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Distribution Analysis of *Impatiens glandulifera* in Kronoberg County and a Pest Risk Map for Alvesta Municipality

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Johan Viscarra Hansson
Master thesis, 30 credits, in Geographical Information Sciences

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Preface

At the moment of writing this thesis I am working as an environmental inspector in the municipality of Alvesta in southern Sweden. One of my areas of responsibility is control and prevention of invasive alien species. My role is informative and administrative, informative in the sense that the municipality provides information about invasive alien species through different channels. It is also common that citizens contact the municipality asking for advice on how to control, eradicate and dispose invasive alien plants found on their properties. The responsibility is also administrative in the sense that regional efforts and funding from the county level is channelized and implemented locally in the different municipalities of Kronoberg.

While working with invasive alien species I noticed a need for geographic visualization of the problem to identify areas of concern where we could focus our control and eradication efforts on. This was the initial spark that led to the realization of the present study. The result of the study is intended to be used practically to prevent and control *Impatiens glandulifera* in Alvesta and the method is intended to be replicated with other species of concern.

I want to thank my supervisor Per-Ola Olsson at the Department of Physical Geography and Ecosystem Science of Lund University for helpful advice along the way. Also, I want to thank Marcus Bjerkelie, GIS-engineer at the Municipality of Alvesta for interesting dialogs and inspiration.

A special thanks to my children Mikaela and Orión Viscarra for spending excursion-free weekends at home because of my work on the thesis, and for being my constant source of motivation.

Abstract

The spread of invasive alien species poses great risks for biodiversity, human health and economies. *Impatiens glandulifera*, an invasive alien plant which has been listed in The European list of Invasive Alien Species of Union concern, is widely spread in Sweden. Multiple studies have been made regarding the plant's characteristics, spread and impacts on invaded areas.

The purpose of this study is to identify areas of potential risk from invasion. For this, a distribution analysis of *I. glandulifera*, covering the county of Kronoberg in Sweden, is presented. The analysis has been made with Geographic Information Systems (GIS) and is based on the records of actual observations of the plant between the years 2000 and 2021. The results indicate that observations of *I. glandulifera* is more commonly found in moist soil, in urban areas and close to roads and bodies of water. Soils made up by artificial fills, which are often found in urbanized areas, are also a significant indicator for the potential presence of *I. glandulifera*.

The result from the analysis is compared with earlier research regarding habitat and spread preferences. A weighted overlay is made to develop a pest risk map for a minor area of the county of Kronoberg, covering Alvesta Municipality. The map depicts areas where it is more probable that *I. glandulifera* will occur.

Key Words

Impatiens glandulifera, pest risk map, distribution analysis, suitability analysis, invasive alien plant, weighted overlay, Himalayan balsam.

Sammanfattning

Spridning och etablering av invasiva främmande arter har en negativ inverkan på biologisk mångfald, människors hälsa och ekonomin. Jättebalsamin (*I. glandulifera*) är en invasiv främmande växt som finns med på EU:s lista över invasiva främmande arter och ska bekämpas i Sverige. Flera studier har gjorts angående växtens egenskaper, spridning och påverkan på invaderade områden.

Syftet med denna uppsats är att identifiera områden med potentiell risk för invasion. För detta presenteras en utbredningsanalys av *I. glandulifera* som täcker Kronobergs län i Sverige. Analysen har gjorts med hjälp av Geografiska Informations System (GIS) och baseras på faktiska fynd av växten mellan åren 2000 och 2021. Resultaten tyder på att fynd av *I. glandulifera* är vanligare på fuktig jord, i tätorter och i närhet till vägar och vattendrag. Jordar som består av fyllnadsmassor, vilka ofta finns i tätorter, är också en betydande indikator på fynd av *I. glandulifera*. Vidare jämförs resultatet från utbredningsanalysen med tidigare forskning om habitat och spridningspreferenser. Baserad på analysen och tidigare forskning genomförs en viktad överlagringsanalys med syfte att ta fram en karta med områden med potentiell risk för invasion. Denna slutgiltiga karta täcker Alvesta kommun.

Nyckelord

Jättebalsamin, *Impatiens glandulifera*, utbredningsanalys, invasiva främmande arter, överlagringsanalys.

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1. Introduction

Humans have, in the course of history, deliberately moved species between environments to promote hunting, fishing and farming. In Sweden, for example, species such as the rainbow trout (*Oncorhynchus mykiss*), the signal crayfish (*Pacifastacus leniusculus*), the Canada goose (*Branta canadensis*) and American mink (*Neovison vison*) have been deliberately introduced into the country during the last centuries (Andersson et al., 1999; Reid et al., 2016; SLU, 2021a; SLU Artdatabanken, 2022).

