomma is bordered by Staffanstorp, Kävlinge, Burlöv and Lund municipalities as shown in Figure 1. Presently the municipality's population is increasing by an average of 500 people per year which is going to require that around one hundred apartments are built per year to meet demand (Nyquist et al. 2011). As one of Sweden's smallest municipalities in terms of area (Statistiska centralbyrån 2014) this places pressure on agricultural land and green areas. Figure 2 is an example of how land use transformation between 1940 and 2012 has caused fragmentation and the loss of habitats within the municipality.

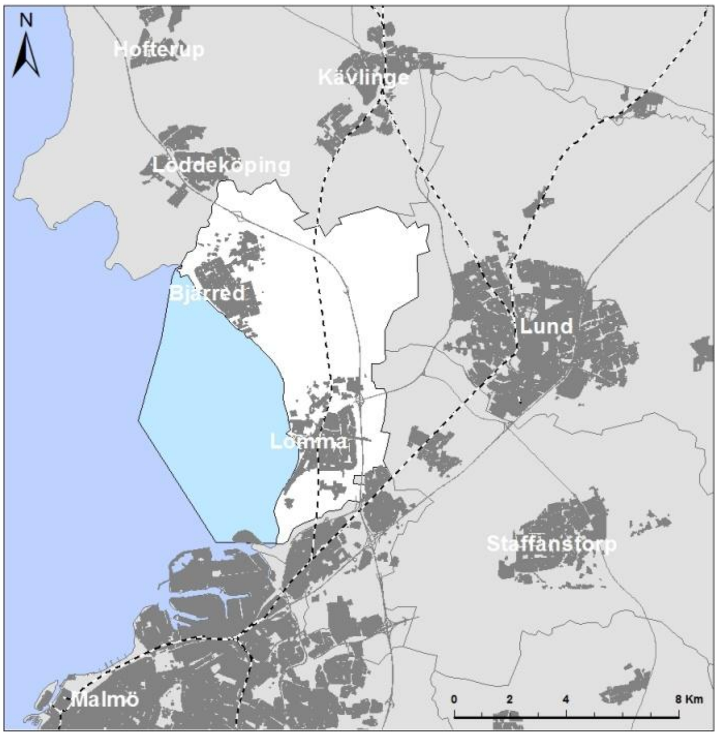


Figure 1. The location of Lomma municipality in western Scania.

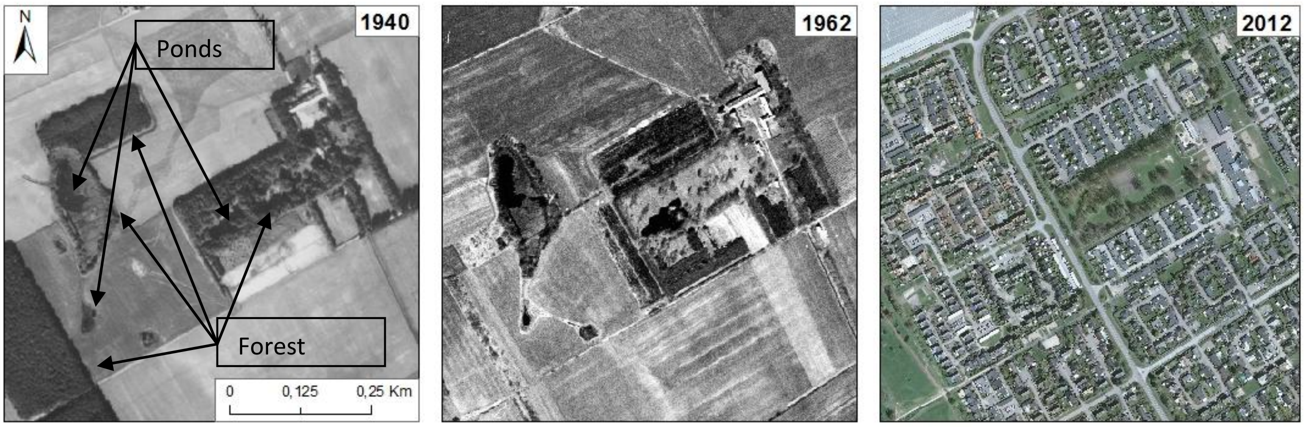


Figure 2. An example of land use change in Bjärred between 1940 and 2012. Forests and ponds are removed to increase agricultural land and later to build a residential area. See Appendix 8 for orthophoto data.

Lomma Municipality's Green Infrastructure

Although there is pressure to find land for development, the green infrastructure in Lomma includes a number of areas of high environmental value. Lomma is characterised by its 14km long coast upon which there are a number of areas of value including Alnarps Fälad and the mouth of Lödde River which are classed as Natura 2000 areas. There are also both national and local nature reserves and a number of areas that provide habitats for a number of the rare species (Nyquist et al. 2011).

Figure 3. Lomma municipality's plan for green infrastructure displaying existing and planned green corridors and migration barriers.

As part of Lomma municipality's Environment Policy it is stated that the preservation of ecosystem structure and function in order to maintain ecosystem services is a priority in all planning, development and administration of land resources. Green infrastructure is included as part of the municipality's work towards meeting several of the environmental quality objectives. These objectives include among others, Number 15, A Good Build Environment, Number 16, A Rich Plant and Animal Life, Number 8, Flourish Lakes and Streams and Number 13, A Varied Agricultural Landscape. (Björn et al. 2014)

Lomma municipality's Development Plan from 2010 includes a map as shown in Figure 3, displaying existing green infrastructure and suggestions for new green corridors. The aim of the green infrastructure according to the Development Plan is to allow the movement of species in a fragmented landscape in order to promote biodiversity and ecosystem services. The map also points out barriers that if possible should be removed in order to create better connectivity in the landscape. Barriers that are not presently possible to remove such as those created by the motorway should be removed in the future when the obstruction is rebuilt (Nyquist et al. 2011).

Flooding in Lomma Municipality

In order to be able to plan for the effects of climate change in the future, Lomma municipality employed the services of SWECO Environment AB in 2009 to model the risk of flooding in three scenarios. The model covers Höje å, Önnerupsbäcken, the coast and parts of Kävlinge River valley. The three scenarios were (i) a 100-year flood[2] in Höje å in combination with today's sea level, (ii) a 100-year flood in Höje å in combination with a sea level of +1.25 meters compared to today's sea level and (iii) a 100-year flood in Höje å in combination with a sea level of + 1.89 meters. (Wettemark et al. 2009) The three scenarios are displayed as Appendix 1-3.

2.6 Habitat Modelling and the Common Toad (*Bufo bufo*)

Part of the aim in this study is to use the common toad as an indicator of connectivity between important biotopes in order to aid planning of green infrastructure. Amphibians have characteristics and requirements that make them suitable as an indicator species for the quality and health of a habitat or environment (Rosquist 2003).The reasons for this are that amphibians use a range of habitats during their lifecycle both aquatic and terrestrial, they are sensitive to water quality due to their permeable skin and are sensitive to barriers as they move long the ground. Barriers are features in the landscape that are more difficult or even impossible for a common toad to cross. This can be for the reason that the surface requires too much energy to cross or because the risk of mortality means that a reduced number of individuals succeed. Roads are an example of a barrier; previous studies (Fahrig et al. 1995) have shown that there is a correlation between traffic intensity and amphibian mortality. Secondary effects of barriers are that they can cause genetic isolation (Beebee 2013). There is a general lack of knowledge about how railways affect amphibian migration (Trafikverket 2014a) but Reh and Seitz (1990) found that they had a significant effect on the genetic structure of populations of the common frog (*Rana temporaria*). Toads migrate between summer and winter habitats and breeding grounds but it is difficult to define an exact maximum distance of migration (MDM) for the common toad as it can depend on the individual and the environment that it is migrating through (Mörtberg et al. 2006). MDM in previous migration studies has ranged from a few meters up to six kilometres (Koffman 2012; Ray 2002).

The decline of amphibian populations around the world has been pointed out by a number of studies (e.g. Buckley et al. 2014; Stuart et al. 2004; Wake and Vredenburg 2008). The main reason for the decline of amphibian populations in Europe since the middle of the 20th century is land use transformation especially as a result of the intensification of agriculture (Carrier and Beebee 2003). In Scania, wetlands have been drained to create space for food production (Cedhagen and Nilson 1991) and in Lomma; the number of amphibians has decreased as a result of habitat destruction due to development of infrastructure or through effects of agriculture. The common spade foot toad (*Pelobates fuscus*), natter jack toad (*Epidalea calamita*) and the European green toad (*Bufo viridis*) haven't been seen in the area since the 1970s. (Pröjts 2012)

[2] 100 year flood is a level of flow in the river that has a 1/100 probability of occurring. It can occur more frequently and is not the highest level in the river that can occur.

In 2012 Ekologgruppen carried out an amphibian inventory at nine locations in Lomma municipality and in 2013 Nils Lundquist, an Environmental Investigator employed by Lomma municipality carried out an inventory at one location. A number of species were found during these species inventories, the common toad was chosen as an indicator species in this study it was found at more than any other species (Pröjts 2012, Lundquist 2013). There is also a range of literature about the species and its migration in the landscape. The common toad can be found throughout Sweden at altitudes lower than 1000 meters above sea level and can be found in many biotopes where there is shade and a moist place to hide such as forest, meadows, parks and gardens. The species is mainly nocturnal but can even search for food during the day in wet weather. In southern Sweden, the toad hibernates between October and the end of March and in the middle of April migrates to a breeding ground to reproduce (Cedhagen and Nilson 1991).

Effect of Climate Change and Flooding on Amphibians

Climate change can have direct or indirect effects on amphibians at the individual, community and population level. Climate change can cause shifts in ranges, affect migration patterns, influence food availability and change predator-prey relationships. It can also have effects on an amphibian's habitat by altering vegetation, soil and hydrology (Blaustein et al. 2010). Flooding has been chosen as part of this study as an example of a disturbance caused by climate change to investigate if the existing and planned green infrastructure is sufficient to allow migration in the landscape and the adaptation to change. The effects of flooding along a coast can result in the intrusion of saltwater into coastal wetlands which can affect the richness of amphibian species due to their permeable skins. Fresh water flooding can introduce fish into fish free ponds which can have a detrimental effect on amphibian reproduction. Flooding can cause changes to vegetation and soil moisture, which can have an impact on post-metamorphic adults and young amphibians (Blaustein et al. 2010). Other impacts of flooding are that eggs or aquatic larvae could be carried from a breeding ground and deposited elsewhere by the flood water[3].