Even if species are intentionally introduced, they can unintentionally spread and adversely affect their new environments, becoming invasive. Garden plants such as giant hogweed (*Heracleum mantegazzianum*), bigleaf lupine (*Lupinus polyphyllus*) and Himalayan balsam (*Impatiens glandulifera*) are examples of species which have been introduced intentionally, but have since spread further in nature causing negative effects on endemic species and local ecosystems (Pyšek et. al, 2008; The Invasive Species Compendium, 2019).

In relation to this problem, the European Union (EU) has consolidated a list of invasive alien species of union concern, currently regulated in *The prevention and management of the introduction and spread of invasive alien species* (Regulation 1143/2014) which entered into force on January 1, 2015. The purpose of the regulation is to prevent invasive alien species from entering the European Union as far as possible and to control and, if achievable, eradicate the species that already exist inside the Union. The EU regulation has been incorporated into the Swedish national legislation in the Swedish Ordinance on Invasive Alien Species *(Förordning om invasiva främmande arter)* (SFS 2018:1939) which entered into force on January 1, 2019.

One of the most problematic invasive alien species in Sweden, also present in the above-mentioned list, is *Impatiens glandulifera*, an annual herb native to the foothills of the Himalayas. *I. glandulifera* was brought to Sweden in the mid-19th century and introduced as an ornamental plant. It has gained popularity and has since been cultivated by many estate owners across the country (Strese, 2012).

Mainly growing in riparian zones (Pyšek & Prach, 1994), but also in wet woodlands, forest plantations, forest clearings, railway embankments, roadside ditches, urban areas and wet meadows (Clements et. al., 2008), it is today commonly found all around the country (Strese, 2012).

According to Clements et al. (2008) high soil moisture is the single most important predictor of the potential presence of *I. glandulifera*, but there are also key environmental variables such as types of soil, land types, closeness to roads and bodies of water, which can also be strong predictors of the occurrence and distribution of invasive alien species (Dimitrakopoulos et al., 2017; Thiele et al., 2009).

To facilitate monitoring, a risk map depicting suitable conditions for occurrence can be useful. From a pragmatic perspective, risk maps can help organizations and managers to select appropriate strategies and tactics with which to mitigate dispersal of unwanted species. The aim of this thesis is to make a distribution analysis of *Impatiens glandulifera* for the county of Kronoberg, and based on the study and earlier research, develop a pest risk map for Alvesta Municipality, depicting areas where it is more likely that *I. glandulifera* would thrive (‘Pest risk map’ being the accepted term for maps depicting the probability that any species (animal, plant, bacteria, virus, fungi, etc.) will arrive and/or, establish and/or, spread within an area (Venette, 2015)).

The research questions the study intends to answer are:

Is there a relationship between environmental properties and the occurrence of *I. glandulifera*?

Do the locations of the observations of *I. glandulifera* in Kronoberg County coincide with other research about the spread and habitat preferences of this plant?

1.1 Objectives

This master thesis has two main objectives. With the use of geographic information system (GIS) it will:

1. Make a distribution analysis of *Impatiens glandulifera* covering the county of Kronoberg.

2. Compare the results from that analysis with earlier research and produce a pest risk map for Alvesta Municipality, depicting areas where it is more probable that *I. glandulifera* would thrive.

2. Theoretical Background

This chapter provides an insight in the definition of what an invasive species is, how this is regulated and the process it must complete to become classified as invasive. Furthermore, *I. glandulifera* is presented and its preferences regarding habitat and spread, as well as impacts, are explained. Finally, a quick overview of types of pest risk maps is given.

2.1 Invasive Alien Species

The establishment of alien plant and animal species outside their endemic habitats can present major challenges to the natural function of the new ecosystems where they are introduced, as well as economic costs through impacts on ecosystem services or damaged infrastructure. Still, the appearance of alien species in new locations is not always a cause for concern and it does not make them invasive per se. In Sweden, for example, the estimated number of alien species is 2000, of which 400 are treated as invasive (County Administrative Board of Kronoberg, 2021). The term invasive alien species, with emphasis on 'invasive', is used to describe an organism that causes ecological and economic harm in a new environment where it is not endemic. It must adapt to the new area easily, reproduce and spread quickly (Davis & Thompson, 2000; Ehrenfeld, 2010).

Common negative effects of invasive alien species on endemic ecosystems are (in the case of animals) competition with native species for food, shelter and nesting grounds; and (in the case of plants) competition with native plant species for sunlight, water and nutrients, direct effects through nitrogen fixation, releasing chemical compounds in the soil etc. For humans and the economy their presence in new environments can cause damage to human health by spreading pathogens or the economy by directly damaging infrastructure (County Administrative Board of Kronoberg, 2021).

Because of the negative effects and because invasive alien species represent one of the main threats to biodiversity and related ecosystem services, The European Union has consolidated a list of invasive alien species of Union concern, currently regulated in *The prevention and management of the introduction and spread of invasive alien species* (Regulation 1143/2014) which entered into force on January 1, 2015. Article 3 in the regulation defines invasive alien species as follows:

invasive alien species means an alien species whose introduction or spread has been found to threaten or adversely impact upon biodiversity and related ecosystem services

The purpose of the regulation is to prevent the introduction of invasive alien species and to control or eradicate those alien species which threaten ecosystems, habitats or species (Regulation 1143/2014).

The species focused on in this study, *I. glandulifera*, was added to the EU-list on August 2, 2017 (European Commission, 2021). This listing means EU member countries are required to implement measures against *I. glandulifera*, such as:

1. prevention,
2. early detection and rapid eradication of new invasions,
3. management of populations that are already widely spread.

The EU regulation has also been incorporated into many national legislations. In Sweden the national legislation is the Swedish Ordinance on Invasive Alien Species (*Förordning om invasiva främmande arter*) (SFS 2018:1939) which entered into force on January 1, 2019. The Swedish regulation outlines the share of responsibilities between national and regional authorities, municipalities and private actors to limit invasive alien species in Sweden by implementing above mentioned measures; emphasizing that local and regional governments have central roles in the work against invasive alien species (SFS 2018:1939).

2.1.1 The Invasion Process

The process of a species becoming invasive can, according to Blackburn et al. (2011), be described using four general spatio-temporal stages:

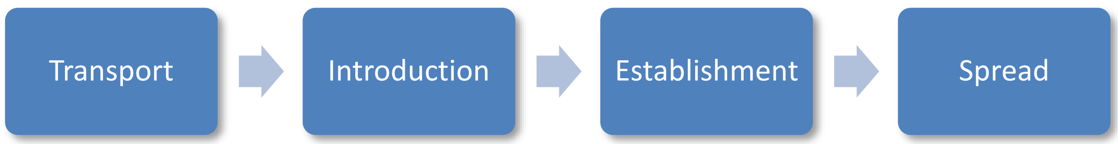

Figure 1: The four stages of the invasion process.

Between each stage there are barriers that a species must overcome to become invasive. A barrier could be a physical barrier, such as a fence or greenhouse wall that prevents a cultivar from spreading, or climatic conditions which can hinder an introduced population from surviving and/or reproducing.

The four steps can be described as follows:

> *Transport*: when the species is moved from and transported beyond the limits of its native geographic range.
>
> *Introduction*: when the species is either deliberately or indeliberately placed or planted in the new environment.
>
> *Establishment*: when the species survives in its new environment and commences to reproduce by itself.
>
> *Spread*: when the species overcomes all previously mentioned stages (and barriers) and commences its dispersal and spread in the new environment.

For species that overcome all the barriers and reach the final stage there are a couple of well identified means of dispersal. According to the Swedish Environmental Protection Agency (2022) dispersal are often due to (list for both animal and plants):

- Spread while transporting and/or incorrect disposal of garden waste.
- Spread as a contaminant during transport on or in animals.
- Spread during transport due to contamination on or in plants.
- Spread due to fishing activities with contaminated or aquaculture gear.
- Spread with machines and other equipment which are used at different sites.
- Spread with water channels.
- Escape from human-imposed barriers, such as: zoos, pisciculture facilities.
- Escape from gardens, nurseries and farms.

2.2 Himalayan balsam (*Impatiens glandulifera*)

Figure 2: Himalayan balsam with pink flowers on an August evening in 2021 near the shoreline of lake Salen in the Alvesta urban area. (Photography: Johan Viscarra Hansson).

I. glandulifera is an annual herb native to the foothills of the Himalayas. It grows typically in large populations and stands 50–250 centimeters tall. The stems are hollow, hairless and reddish colored and are commonly 0.5 to 5 centimeters in diameter. The leaves are up to 25 centimeters long, 7 centimeters wide, and sharply serrated (The Invasive Species Compendium, 2019). The flowers are up to 4 centimeters long and 2 centimeters wide and commonly pink or white, sometimes purple (Naturhistoriska riksmuseet, 1997), see Figure 2.

In its native Himalaya, *I. glandulifera* is found in India and Pakistan, from Kashmir to Garhwal, commonly at altitudes between 2000 and 2500 meters above sea level, frequent along roadside ditches and around field borders (Gupta, 1989).

In Europe it is commonly a weed of riparian systems due to the large number of seeds produced and easy dispersal by water (Pyšek & Prach, 1994). It is also commonly observed in wet woodlands, forest plantations, forest clearings, railway embankments, roadside ditches, urban areas and wet meadows (Clements et. al., 2008).