[3] Lundquist, N. Environmental Investigator, Lomma municipality. 31st March 2014

3. Method

This section describes the methodology and rationale behind the choices made during this study. It includes a description of how the aerial photography were interpreted in order to create a land use map of the study area and how scores were assigned to this map so that the common toads migration could be modelled.

3.1 Data

All GIS work in this study was performed in ESRI ArcGIS 10 with a Spatial Analyst License, graphs and calculations were completed in Microsoft Excel. A number of data layers were available from Lomma municipality, the details of these can be found in Appendix 5 and 6. The properties and sources of the orthophotos used in this study are described in Appendix 8. All maps and illustrations have been produced by the author using the available data or data created by the author.

3.2 Interpretation of Aerial Photographs

The basis to creating a model of the common toad's habitat in Lomma municipality is a digital map that covers different land use types. This was created in a Geographic Information System (GIS) by initially analysing and interpreting different land use and vegetation types from digital orthophotos and secondly by digitalising the interpreted areas. The properties of the orthophotos used for this study are listed in Table 1. Land use and vegetation types can be identified in orthophotos by their shape, size, position, texture and the shadows they create. The most recent photo available was a colour orthophoto taken in spring/summer 2012 and was used to ensure that the information used in this study was as up to date as possible. A second orthophoto in colour and at a higher resolution, taken in April 2010 was used to aid vegetation interpretation as it was taken before the deciduous vegetation had gained their leaves for the season. A third orthophoto, in colour- infrared (CIR), was also used to aid vegetation interpretation as the spectral reflectance of vegetation differs more in the near infrared part of the light spectrum than in the traditional colour part meaning that different vegetation types are more easily identifiable on a CIR image than a traditional colour image. The sources of the orthophotos are given in Appendix 8.

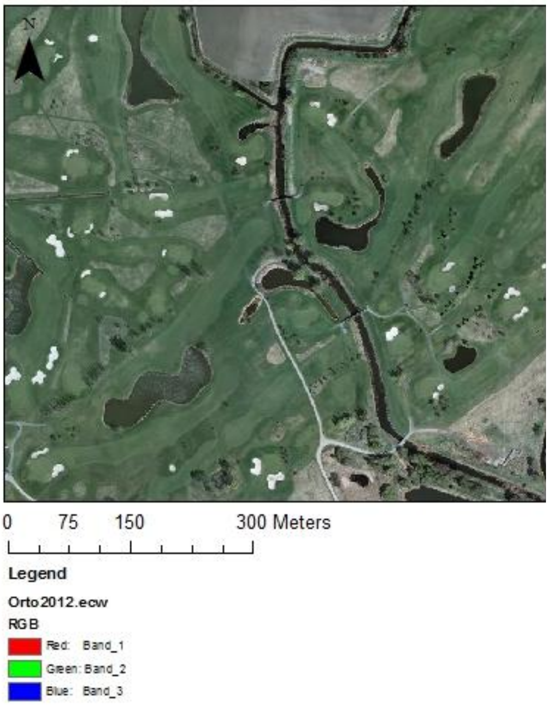
Table 1. The properties of the orthophotos used for creating the digital map of Lomma municipality.

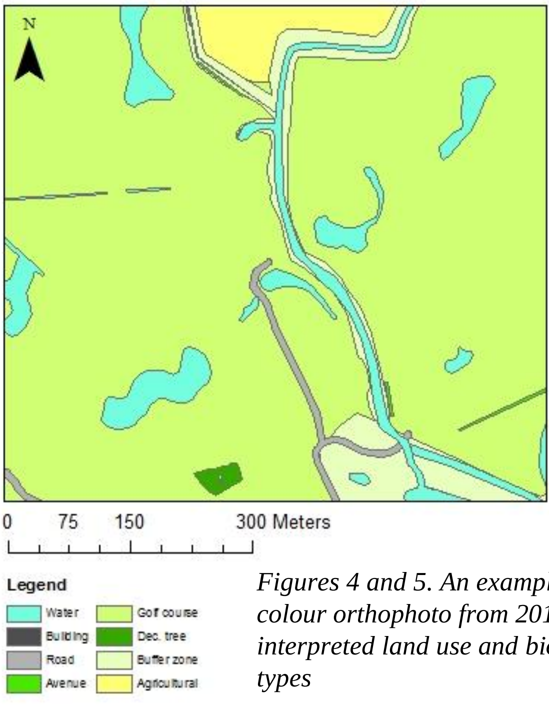
Date	Reflectance properties	Spatial resolution (cm)	Reference system
Apr-10	Colour	10	SWEREF99 13.30
Jun-10	CIR	25	SWEREF99 13.30
Spring/summer 2012	Colour	25	SWEREF99 13.30

Digitalising Land Use Types

ESRI ArcMap 10 was used for both interpreting and digitalising land use and vegetation types in the study area. During the digitalising phase, vector data was created containing polygons with related attributes for the different land use and vegetation types. A number of land use types in the study area (such as the coast line, watercourses, agricultural land, buildings and the road network) were available as vector data from Lomma municipality (see Appendix 5). The aim of creating the digital map was that it would be used to define biotope[4] types important for the common toad's habitat in order to model connectivity between breeding grounds.

A common toad's habitat is built up of a number of different biotopes and it was therefore considered appropriate to classify the different land use and vegetation types in the study area based the type of biotope they belonged to rather than the type of vegetation type they contained. Information published by the Swedish Environmental Protection Agency (Naturvårdsverket 2013a) and the Department of Agriculture (Eriksson et al. 2008) was used to help classify land use and vegetation types into biotope types. The different biotopes used in this study were modified from previous studies focusing on modelling the habitat of a common toad population (Henriksson 2007; Mörtberg et al. 2006). Advice was sought from Nils Lundquist, an Environmental Investigator working for Lomma municipality who has previous experience of amphibian studies. An example of the classification method is an area of deciduous trees belonging to a rural farm was classified as a 'Farm Environment' and a description of the vegetation type saved as an attribute. A description of the biotope classification and a description of the modification to data available from Lomma municipality can be found in Appendix 4 and 5. Figure 4 below is an example of a small section of the 2012 colour orthophoto that covers the study area. Figure 5 shows the same area digitalised into biotope and land use types.





Figures 4 and 5. An example of a colour orthophoto from 2012 and interpreted land use and biotope types

[4] A biotope is defined as an area of relatively homogeneous structure and composition in a varied landscape, for example a meadow or deciduous forest. A biotope can represent just a small part of one species' habitat or contain a number of different habitats for other species (Mörtberg et al. 2006).

Interpretation Difficulties and Evaluation

For those land use or vegetation types that were difficult to interpret from the available orthophotos it was, depending on the location of the area in the landscape, occasionally possible to use the Street View function available in Google Maps. A number of areas were also visited in the field to evaluate if the vector data created during the digitalising phase was accurate enough to be used to calculate a model of the common toad's habitat. Twenty areas were chosen using the Create Random Points function available in ArcMap. Any points created in the sea or on a road were ignored and the process repeated until twenty suitable points had been produced. The biotope type found at all of the twenty points matched the classification identified during the digitalising phase.

3.3 Calculating the Effect of Flooding on Green Infrastructure

The total perimeter length and area of the individual biotopes was first calculated in ArcMap. The total area was used to quantify the individual biotope types in the landscape with the exception of agricultural trenches and allée[5] where length was used instead. This was deemed more appropriate than area due to their long, thin shape. The three flooding scenarios calculated by SWECO Environment AB were used to calculate the temporary loss of the different biotope types that form Lomma municipality's green infrastructure. This was done by using the Erase function in ArcMap to remove to section of each biotope flooded in each scenario. The remaining area or length of each biotope was recalculated.. The three flooding scenarios were (i) a 100-year flood in Höje å in combination with today's sea level, (ii) a 100-year flood in Höje å in combination with a sea level of +1.25 meters compared to today's sea level and (iii) a 100-year flood in Höje å in combination with a sea level of + 1.89 meters (Wettemark et al. 2009) see Appendix 1-3.

3.4 Modelling of the Common Toad's Habitat

Potential migration zones for the common toad in Lomma municipality were modelled using the Cost Distance tool that is available under the Spatial Analyst extension in ArcMap. The starting points of the migration zones were ponds or wetlands that were confirmed suitable or judged to be suitable as breeding areas for the common toad. Migration was based on friction values assigned to a land use map, known as a friction map, and a maximum distance assigned to the toad's migration. In areas where calculated migration zones met, it suggested that it is possible for a common toad to migrate between breeding grounds.

The tool Cost Distance is based on graph-theory and uses an algorithm to find the path in the landscape that causes least 'cost' to the toad as it passes different land use types. Each theoretical toad population is assigned a Potential Migration Energy (PME) (Joly et al. 2003) also known as a Maximum Cost of Migration (MCM) (Ray et al. 2002) that decreases as the toad migrates over different land used and biotope types. As in a previous studies on toad migration (Joly et al. 2003; Ray et al. 2002; Henriksson 2007) it has been assumed that the toad does not forage during the migration and therefore when PME falls to zero, the limit of

[5] A single or double line of deciduous trees planted along a road or in an open landscape (Naturvårdsverket 2013a) Also known as an avenue.

the migration zone has been reached. PME is calculated my multiplying the maximum distance of migration (MDM) by the cost of the most favourable biotope type for migration and reproduction from the perspective of a common toad (Ray et al. 2002).

The friction map is in raster format where the cost to the toad to pass a cell is calculated by the Cost Distance tool as the sum of the assigned friction value multiplied by the cell size. The cost of moving between cells depends on the direction of movement and is calculated using equations 1 and 2 below (Esri 2011).

The cost of moving between cells in a horizontal or vertical direction is calculated using equation 1.

$a1 = \frac{\text{Cost 1}+\text{Cost 2}}{2}$ *Equation 1*

The cost of moving between cells in a diagonal direction is calculated using equation 2.