The preferred climate zones of *I. glandulifera*, according to the Köppen classification system, are temperate climates with dry summers, but it is also common in temperate climates with no dry seasons (The Invasive Species Compendium, 2019). Even though the south of Sweden is not classified as any of the mentioned classifications the plant’s ability to thrive in relatively cool climates has been discussed, and its northern distribution limits set to roughly 64°N in north-west Europe (Beerling, 1993; Beerling & Perrins, 1993).

2.2.1 Introduction, Establishment and Spread in Sweden

I. glandulifera was brought to Sweden in the mid-19th century and introduced as an ornamental plant. It gained popularity and was cultivated by many estate owners across the country (Strese, 2012). The first documented observations of wild populations of *I. glandulifera* were made in 1918 in Scania and 1928 at Frihamnen in Stockholm (Naturhistoriska riksmuseet, 1997). It is today common throughout Sweden, except in the interior of Norrland (Swedish Environmental Protection Agency, 2020).

I. glandulifera is exclusively propagated by seeds and it is both insect and self-pollinated. It has a higher sugar nectar production per flower than any native European plant species, which enables the plant to attract numerous insect pollinators (Chittka & Schürkens, 2001). A single plant can produce up to 2500 seeds and disperse them explosively up to 5 meters from the parent plant (Beerling & Perrins, 1993).

Besides the local dispersal around the plant, spread analysis studies have shown that longer dispersal of seeds is made by water bringing the seeds downstream. Another commonly mentioned cause of dispersal is transportation of plants and soil containing seeds and via movement of people or vehicles that have worked in soil containing seeds (Swedish Environmental Protection Agency, 2020).

2.2.2 Negative Impacts of *I. glandulifera* as an Invasive Species

I. glandulifera has been identified as one of the most problematic invasive alien species in Sweden. Common negative effects are:

- Competition with native species.
- Erosion.
- Chemical effects in the soil.

Competition: It is established in large parts of the country, forms large stocks and there is a risk of long-term spread. The large dense stocks it creates compete with native plants for space and sunlight. Further, as mentioned above, it has higher sugar nectar production per flower than any native species, making it attractive for pollinators, for example bees. This in turn results in fewer visits from pollinators for endemic species, affecting their seeding and reproduction (Swedish Environmental Protection Agency, 2019).

Erosion: It has the capability to spread into very large dense stocks of several hundred square meters. When the plant withers in the autumn, there is no other soil vegetation left, such as grass and shrubs that bind the soil, which in turn leads to soil erosion. Since it thrives along watercourses it can create erosion problems during high water flows after the winter months (Greenwood et. al, 2018).

Chemical effects: Another threat from *I. glandulifera* discussed recently, is its release of allelopathic compounds that affects soil fungi and arbuscular mycorrhiza, thus altering the nutrient cycling (Čuda et. al., 2019).

2.3 Pest Risk Mapping

Pest risk modeling aims to assist decision makers to identify establishment and prognosticate further spread of invasive alien species, and in some cases quantify risk and impacts of further spread. Maps with information regarding occurrence of species are considered helpful tools to control the spread in a given area (Klinken et. al, 2015).

In Venette et. al. (2010), different kinds of pest risk maps are compared and divided into distinct types. The two main types are impact maps and distribution maps. The first one addresses the probable consequences of an invasion while the latter the probability of occurrence of a species in a certain geographic location. Distribution maps are further divided into deductive and inductive types. Deductive approaches use detailed knowledge of climatic and environmental preferences determined from laboratory studies to infer where a species can occur, while inductive approaches are based on actual findings and observations to determine the relationship between environmental covariates and the occurrence of an invasive alien species. The latter is explained to require less knowledge of a species' biology and they can rapidly provide simple pest risk maps for surveillance, etc. According to Venette et. al. (2010) there are certain advantages and disadvantages with the different types of approaches, and it is suggested to combine methods.

For *I. glandulifera*, different approaches have been used to make distribution analysis and consequent pest risk maps; two of these are mentioned below to exemplify the different approaches:

1. Beerling (1993) uses a deductive approach, based on climatic conditions, and adds a risk map for potential spread of *I. glandulifera* northwards due to global warming.
2. Dajdok et al. (2003) base their investigation on actual observations of *I. glandulifera* made between 1996 and 2000 in their study area. A distribution map is made to depict the locations of the observations and a comparison is made of a couple of environmental conditions at the sites.

In this thesis, an inductive approach based on actual observations, is used. Current distribution equals the locations of observations of *I. glandulifera* represented by points on a map (Dajdok et al. 2003). Single observations of *I. glandulifera* in Kronoberg County are quantified on each specific environmental condition found at the location with the purpose of identifying preferences. For the final risk map, a weighted overlay is made with the purpose of increasing or decreasing the importance of certain conditions by assigning weights to them before the overlay. For a more in-depth discussion about the method used for this thesis, see Chapter 3.