$a1 = \sqrt{2}\frac{Cost\ 1+Cost\ 2}{2}$ *Equation 2*

Where:
$a1$= Cost of moving between cells
Cost 1 = assigned friction value in cell 1
Cost 2 = assigned friction value in cell 2

Based on previous studies, the MDM for this study has been set to 500 m and 2000 m (Ray et al. 2002; Henriksson 2007). PME was calculated based on the most favourable friction value (see page 18) to be 2500 m and 10000 m.

Friction Map

A friction map consists of a matrix of cells covering the study area where friction values are assigned to each land use type. It was first thought that Swedish Land Cover Data (SMD) would be suitable for this purpose. On closer inspection it was decided that because SMD has a resolution of 25 m × 25 m it would produce better results in the habitat model to create a new friction map of higher resolution using the vector data created by digitalising the high resolution orthophoto. A 2 m × 2 m resolution was chosen for the new friction map as a digital elevation model (DEM) of the study area with the same resolution was available that could also be incorporated in to the model. To produce the friction map a raster map was produced coving the study area by first converting all polygon features to raster features and then combining them using Raster Calculator.

Assigning Habitat Suitability Scores to Land Use Types

Suitability scores were assigned to each land use and biotope type based on their properties as potential habitats or migration zones for a common toad (Majka et al. 2007). The suitability score classes were modified slightly from a scale of 0-100 to 0-95, where zero is least and 95 is the most favourable biotope type. The reason for this modification was that the scores would later be subtracted from 100, meaning that a land use type with a maximum suitability score would result in a friction value of zero in the final friction map. A score of 5 for the biotope type most favourable as a habitat or migration zone for a common toad was based on previous toad studies (Henriksson 2007; Ray et al. 2002). The suitability score classes are show in table 2 below.

Table 2. The habitat suitability scores used in creating the friction map

Habitat Suitability Score	Properties
95	Optimal - best habitat, highest survival and reproduction
75	Good - suitable for food and migration
50	Sub-optimal -less suitable for food and migration
25	Unsuitable - occasional use and migration
0	Migration barrier

The assignment of suitability scores was carried out with advice from Tim Schnoor, an Environmental Strategist and Nils Lundquist[6], an Environmental Investigator who both work for Lomma municipality and have experience of amphibian studies, and also by consulting previous toad migration studies (Mörtberg et al. 2006; Henriksson 2007; Ray et al. 2002). Suitability scores assigned to each land use and biotope type are shown in Table 3. It was decided that it would be too general to assign the same score to every barrier and so they were separated into extra suitability classes as shown in Table 4.

Table 3. The assignment of habitat suitability scores to land use types

Habitat Suitability	Biotope Classification
Optimal	Deciduous forest, mixed forest, natural grass, ponds, agricultural trenches, watercourses, buffer zones along watercourses, vegetation surrounding ponds
Good	Coniferous forest, farm environment, in-field buffers
Sub- optimal	Allée, park, agricultural ground, golf course
Unsuitable	Road verge, urban areas, industrial areas
Barrier	See Table 4

[6] Schnoor, T. Environmental Strategist, and N. Lundquist, Environmental Investigator, Lomma municipality. Verbal communication, 18th February 2014

Barriers to Migration

Roads in Lomma municipality were classed according to the average daily traffic volume (ÅDT). This was based on data available from the Swedish Transport Department (Trafikverket 2014b). The classes were based on a study around the effects of barriers on cervids (Helldin et al. 2010). As the suitability scores assigned to each class could be modified for the common toad it was deemed that the four classes used in (Helldin et al. 2010) would also be suitable for this study.

The same scoring system as used previously was used to assign suitability scores to barriers. Score assignment was again completed with advice from Schnoor and Lundquist[7]. All roads with an ÅDT of fewer than 10000 vehicles per day were assigned a score that meant that a proportion of the toads that attempted to cross would succeed for the reason that toads are most active during the evening and night whereas the highest traffic load occurs during the day. Roads with an ÅDT of over 10000 vehicles were assigned a score of zero meaning that toads had a zero percent chance of successfully crossing the barrier. In certain places in the study area are tunnels that allow the flow of water from agricultural trenches under major roads. Such tunnels were considered possible for the common toad to use in order to pass the barrier.

An average of twelve trains pass through the study area per day (Petersson 2014) so the chance of mortality on the railway line is less than on many of the roads. As the common toad moves along the ground and does not jump, the railway rails make it difficult for the toad to pass. For this reason the railway line was also assigned a score of zero. The sea and all buildings were assigned a score of zero because they are physically impossible for the toad to cross. The classes and suitability scores assigned to each barrier are shown in Table 4.

Table 4. The suitability scores assigned to barriers

Barrier	**Suitability Score**
Road ÅDT 0-1000	25
Road ÅDT 1001-4000	20
Road ÅDT 4001–10000	10
Road ÅDT>10000	0
Railway	0
Sea	0
Buildings	0

[7] Schnoor, T. Environmental Strategist, and N. Lundquist, Environmental Investigator, Lomma municipality. Verbal communication, 28th February 2014

Effect of Ground Gradient on Migration

Depending upon how an animal moves in the landscape there can be other factors that affect the ease of migration. As a common toad moves along the ground it is likely that the gradient of the ground can have an effect on the amount of energy it takes to cross certain surfaces. In 2008 Lomma municipality employed the services of Blom Sweden AB to carry out a laser scanning over the landscape with the aim of creating a high resolution Digital Elevation Model (DEM). Slope gradient was calculated from the available DEM using the Slope tool under Spatial Analyst in ArcMap. Ground gradient was divided into classes of 5° and assigned suitability scores following the same system as previously with advice from Schnoor and Lundquist[8]. Ground gradient classes and suitability scores are shown in Table 5.

Table 5. Ground gradient classes and the assigned suitability scores

Ground Gradient (°)	Suitability Score
0 - 5	95
6 - 10	90
11 - 15	85
16 - 20	80
21 - 25	75
26 - 30	70
31 - 35	65
36 - 40	60
41 - 45	55
45 -	50

Combining Land Use and Ground Gradient

In order to combine the suitability scores assigned to land use types and ground gradients into one friction map, each factor had to be assigned a weight that represents each individual factor's importance from the perspective of a common toad's migration. There was a lack of literature about the effects of ground gradient on amphibian migration but according to Lundquist[9] the common toad is one of the amphibians least affected by ground gradient. For this reason, ground gradient was assigned a weight that made it less important than land use type. The two factors were combined into one raster layer using the weighted geometric mean method which means that a high suitability score in one factor cannot compensate for a low score in another factor. If a class in one of the factors has suitability score of zero, the resulting value after the combination will be zero (Majka et al. 2007). An example of how the two factors were combined is shown in Table 6.

[8] Schnoor, T. Environmental Strategist, and N. Lundquist, Environmental Investigator, Lomma municipality. Verbal communication, 28th February 2014

[9] Lundquist, N. Environmental Investigator. Verbal communication, 28th February 2014

Table 6. An example of how land use types and ground gradients were combined

Factor	Class	Suitability Score	Function	Weight	Value	Function	Final Cell Value
Land use	Road verge	25	Exponentiate	80 %	13,12	Multiply	30,2
Ground gradient	31-35°	65		20 %	2,3		

At this stage the value in each cell in the raster data represented the suitability of each biotope or land use type as a habitat or for migration from the perspective of the common toad. In order to convert suitability scores into friction values, all values were subtracted from 100 using Raster Calculator. All barriers that were assigned a suitability score of zero according to Table 4 received a friction value of 100. During early attempts to model the common toad's habitat in this study it became obvious that a friction value of 100 was too low to have the effect of a total barrier. To correct this, raster data was created containing all of the total barriers in the municipality. These were assigned a friction value of 10000 with the reason that when added to the raster data created with the geometric mean method the final value of the total barriers would be greater than the common toad's PME making the barriers impossible to cross. The final friction values were compared with previous studies (Henriksson 2007; Ray et al. 2002; Joly et al. 2003).

Selection of Breeding Grounds

Calculation of the common toad's migration over the whole study area required that a greater number of ponds were defined as suitable breeding grounds than those covered by the species inventories carried out by Pröjts (2012) and Lundquist (2013). As it was not possible due to time constraints and it being the wrong time of year to carry out an inventory on toad presence, breeding grounds had to be defined from properties identifiable from orthophotos and from local knowledge.

A table was produced containing the properties of those breeding grounds where the common toad had been identified. There were too few areas covered in these inventories to be able to carry out a statistical analysis but the characteristics were used to help identify other possible suitable areas for breeding. A similar method as used by Joly et al (2001) was tested where a buffer zone was created around each area identified by the two studies as breeding grounds and the characteristics of the landscape within each zone was quantified in Appendix 7. A radius of 500 m was chosen as this distance was used by Koffman (2012) to represent the activity area of a common toad. No correlation was found between the characteristics of the landscape and the each of the identified breeding grounds but after comparison with a similar study (Hartel et al. 2008) the properties of the landscape features were used to set parameters for the selection of other suitable breeding grounds such as minimum pond area, minimum area of vegetation surrounding the each pond and soil type.

The suitability of ponds and wetlands as breeding grounds were classified as one of four categories using a similar method as Henriksson (2007). The categories were named: (i) Confirmed presence, (ii) Suitable, (iii) Less suitable and (iv) Unsuitable. As well as the previously named parameters used to estimate breeding ground suitability, local knowledge was also used. Schnoor and Lundquist[10] identified the ponds and wetlands they considered unsuitable based on them never having found amphibians at those locations and their knowledge of amphibians. Toads are not as sensitive to the presence of fish as other amphibians. As it is difficult to determine the presence of fish in ponds from orthophotos, this was not a significant factor in the suitability classification in this study. Using a map of soil types in the study area, the ponds and wetlands located on land built up of unnatural material such as waste were classified as ‘Unsuitable’ based on the risk for poor water quality. Ponds or wetlands that dried out during the summer months were also classified as ‘Less suitable’ as toads prefer permanent water to reproduce in.

Under the right conditions a golf course can be an important habitat for amphibians. A study of the water hazards on Kvarnby golf course in Malmo in 2012 found a number of amphibian species (Stenberg et al. 2012) but according to Lundquist[11] the way in which a golf club manages and maintains the course is an important factor in whether or not it is a suitable habitat for amphibians. Örestads golf club in Habo Ljung has not carried out an inventory on the presence of amphibian or fish species in the water hazards on the golf course and had no special measures implemented in the way the golf course is managed to promote amphibian presence[12]. Therefore, all of the water hazards on the golf course have been classified as ‘Less suitable’ as breeding grounds for the common toad in this study. The number of ponds or wetlands in each suitability class in the study area is shown in Table 7. Only those classified as Class 1 or 2 have been used in modelling the toad’s habitat in this study.