3. Methodology

The first objective of this study was to analyze the distribution of *I. glandulifera* in the county of Kronoberg. The method used is inspired by similar studies, such as Dajdok et al. (2003), mentioned in the previous chapter. The workflow for the distribution analysis is explained in detail in Section 3.2

The second objective was to create a risk map and to visualize preferred locations for occurrence based on spread and habitat preferences discussed in Chapter 2 and on the distribution analysis (Section 3.2). The workflow for producing the pest risk map for Alvesta Municipality with a weighted overlay is explained in Section 3.3.

3.1 Data and Study Area

The study area for the distribution analysis is the County of Kronoberg, in southern Sweden. For the spread and risk map, the area of focus is Alvesta municipality, in the center of the county. See figure 3:

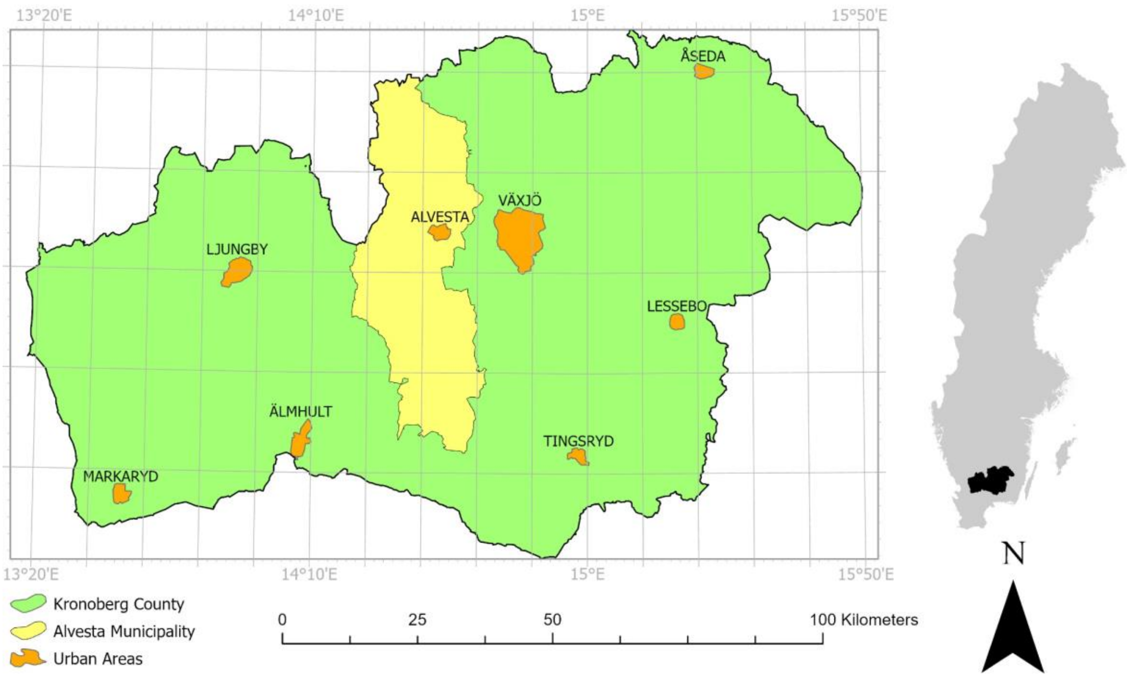

Figure 3: The county of Kronoberg with Alvesta municipality's borderline.

The data used for this study is listed below in Table 1 and described in detail below.

Table 1: Summarized information about the data used in this study.

Data	Date downloaded	Type	Resolution	Source
Observations of *I. glandulifera*	2022-01-28	Shapefile Feature Class	N/A	*Artportalen* of The Swedish University of Agricultural Sciences (SLU Artdatabanken, 2021).
Administrative borders	2021-06-06	Shapefile Feature Class	N/A	Lantmäteriet (Lantmäteriet, 2021).
Roads	2021-06-27	Shapefile Feature Class	N/A	Lantmäteriet (Lantmäteriet, 2021).
Water	2021-06-27	Shapefile Feature Class	N/A	Lantmäteriet (Lantmäteriet, 2021).
Land cover	2021-06-27	Shapefile Feature Class	N/A	Lantmäteriet (Lantmäteriet, 2021).
Soil moisture	2021-06-19	Raster	2x2 m	Swedish University of Agricultural Sciences (SLU, 2021c)
Soil type	2021-07-02	Shapefile Feature Class	N/A	Geological Survey of Sweden (Geological Survey of Sweden, 2021)

All datasets mentioned above have been clipped to the study area and projected to SWEREF 99 TM.