Table 7. The number of breeding grounds in each suitability class

Class	Common Toad	Number of breeding grounds
i	Confirmed	7
ii	Suitable	72
iii	Less suitable	48
iv	Unsuitable	21

The result of the Cost Distance calculations was a model of the common toad’s habitat displayed as raster data. The area of the migration was compared to Lomma municipality’s map of planned green corridors in order to ascertain if there were areas in the landscape that lacked green infrastructure and where connectivity could be improved.

3.5 Calculating the Effect of Flooding on the Common Toad’s Migration

Flooding Scenario iii was used to assess the possible effects of a ‘worst case scenario’ on the common toad’s migration in the study area. Areas that had been flooded due to a rise in sea level, mostly located along the coast, were classed as a barrier in the same way the sea had been in earlier calculations. Areas flooded by watercourses breaking their banks were classed

[10] Schnoor, T. Environmental Strategist, and N. Lundquist, Environmental Investigator, Lomma municipality. Verbal communication, 4th March 2014
[11] Lundquist, N. Environmental Investigator, Lomma municipality. E-mail, 11th March 2014
[12] Gripwall, A. Course manager, Örestads GK. E-mail, 18th March 2014

as a suitable environment for the toad to migrate. Suitable breeding grounds that became flooded were re-classed as unsuitable. The effect that flooding could have on a toad’s habitat and migration patterns would depend upon which time of year flooding occurred. The differences in habitat area before and after flooding were compared.

4. Results

The results of the study are presented in this section. The results can be divided into four categories, quantification of the composition of Lomma municipality's green infrastructure with and without the effects of flooding and the common toad's habitat with and without the effects of flooding. The results of the habitat model are compared to the existing green infrastructure plan and a new green corridor is suggested.

4.1 Composition of Green Infrastructure 2012

The total land area of Lomma municipality is 56 km^{2,} of which 17% is covered by green infrastructure. Approximately 30% of green infrastructure is made up of the natural grass biotopes including meadows and wetland (Figure 6). Deciduous trees are the most common in forest areas making up roughly 13% of green infrastructure's total area (Figure 6). The total lengths of Allées and Agricultural Trenches and the total areas of all other biotopes within Lomma municipality are presented in Table 8.

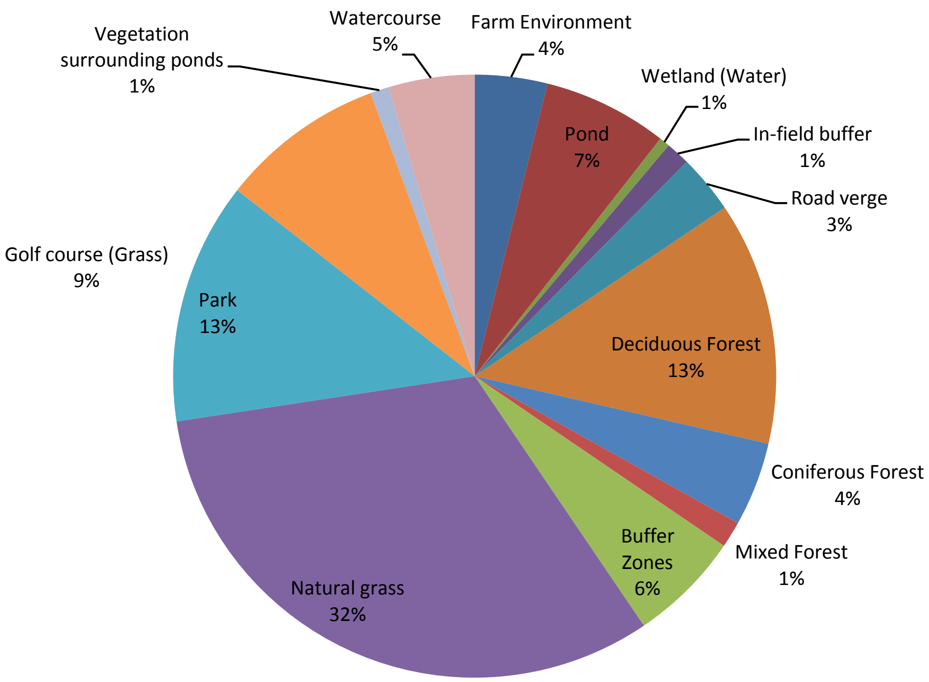


Figure 6. Composition of green structure by biotope area for Lomma municipality 2012

Table 8. Total areas and lengths of biotopes for Lomma municipality 2012

Biotope	Area (ha)	Biotope	Area (ha)	Length (m)
Farm environment	37	Buffer zones	57	
Pond	64	Natural grass	305	
Wetland (water)	5	Park	123	
In-field buffer	12	Golf course (grass)	84	
Road verge	30	Vegetation surrounding ponds	9	
Deciduous forest	124	Agricultural trench		28866
Coniferous forest	43	Allée		17370
Mixed forest	13			

4.2 The Habitat Model for the Common Toad

Presented below is the habitat model for the common toad in Lomma municipality for the green infrastructure as it was in 2012. The green areas in Figures 7 to 10 represent a MDM of 500m or activity area for the toad and a MDM of 2000m (red colour) represents migration between breeding areas.

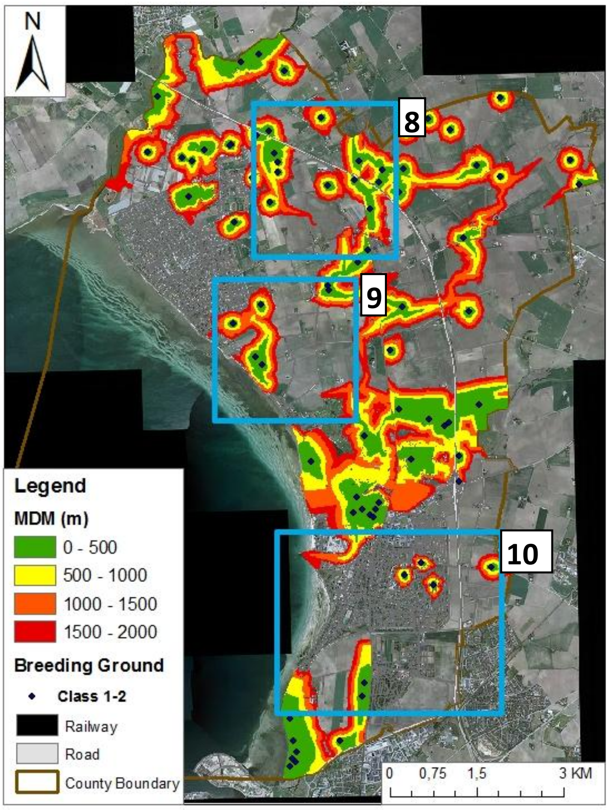


Figure 7. The habitat model for the common toad in Lomma municipality

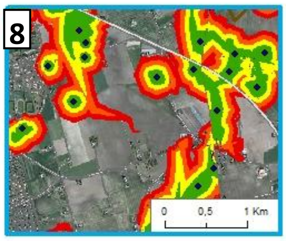


Figure 8. An example in the north of the municipality that lacks connectivity

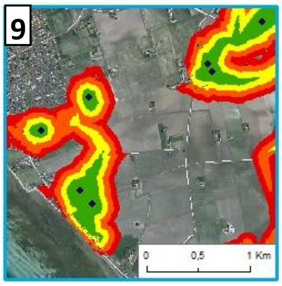


Figure 9. An area of habitat in the west of the municipality isolated from other habitat areas

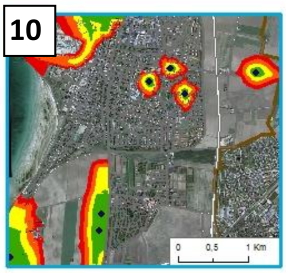


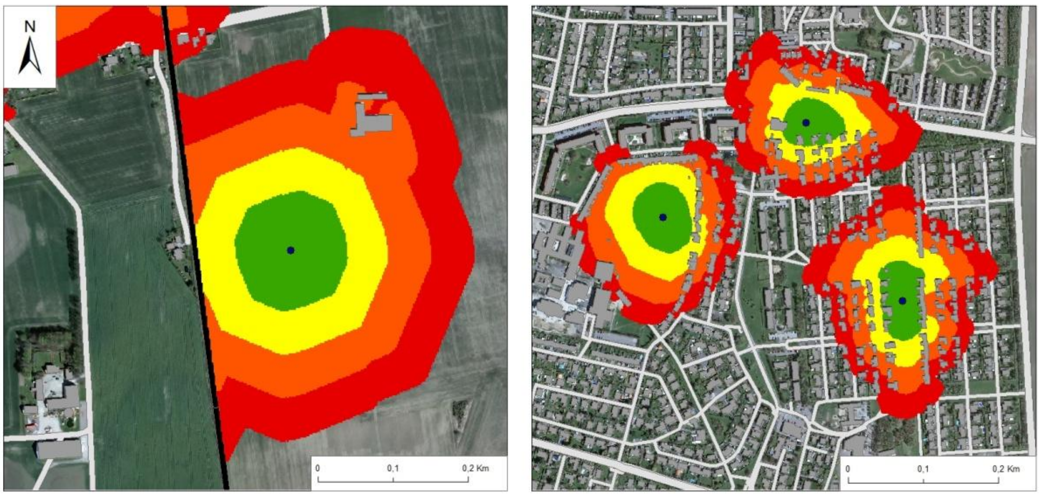
Figure 10. A gap in habitat connectivity created by Lomma urban area

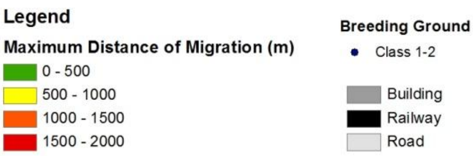
Analysis of Connectivity

It is evident from the model that there are areas in the habitat model that lack connectivity. There are three areas of habitat model that stand out as having poor connectivity (Figures 8, 9 and 10). The area in Figure 9 is a modelled habitat surrounding four breeding grounds that is separated from the larger habitat area in the centre of the municipality by agricultural land. The distance between habitat areas at the shortest point is roughly 650 meters. Figure 10 shows an area of habitat separated from the larger habitat in the centre of the municipality by Lomma urban area, the distance between these two habitat areas is at the shortest point roughly 1.3 km. There is also a habitat area in the north of the municipality, displayed in Figure 8 that lacks connectivity, the distance here is less than the previous examples at roughly 350m. In the centre of the municipality (as seen in Figure 7) there is a concentrated area of habitat that is due to a high concentration of green areas containing ponds that are water filled clay quarries. Although this area does not appear to lack connectivity, there are a limited number of places to pass the railway line which effects migration in the area.