Artportalen – data about presence of I. glandulifera

The database *artportalen* contains over 70 million observations of wild species in Sweden recorded. The data is mainly from recent decades, but a certain amount of historical data is available (SLU, 2021b).

The observations of *I. glandulifera* are represented by points. The specific observation points used for this study were filtered and downloaded from Artdatabanken's webpage

(SLU Artdatabanken, 2021). The filter selection gave a point layer representing findings between 2000-09-01 and 2021-12-31 in the County of Kronoberg.

Administrative Borders, Roads, Water and Land Use

The administrative borders for Kronoberg County and Alvesta Municipality, as well as the roads, water and land use datasets were extracted from Lantmäteriet's property map, in vector format (Lantmäteriet, 2021).

Soil Moisture

The soil moisture layer used for this study was elaborated by the Swedish University of Agricultural Sciences and published in 2021. It is based on hydrological modelling using machine learning on training sets, the index is static and has a resolution of 2×2 meters. The soil moisture map was primarily developed for use in forest planning, but it is encouraged to be applied in other contexts/uses (SLU, 2022).

There are two versions available for download at the webpage of The Swedish University of Agricultural Sciences, an index version with values on a scale from 0 to 101, were low values indicate dry soil and high values indicate wet soil, and another version with three classes: 1) wet to moist, 2) moist to fresh and 3) fresh to dry.

For the distribution analysis the version with values ranging from 0 to 101 was used. It was reclassified to ten classes: *1)* 0-10, *2)* 11-20, *3)* 21-30, *4)* 31-40, *5)* 41-50, *6)* 51-60, *7)* 61-70, *8)* 71-80, *9)* 81-90 and *10)* 91-100 (101 equals water).

Soil Type

The soil type data was elaborated and published by The Geological Survey of Sweden and it contains information on soil types, land shape, ground blockiness, line object, and point object distribution of soil types in or near the surface layers. It is advised to be used with care when analyzing and assessing soil conditions for investigation purposes (The Geological Survey of Sweden, 2022).

3.2 Distribution Analysis

In the following sections (3.2.1 – 3.2.5) descriptions are provided on how the data layers presented above, were handled and utilized to be able to examine the relationships between the observations of *I. glandulifera* and various environmental conditions (distance to roads, distance to water, different land cover types, different soil types and soil moisture classes).

The first step, after converting and projecting all data to the same coordinate system, was to clip to the data to the extent of the county of Kronoberg. After that and depending on if the data was raster or vector, different tools in ArcGIS Pro were used. The general workflow is seen in Figure 4.

The results were later counted, calculated and summarized in Excel.

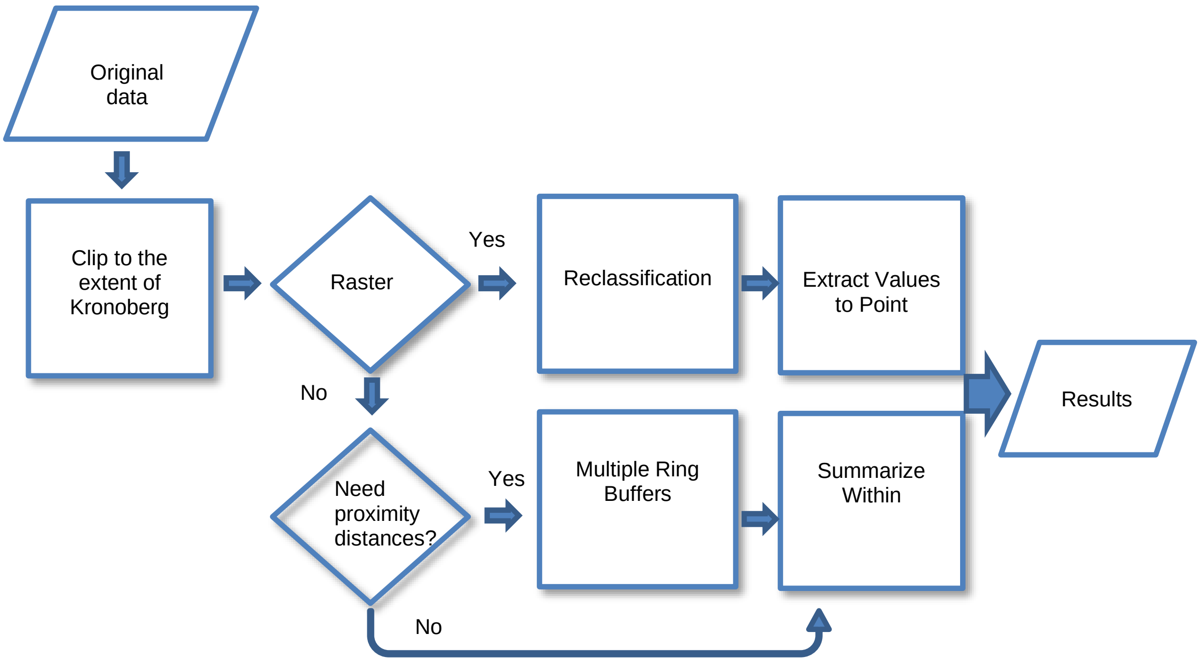

Figure 4: General workflow for the distribution analysis.