Effects of Barriers on the Common Toad’s Migration

Various examples of barriers to the toad’s migration can be seen in the habitat model in Figure 7. Barriers are seen in the model either through that the habitat becomes smaller or narrower as it passes a barrier, representing that reduced numbers of individuals have succeeded in crossing the barrier or that the habitat has a straight edge, representing a total barrier. There are examples in the model, along the municipality’s administrative boundary, where the modelled habitat appears to meet a barrier. The reason for this is that the municipality boundary was also the boundary for the habitat model.



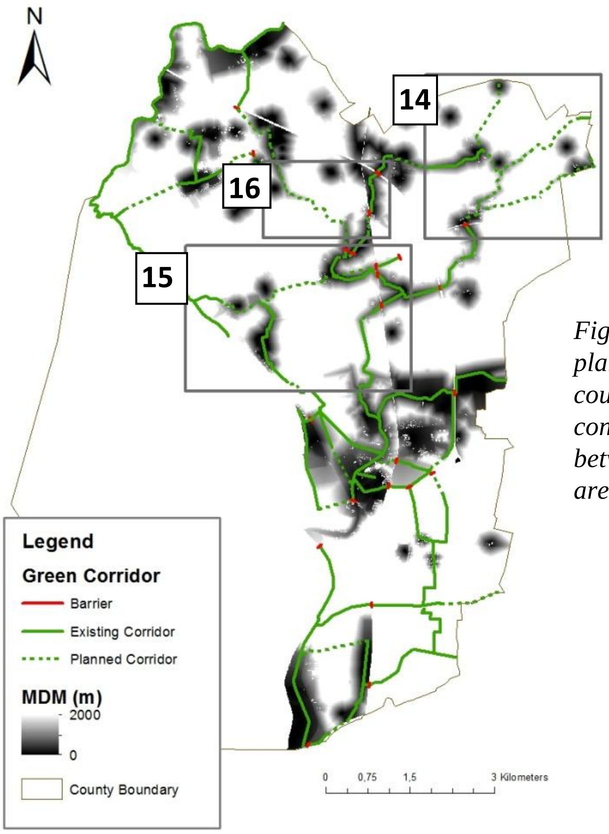


Figures 11 and 12. Examples of when roads and railways impede toad migration

Figure 11 clearly shows from the straight edge in the west of the modelled area that the railway has had the effect of reducing connectivity and size of the toad’s habitat. Roads have varying levels of effect on connectivity depending upon the average number of vehicles passing each day (ÅDT). Even roads that were assigned the lowest friction value due to low traffic levels can have a noticeable effect on migration when the density of roads is high in the immediate surroundings of a breeding ground. This can be seen in Figure 12. Migration from the three breeding grounds located within Lomma urban area is affected by the dense road network. This limits connectivity between the breeding grounds and to other areas of the habitat.

4.3 Evaluation of Lomma Municipality's Green Infrastructure Plan

The model of the common toad's habitat was compared with Lomma municipality's plan for future green corridors according to the Development Plan from 2010. This was undertaken in order to evaluate if there are planned measures in place that could increase connectivity between areas of the toad's habitat. In Figures 13 to 16 the habitat is shown in a grey scale instead of green to red as in Figures 7 to 12 to allow clear presentation of other data.



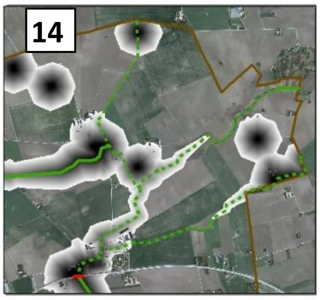
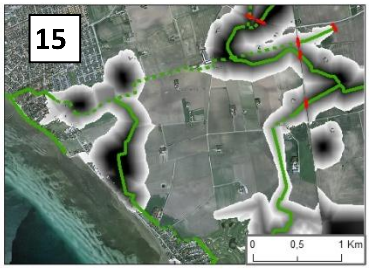


Figure 14. An example of where planned green structure could increase connectivity over the administrative boundary

Figure 15. Two planned corridors could increase connectivity between habitat areas



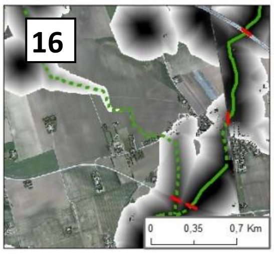


Figure 16. A green corridor is planned that could increase migration possibilities over agricultural land

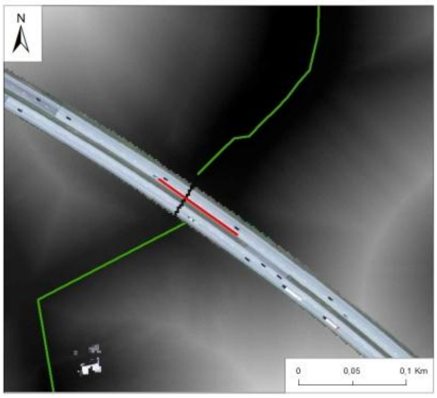
Figure 13. Existing and planned green infrastructure in Lomma municipality and the common toad's habitat

Lomma municipality's existing and planned green corridors, as presented in the Development Plan from 2010 are shown in Figure 13. In general, in the areas where existing green infrastructure coincides with the toad's habitat, the habitat follows the green infrastructure. In the habitat area in the north of the study area as shown by Figure 16, Lomma municipality has planned a new green corridor that could increase connectivity between this area and the habitat area to the south. Figure 15 shows the area of habitat in the west of the study area that lacked connectivity. The Development Plan includes two new green corridors in this region that could increase connectivity and the chances for the common toad to migrate in the landscape. Figure 14 shows another area where the Development Plan includes measures that could benefit the toad's migration. These green corridors could possibly increase connectivity between the breeding grounds that are in isolation and with other habitat areas on the other side of the municipality boundary.

Figure 17. Even when a green structure exists it may not meet the requirements for every species. The toad's migration is impeded by distance and barriers.

There are certain areas where the common toad's habitat fails to follow the existing green infrastructure. The area in Figure 17 is an example of this. Despite the fact that there is a green infrastructure is in place that should connect the area of habitat in the south with that in the centre of the study area, the infrastructure does not meet the toad's requirements for migration. The problem is most likely that the distance between breeding grounds is too great. The green infrastructure in this region may have allowed another species with different requirements to migrate in the landscape. The area shown in Figure 12 (page 23) in Lomma urban area is also visible here and is another example of how the existing green infrastructure doesn't meet the toad's requirements. The green infrastructure in this region should provide connectivity between the larger area of habitat in the centre of the municipality but the road network that divides the green infrastructure is so dense that the PME reaches zero before the toad succeeds in migrating that far.

Lomma municipality has included barriers to species migration in the Development Plan which are displayed in red in Figures 13 to 19. Different species are sensitive to different types of barriers depending upon how they migrate in the landscape. Certain barriers pointed out in the Development Plan



Figures 18 and 19. An example of a barrier pointed out in the Development Plan that did not impede the toad's migration due to a tunnel under the road (seen in Figure 19).

don’t impede the common toad’s migration. An example of this situation is shown in Figures 18 and 19 where water collected in an agricultural trench runs through a tunnel under the motorway. For another species unable to use the tunnel, the motorway would act as a barrier as suggested by the Development Plan 2010.

A Suggestion of an Addition to the Green Infrastructure Plan

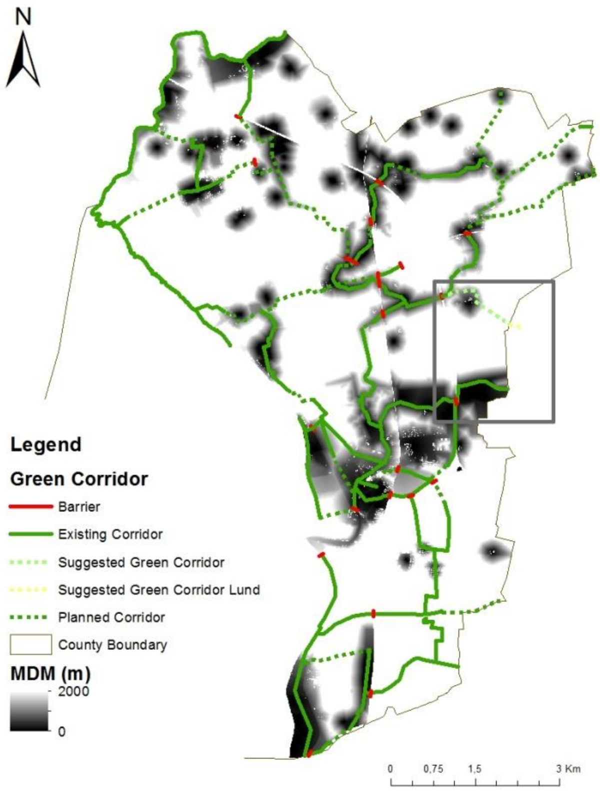


Figure 20. The location of the area pointed out in Figure 21 in Lomma municipality

Figure 21. A suggestion to a new green corridor to improve connectivity in the landscape

The area shown in Figure 21 is a suggestion for a new green corridor that could have the effect of improving connectivity between Point A and Point B. The green corridor would have the aim of connecting the small watercourse and pond seen on the in the east of the Figure. In order to migrate between these two points presently a species would need to follow the existing green infrastructure west, south and then east (Figure 20) crossing both the railway line and motorway twice. The suggested corridor would require a small section to be placed in Lund’s municipality, shown as dashed yellow in Figure 21. To avoid dividing agricultural land, the suggested green corridor has been placed along its edges.