3.2.1 Analysis of Occurrence in Relation to Distance to Roads

Closeness to roads is often a strong predictor of the occurrence and dispersal of invasive alien species (Mortensen et al., 2017; Dimitrakopoulos et al., 2017; Thiele et al., 2009). To analyze the spread of *I. glandulifera* at different distances from roads, four buffer zones were created around the line features, representing roads in the county of Kronoberg. The spread of *I. glandulifera* at different distances from roads was assessed in buffer zones of 0-70 meters, 70-200 meters, 200-300 meters and 300-max, see figure 5.

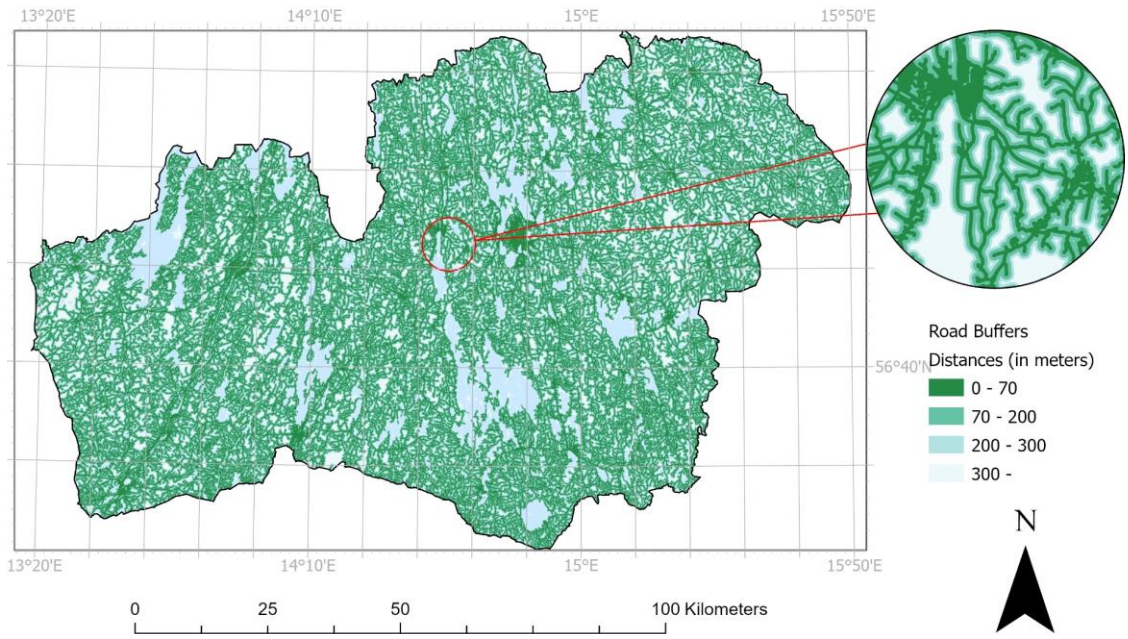

Figure 5: Buffer zones around the roads of Kronoberg County.

3.2.2 Analysis of Occurrence in Relation to Distance to Water

According to Dimitrakopoulos et al. (2017) there is a positive relationship between proximity to bodies of water and the presence of a number of invasive species. In the case with *I. glandulifera*, areas adjacent to a watercourse should theoretically have more observations because of the dispersal of seeds made by water transporting the seeds downstream (Pyšek & Prach, 1994). To analyze the spread of *I. glandulifera* at different distances from water bodies, buffer zones were created around the bodies in Kronoberg County, see Figure 6. Observation points of *I. glandulifera* were later counted and summarized inside the zones. The spread of *I. glandulifera* at different distances from water bodies were counted in buffer zones of 0-500 meters, 500-1000 meters, 1000-1500 meters and 1500-max.