4.4 The Effect of flooding on Green Infrastructure

All biotopes type in Lomma municipality would suffer a temporary loss in area or length should any of the three flooding scenarios occur with the exception of Coniferous Forests. Örestads golf course in Habo Ljung would be severely affected during any of the scenarios, roughly three quarters of the course's grass area would be flooded should scenario iii occur. The percentage reduction in biotope area for the three flooding scenarios is displayed in Table 9. Allées and Agricultural Trenches have been included in the table but show a change in length rather than area.

Table 9. The percentage reduction in area or length for each biotope type for three flooding scenarios

Biotope	Scenario i Change from 2012 (%)	Scenario ii Change from 2012 (%)	Scenario iii Change from 2012 (%)
Farm Environment (area change)	-0,2	-1,7	-3,6
Pond (area change)	-20,2	-23,1	-44,0
Wetland (water) (area change)	-33,2	-88,3	-88,4
In-field buffer (area change)	-1,0	-1,1	-1,1
Road verge (area change)	0,0	-1,8	-2,5
Deciduous forest (area change)	-0,1	-1,0	-10,7
Coniferous forest (area change)	0,0	0,0	0,0
Mixed forest (area change)	-2,4	-5,2	-8,5
Buffer zone (area change)	-17,9	-34,9	-42,4
Natural grass (area change)	-18,3	-44,2	-55,2
Park (area change)	-0,1	-2,6	-7,7
Golf course (grass) (area change)	-57,3	-64,1	-73,7
Vegetation surrounding ponds (area change)	-0,1	-0,5	-2,1
Agricultural trench (length change)	-12,0	-18,0	-24,0
Allée (length change)	-4,0	-6,0	-11,0

4.5 The Effect of Flooding on the Common Toad's Habitat

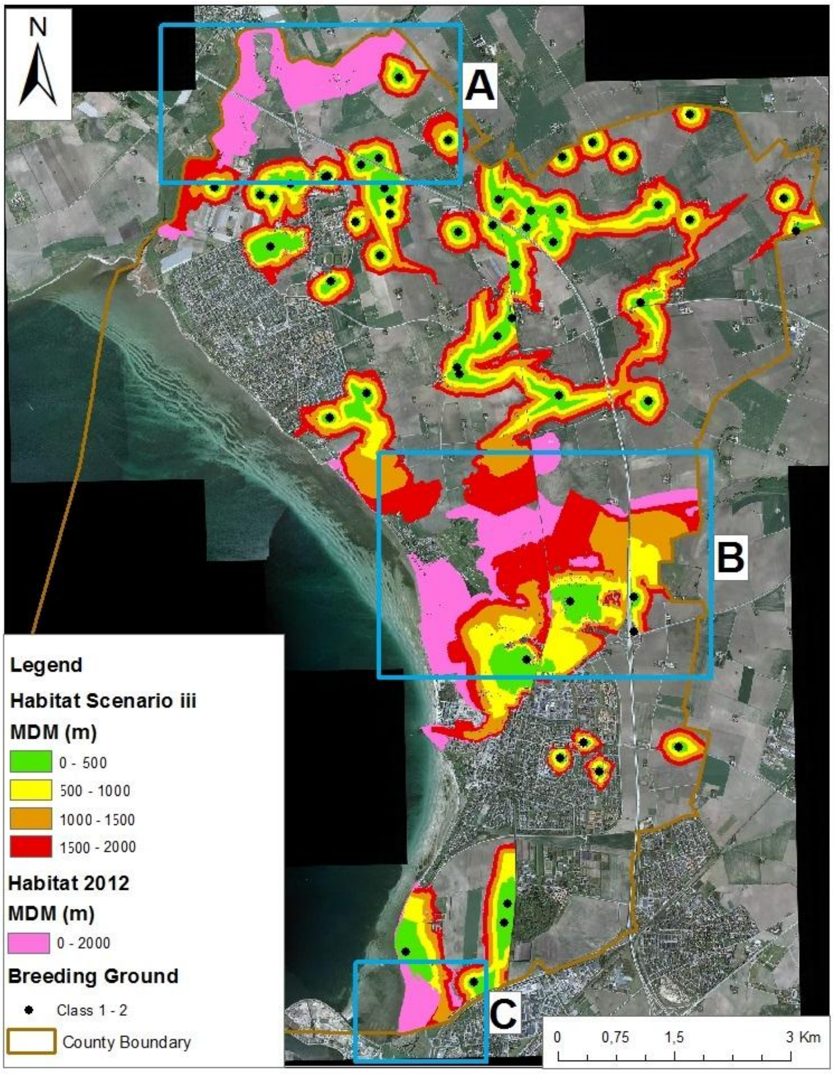


Figure 22. Differences in the toad's habitat for flooding scenario iii compared to 2012

The common toad's habitat during flooding scenario iii has been calculated and the results compared to the toad's habitat for 2012 in order to discover implications for connectivity in the landscape. The effects of flooding on the habitat can be seen in the three regions labelled A, B and C in Figure 22. The most noticeable change to the habitat is the break in connectivity shown in Region B. As the flood water was regarded as a favourable environment for toad migration it is the reduction in the number of suitable breeding grounds that has caused a break in connectivity. The railway line having been built on an embankment has not been flooded and can be seen continuing to have an effect on the connectivity of the habitat in this region. Changes to Region A are as well as a loss of habitat area, that the breeding ground in the north eastern corner that was once part of the habitat has become isolated. The area of the model that lacked connectivity that was pointed out in Figure 9 (page 22) has increased its extent southwards almost to the point of establishing a connection with the habitat area to the east. This has occurred due to the flood water providing less resistance to toad migration than the land use type that lay under it. The reduction in habitat area in Region C is due to flooding from the sea that has removed a suitable breeding ground and created a barrier.

To quantify these changes, the area of the toad's activity area (MDM of 500m) and the area of the habitat (MDM 2000m) were compared to the same areas in the model for 2012. The results are shown in Table 10.

Table 10. The percentage reduction in activity area (MDM 500m) and habitat area (MDM 2000m) for flooding scenario iii compared to 2012's model (no flooding)

MDM	Habitat 2012 (ha)	Habitat Scenario iii (ha)	Change (%)
500	533	304	-43%
2000	2140	1879	-12%

Table 10 shows that in terms of percentage area lost, flooding has had the greatest effect on the common toad's activity area with a 43% reduction compared to a reduction of 12% in habitat area. One of the reasons for the large reduction in activity area is the loss of suitable breeding grounds. Each breeding ground in 2012 had an average of 7 ha activity area surrounding it and the number of breeding grounds fell from 79 in 2012 to 54 for flooding scenario iii. The loss of breeding grounds has implications not only for the size of the activity area but also for the connectivity in the landscape as seen in Region B. A loss of 12% in habitat area represents 261ha.

5. Discussion

This section presents the benefits of quantifying the size of each biotope that make up a green infrastructure and the percentage losses due to flooding. The benefits and limitations of this study and of the Cost Distance tool are discussed as is Lomma municipality's existing green infrastructure plan.

5.1 Composition of the Municipality's Green Infrastructure

In order to create a habitat for certain species or achieve a certain ecosystem service, a minimum biotope area may be required within the landscape. By quantifying the composition of a landscapes green infrastructure, types of biotope that do not meet the criteria can be easily identified. This could facilitate decisions over which type of environmental value is to be created when planning new green areas. An area that is created as a result of the compensation method is not required to be of the same type as the area that was lost (Persson 2011). In Lomma for example, if an area of natural grass was lost due to the development of new houses, it may be suitable to replace it with a biotope type that can provide another sort of habitat or service such as a mixed forest. As mentioned previously, there are other considerations here including the aim of creating the new area, if the aim is to facilitate the migration of a certain species then it is likely that the species requirements will determine the biotope type. The same can be said if the aim is to achieve a certain ecosystem service. A consideration here is the time that takes to create an area of value that has the ecosystem structure to be able to provide a specific service.

5.2 The Habitat Model for the Common Toad

The Cost Distance calculations have identified areas that are important for the common toad's activity and paths in the landscape that are important for toad migration in Lomma municipality. Areas of the habitat that lack connectivity and the reasons behind them be it the type of barriers or migration distance, can be identified and included in a plan for developing the existing green infrastructure. The model can also be used with the aim of conserving connectivity in the landscape. If a certain piece of land can be identified from the habitat model as the only link between two habitat areas, this land can be avoided for new development of new houses of infrastructure because of the risk of reducing connectivity and increasing habitat isolation.

Limitations of the Habitat Model

The habitat model for a common toad as calculated in this study is a simple representation of the toad's habitat that has limitations. It should therefore be interpreted carefully and extra investigations should be carried out before making decisions based on the results of the habitat model. Many of the factors in the model such as maximum migration distances and friction values for land use types and barriers were based on the opinion of people with experience. Despite the fact that the values used in this study were compared with previous toad migration studies (Ray et al. 2002; Joly, 2003; Koffman 2012; Henriksson 2007), the values in those studies were also based upon expert opinion. Ray et al (2002) even points out that the values need to be tested and evaluated in order to improve accuracy.

There are many factors that affect the migration of a species in a landscape. This study has included slope gradient as a factor by incorporating a DEM of the study area into the friction map. There was a lack of literature regarding the effects of gradient on toad migration and so the weight the factor received was difficult to define. Lomma is also a flat landscape meaning that the effects were not noticeable in the habitat model. In an area with greater elevation differences there may have been a more noticeable effect. There are other factors that could affect toad migration that were not included in the model. Mörtberg et al (2006) included noise pollution screens in their model as these act as a barrier to migration. The railway line was included in this study as it was deemed difficult for the toad to cross, pavement curbs could have a similar effect but these were not included here. To include such factors would require an in depth knowledge of the study area and time to create a GIS database including such factors.

Another limitation is the definition of starting points for toad migration. Those breeding grounds where the presence of the toad had been confirmed by (Pröjts 2012) and (Lundquist 2013) were included in the study. The others were assumed suitable based on their characteristics. These starting points are the basis of the whole habitat model so changes to these could affect the connectivity of the habitat. Based on the inventory of ponds and literature (Cedhagen and Nilson 1991) the common toad is more likely to be found at a wide range of locations compared to other amphibians due to it being less sensitive to dehydration and it greater tolerance of fish. In order to gain a more accurate picture of the distribution of breeding grounds in Lomma municipality requires an amphibian inventory covering a wider area.

The tool used in this study also had has limitations. Cost distance chooses a path based of the friction value assigned to every cell in raster data. This could mean that the tool could produce a migration path that is only one cell wide in the habitat model. This makes it sensitive to cell size and errors made when classifying and converting data from vector to raster format (Majka et al. 2007). The results of the Cost Distance calculation should therefore be interpreted carefully with the relevant orthophoto to hand to investigate if a modelled migration path would be feasible in reality.

5.3 Evaluation of Lomma Municipality's Green Infrastructure Plan

The common toad was used in this study to model migration in the landscape but the toad is not representative of all species. A green infrastructure should facilitate the migration of plants and animals of all sizes and on all scales. Different species have different requirements for migration and are sensitive to different types of barriers. For this reason there were places in the habitat model that lacked connectivity despite there being an existing green infrastructure (Figure 17, page 25). At the same time, there were barriers pointed out in the Development Plan (Nyquist et al. 2011) that didn't impede toad migration (Figures 18 and 19, page 25).

Lomma municipality have pointed out areas where new green corridors are planned (Figure 3). The result of comparing the toad's habitat to the plan is that these green corridors are in the correct place and that they could increase the possibility for toad migration between breeding grounds as long as the MDM is not exceeded between breeding grounds. According to the habitat model, there are a number of breeding grounds situated in the north of the study area that are isolated in the landscape but that are not covered by a new green corridor. These could either be a result of a limitation in identifying suitable breeding grounds and they are in fact not breeding grounds or they may be part of another habitat on the other side of the administrative boundary that has not been included in this study.

The effects of barriers in the landscape have been shown to have a clear effect on migration in this study. The railway line and motorway have the greatest effect as they were defined as 'total barriers' and because they run straight through the centre of the municipality effectively dividing it. The toad had the possibility in places to use tunnels that allow the flow of water from agricultural trenches to cross these barriers but other species may not have the same opportunity. Lomma municipality states in the Development Plan (Nyquist et al. 2011) that barriers to migration will be removed when roads and railways are rebuilt. If a habitat model is taken into consideration when planning roads and buildings, connectivity in the landscape could be improved. Other possibilities for increasing connectivity is the implementation of wildlife crossings such as tunnels, underpasses, viaducts and culverts to allow species to pass barriers and increase migration possibilities.

5.4 The Effect of flooding on Green Infrastructure

If Hartman's et al (2013) prediction of extreme weather events is realised, with the possibility of increased flooding then it should be considered as part of the green infrastructure planning process. The results showed the reduction in area or length of the different biotope types during the three flooding scenarios, (i) a 100-year flood in Höje å in combination with today's sea level, (ii) a 100-year flood in Höje å in combination with a sea level of +1.25 meters compared to today's sea level and (iii) a 100-year flood in Höje å in combination with a sea level of + 1.89 meters (Wettemark et al. 2009). The differences in the reduction of each biotope are due to their location in the landscape and the elevation at that point. It was expected that wetlands would become flooded as they are located in low lying areas often close to a watercourse. By taking the natural characteristics of the landscape into consideration during the planning process, a suitable biotope can be planned for this area. Increasing the number of wetlands or ponds could have the effect of both increasing species migration possibilities and biodiversity and also providing an ecosystem service by storing water in times of heavy precipitation and therefore reduce the risk of flooding.

5.5 The Effect of Flooding on the Common Toad's Habitat

For an ecosystem to be resilient, it must be able to adapt to change. Part of that adaption is the possibility for species to migrate in the landscape (Chapin et al. 2011). Flooding was used as an example of a disturbance on the study area to investigate the effects on the common toad's habitat. The effect that flooding would have on the toad would depend upon the time of year that flooding occurred. By classifying the breeding grounds as unsuitable for reproduction during the time that they were flooded caused a break in the connectivity of the habitat despite the flood water being classed as Optimal for migration. There was not time to calculate the effects on the habitat based upon a loss of summer habitat or winter hibernation habitat, but the results of these calculations would probably have been similar to the results found in this study. The starting points in the Cost Distance calculation would have changed but flooded summer and winter habitats would also have been classed as unsuitable during the time of flooding. Literature regarding the effects of flooding on the common toad was sparse but the effect on the toad's migration and the migration of other species is likely to depend upon the frequency of the flooding. Once the flood water had receded it is possible that the area would be suitable once again for reproduction, foraging and hibernating. Upon reflection the use of another species might have given more useful results regarding the effects of flooding on a habitat. Water is a part of a toad's habitat, a species that is totally land based might have been more affected by flooding.

Despite flood water allowing the habitat model to expand in some directions due to it being classified as a more suitable environment for migration for the toad than the land use type below it, the same areas as mentioned and shown previously in Figures 14-16 (page 24) would benefit from the planned green corridors as set out by Lomma municipality's Development Plan (Nyquist et al. 2011). The railway line continues to have the effect of impeding migration so this should also be an area for consideration in the planning of green infrastructure.

5.6 Suggestions of Additions to the Green Infrastructure Plan

In terms of the common toad in Lomma municipality, new ponds or wetlands in areas where connectivity is low or none existent could possibly improve migration opportunities. An example of this could be the area pointed out in Figure 17 (page 25) where the distance between breeding grounds too great for migration despite there being a green infrastructure in place. The green corridor suggested in Figure 21 (page 26) could also have the effect of connecting the two areas of habitat that became separated by flooding scenario iii (Region B, Figure 22, page 28). Practical issues such as landownership and cooperation between municipalities would need to be explored.

6. Conclusion

The following conclusions can be drawn from this study:

- GIS is a useful tool for planning green infrastructure. The method used in this study could be used to combine any number factors representing the character of the landscape as long as literature or expertise is available. The results should be interpreted carefully and supported by field studies to confirm accuracy. Data collection from the field could also help improve the accuracy of a habitat model. This could include species inventories at breeding grounds or other habitats and the collection of information that would influence choice of friction values and maximum migration distances. All of these factors could have a large impact on the size and connectivity of a habitat model.

Lomma Municipality's Green Infrastructure Plan

- Lomma municipality have identified the main areas lacking connectivity in the Development Plan 2010 for new green corridors. The results from this study show that there are other areas where connectivity in the landscape could be improved, either through the creation of new green corridors or through the creation of new breeding grounds

- This study has shown that barriers in the landscape disrupt species migration. Barriers that disrupt the toad's migration could be looked more closely and measures be taken into account during future planning of green infrastructure to minimise their effect.

- A habitat model can be used not only for planning of green infrastructure but also for identifying areas to avoid in the development of houses, roads and railways. This study has identified areas that are important to the common toad that could be used as a basis for choosing areas for a species inventory.

The Effect of Flooding on Green Infrastructure and on the Common Toad's Habitat

- A functional green infrastructure is vital in a changing climate to allow species adaption by providing the opportunity to migrate. This allows ecosystems to be resilient and maintain the provision of services that are vital for society's adaptation to a changing climate. This study may have shown greater differences in habitat areas when comparing 2012 with flooding scenario iii, had a species been used that cannot migrate in water.

- This study has shown that flooding in Lomma would have a negative effect on the area of the common toad's habitat and two large parts of the habitat would become separated impeding migration.

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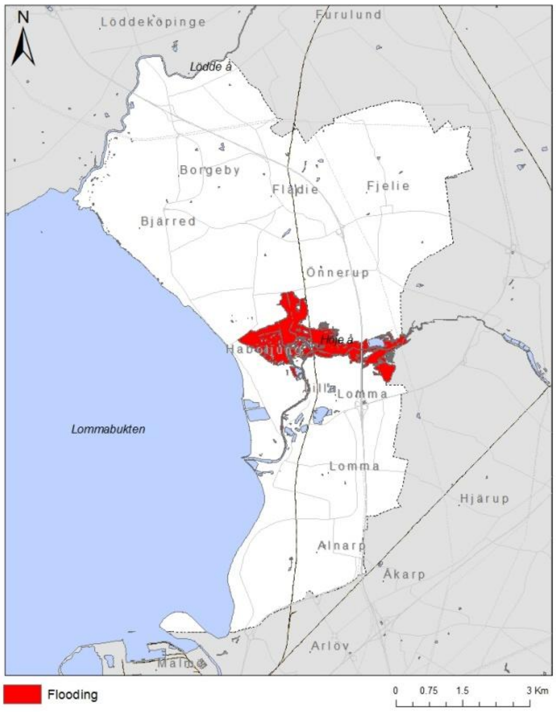
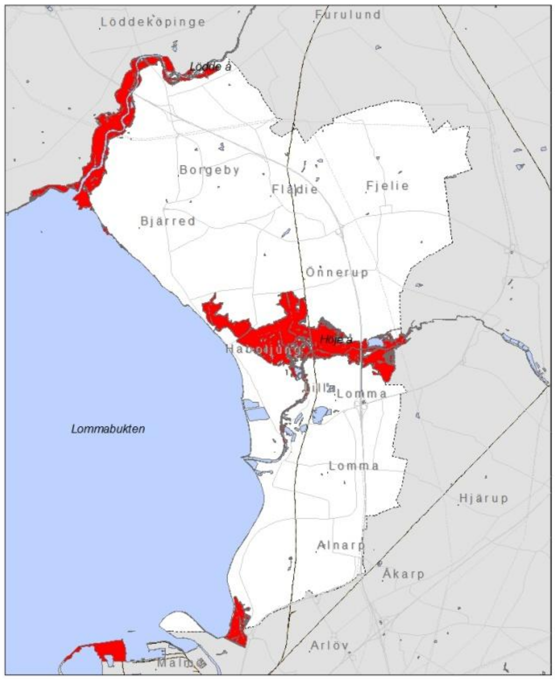
8. Appendices

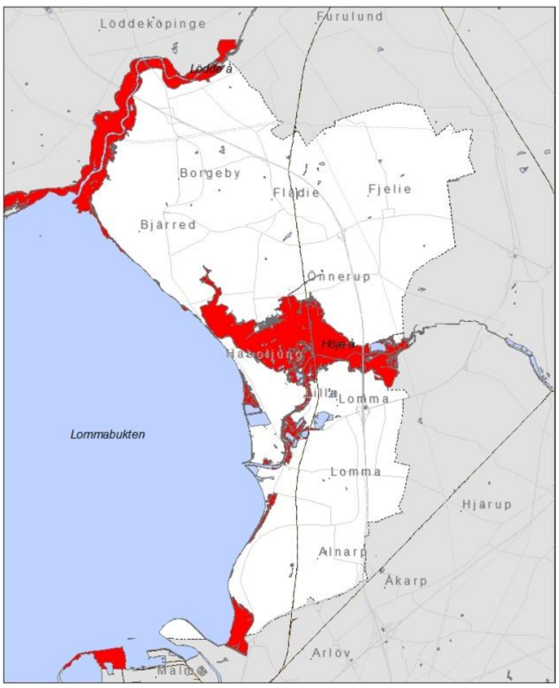
Appendix 1 to 3 display the Flooding Scenarios calculated by SWECO Environment AB (Wettemark et al. 2009) that were used for calculations in this study



Appendix 1. Scenario i, a 100-year flood in Höje å in combination with today's sea level



Appendix 2. Scenario ii, a 100-year flood in Höje å in combination with a sea level of +1.25 meters compared to today's sea level.



Appendix 3. Scenario iii, a 100-year flood in Höje å in combination with a sea level of + 1.89 meters compared to today's sea level.

Appendix 4. An explanation of the biotope classes used and attribute information saved

Digitalised Biotope	Class	Vegetation	Other Information	Explanation
Deciduous forest	Forest (>5000m²) Tree area (<5000m²)	Deciduous trees	Area, perimeter	Areas without visible coniferous trees, small area to forest
Coniferous forest	Forest (>5000m²) Tree area (<5000m²)	Coniferous trees	Area, perimeter	Areas without visible Deciduous trees, small area to forest
Mixed forest	Forest (>5000m²) Tree area (<5000m²)	Mixed coniferous and Deciduous trees	Area, perimeter	Areas with visible coniferous and Deciduous trees, small area to forest
Natural grass	Meadow (Äng) Meadow (Strandäng) Wetland (grass)	Grass Bushes and grass	Area, perimeter	Areas of natural character without visible maintenance
Farm environment		Deciduous trees Coniferous trees Mixed trees	Area, perimeter	Area of trees in close proximity to rural farm
Vegetation surrounding pond	Pond	Deciduous trees Deciduous trees and bushes Deciduous trees, bushes and grass Deciduous trees and grass Coniferous trees and grass Mixed trees Bushes and grass Grass	Area, perimeter	Classification of vegetation surrounding ponds situated on agricultural land
In-field buffer		Deciduous trees Deciduous trees and bushes Deciduous trees, bushes and grass Deciduous trees and grass Mixed trees Bushes and grass Grass	Area, perimeter	Vegetation strip on or between agricultural land
Avenue		Deciduous trees	Area, perimeter	At least 5 trees in a row with a maximum of 40m between
Park		Deciduous trees Deciduous trees and bushes Deciduous trees, bushes and grass	Area, perimeter	Urban green areas with signs of maintenance

		Deciduous trees and grass Mixed trees Bushes and grass Grass		
Road verge		Deciduous trees Deciduous trees and bushes Deciduous trees, bushes and grass Deciduous trees and grass Mixed trees Bushes and grass Grass	Area, perimeter	Vegetation strip at road side
Golf course		Grass	Area, perimeter	Golf courses grass area
Buffer zones along trenches and watercourses	Water course Trench	Deciduous trees Deciduous trees and bushes Deciduous trees, bushes and grass Bushes and grass Grass	Area, perimeter	Uncultivated land next to trenches and watercourses

Appendix 5. The Vector and raster data available from Lomma municipality used in calculations in this study

Available vector data	Modification	Explanation	Source
Agricultural land	Clip to county boundary	Agricultural land in study area	Lommakartan
Water	Updating, re-draw certain polygons, create attribute information	All watercourses, ponds, open water in wetlands	Lommakartan
Built up areas	None	Hard ground	Bakgrundskarta ÖP 2010
Roads	Save average daily traffic as attribute	Road network in study area	Lommakartan
Buildings	Clip to county boundary	Buildings in study area	Bakgrundskarta ÖP 2010
Railway	Available as line data. 4m buffer created and clipped to county boundary	8m wide to include hard ground along railway	Bakgrundskarta ÖP 2010
County boundary	None	Lomma county's administrative boundary	Bakgrundskarta ÖP 2010
Soil type	Clip to county boundary, dissolve	Soil or ground type	SGU
Green Infrastructure	Legend - Swedish to English	Existing and planned green corridors in Lomma municipality	Bakgrundskarta ÖP 2010
Flooding Scenarios	None	Three flooding scenarios calculated by SWECO Environment AB	Översvämningskartering _20090703

Raster Data	Modification	Explanation	Source
Digital Elevation Model	None	Covering Lomma municipality, 2m resolution, produced from laser scanning 2008	Blom Sweden AB

Appendix 6. Vector data available from Lomma municipality used in producing the maps in this report

Vector Data	Explanation	Source
Roads	Roads in Scania	Lommakartan
Built up areas	Built up areas in Scania	Bakgrundskarta ÖP 2010
Lomma boundary	Municipality administrative boundary	Bakgrundskarta ÖP 2010
Scania	Scania outline with municipalities	Bakgrundskarta ÖP 2010
Green Infrastructure	Existing and planned green corridors, barriers	Bakgrundskarta ÖP 2010
Mask	Grey area around municipality	Bakgrundskarta ÖP 2010
Labels	Water and towns	Bakgrundskarta ÖP 2010
Railway	Railway line in Lomma	Bakgrundskarta ÖP 2010
Roads	Roads in Lomma	Bakgrundskarta ÖP 2010
Power Lines	Power lines in Lomma	Bakgrundskarta ÖP 2010
Water	Sea and watercourses	Lommakartan
Built up areas	Built up areas in Lomma	Bakgrundskarta ÖP 2010
Flooding Scenarios	Three flooding scenarios calculated by SWECO Environment AB	Översvämningskartering_200907 03

Appendix 7. Properties of the breeding grounds where the presence of the common toad was confirmed

FID	Name	Type	Area m²	Surroundings	Area veg m²	Fish Y/N	Dom. Soil	Dec. tree (m²)	% Dec. tree	Con. tree (m²)	% Con. Tree	Mix tree (m²)	% Mix tree	Nat. grass (m²)	% Nat. Grass	Agr (m²)	% Agr	Trench (m)
0		Pond	127	Deciduous trees	1678	N	Clay	51387	6%	235	0%	0	0%	30079	4%	360216	45%	663
1	Öster Björkhagen	Pond	726	Grass, open	1946	N	Sand	1302	0%	696	0%	0	0%	1946	0%	744603	89%	890
2	Stora dammen	Pond	8460	Grass, open	44066	N	Moraine/clay	11680	1%	10325	1%	1395	0%	67109	7%	812480	79%	992
3	Damm vid E6	Pond	376	Deciduous trees	5663	N	Sand	7433	1%	9335	1%	2487	0%	91965	11%	566306	69%	564
4	Domdejla mosse	Pond	875	Deciduous trees	87451	N	Sand	136232	15%	11187	1%	1173	0%	4024	0%	353985	38%	0
5	Augustenborg	Pond	411	Deciduous trees	30940	N	Sand	40322	5%	0	0%	22684	3%	41107	5%	478197	56%	0
6	Sydväst Augustenborg	Pond	107	Deciduous trees	4976	N	Sand	45643	6%	1696	0%	21592	3%	21116	3%	501139	62%	0
7	Alkärret i Habo Ljung	Pond	803	Deciduous trees	101603	N	Sand	101603	12%	370298	43%	0	0%	6160	1%	0	0%	0
Mean			1486					49450	6%	50472	6%	6166	1%	32938	4%	477116	55%	389
Mean without zero values										57682		9866				545275		777

Appendix 8. The properties of all orthophotos used in this study

Date	Reflectance properties	Spatial resolution (cm)	Ref system	Source
1939-1940	B & W	100	RT90	Lantmäteriet. Skåne från luften, flygbilder från 40- talet. Ortofoton digitaliserade av GIS-centrum, Lunds universitet.
1962	B & W	46.7	SWEREF99 13.30	Lomma municipality
10-apr	Colour	10	SWEREF99 13.30	Lomma municipality
10-jun	CIR	25	SWEREF99 13.30	Geodatacenter Skåne AB, 2010. Digitala ortofoton från 2010 i konventionell och IR färg med 25 cm geometrisk upplösning över Skåne.
Spring/ summer 2012	Colour	25	SWEREF99 13.30	Lomma municipality

Institutionen för naturgeografi och ekosystemvetenskap, Lunds Universitet.

Student examensarbete (Seminarieuppsatser). Uppsatserna finns tillgängliga på institutionens geobibliotek, Sölvegatan 12, 223 62 LUND. Serien startade 1985. Hela listan och själva uppsatserna är även tillgängliga på LUP student papers (www.nateko.lu.se/masterthesis) och via Geobiblioteket (www.geobib.lu.se)

The student thesis reports are available at the Geo-Library, Department of Physical Geography and Ecosystem Science, University of Lund, Sölvegatan 12, S-223 62 Lund, Sweden. Report series started 1985. The complete list and electronic versions are also electronic available at the LUP student papers (www.nateko.lu.se/masterthesis) and through the Geo-library (www.geobib.lu.se)

285 Cansu Karsili (2013) Calculation of past and present water availability in the Mediterranean region and future estimates according to the Thornthwaite water-balance model
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287 Manon Marcon (2013) Analysis of biodiversity spatial patterns across multiple taxa, in Sweden
288 Emma Li Johansson (2013) A multi-scale analysis of biofuel-related land acquisitions in Tanzania - with focus on Sweden as an investor
289 Dipa Paul Chowdhury (2013) Centennial and Millennial climate-carbon cycle feedback analysis for future anthropogenic climate change
290 Zhiyong Qi (2013) Geovisualization using HTML5 - A case study to improve animations of historical geographic data
291 Boyi Jiang (2013) GIS-based time series study of soil erosion risk using the Revised Universal Soil Loss Equation (RUSLE) model in a micro-catchment on Mount Elgon, Uganda
292 Sabina Berntsson & Josefin Winberg (2013) The influence of water availability on land cover and tree functionality in a small-holder farming system. A minor field study in Trans Nzoia County, NW Kenya
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