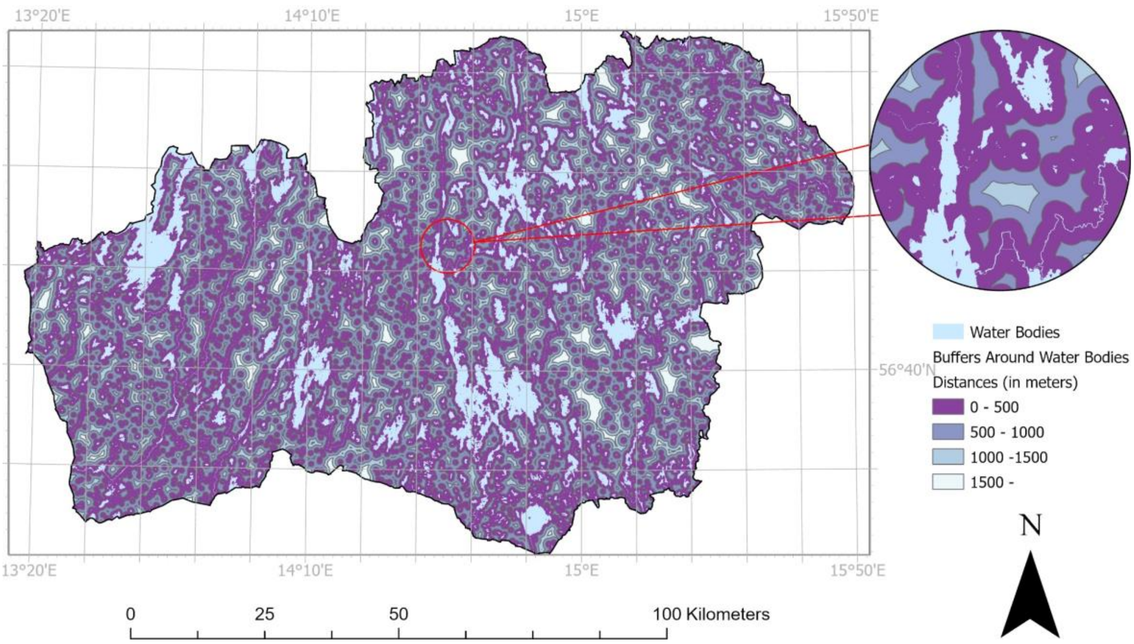

Figure 6: Buffers created around the water bodies of Kronoberg County.

3.2.3 Analysis of Occurrence in Relation to Land Cover

Appearance of *I. glandulifera* may be facilitated by particular land covers or changes of land uses (Bieberich et al., 2020). To investigate if we could see a particular relationship between types of land cover in Kronoberg and observations of *I. glandulifera*, observation points were counted and summarized within each polygon of land cover, see Figure 7.

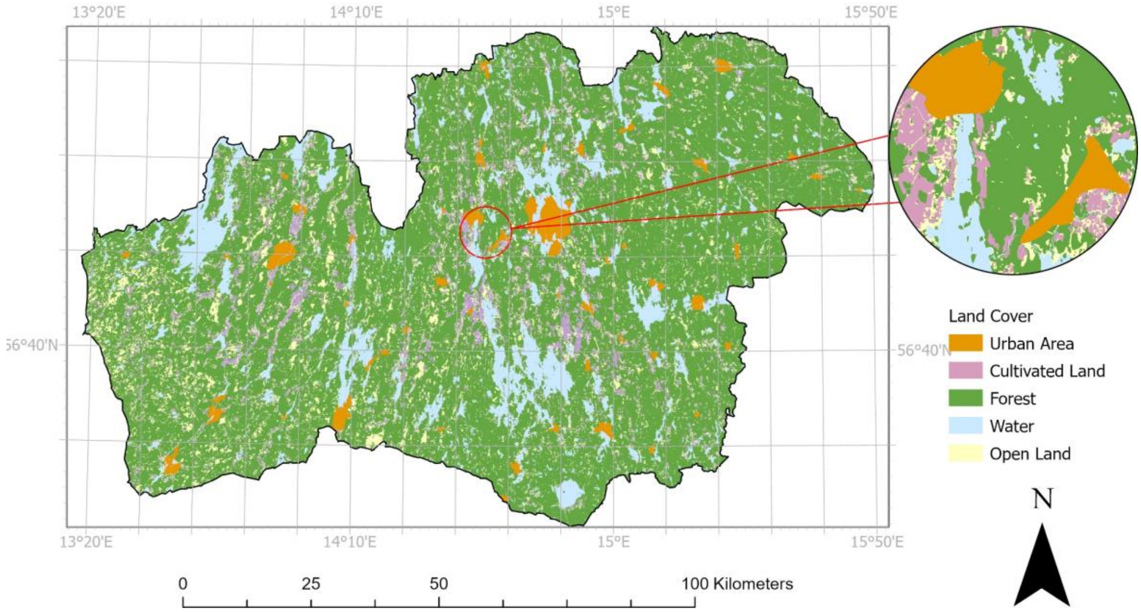

Figure 7: Land cover types in Kronoberg County.

3.2.4 Analysis of Occurrence in Relation to Soil Types

The occurrence of *I. glandulifera* on different types of soils was analyzed similarly as with land use, that is, observation points were counted and summarized within each polygon of soil type, see Figure 8.

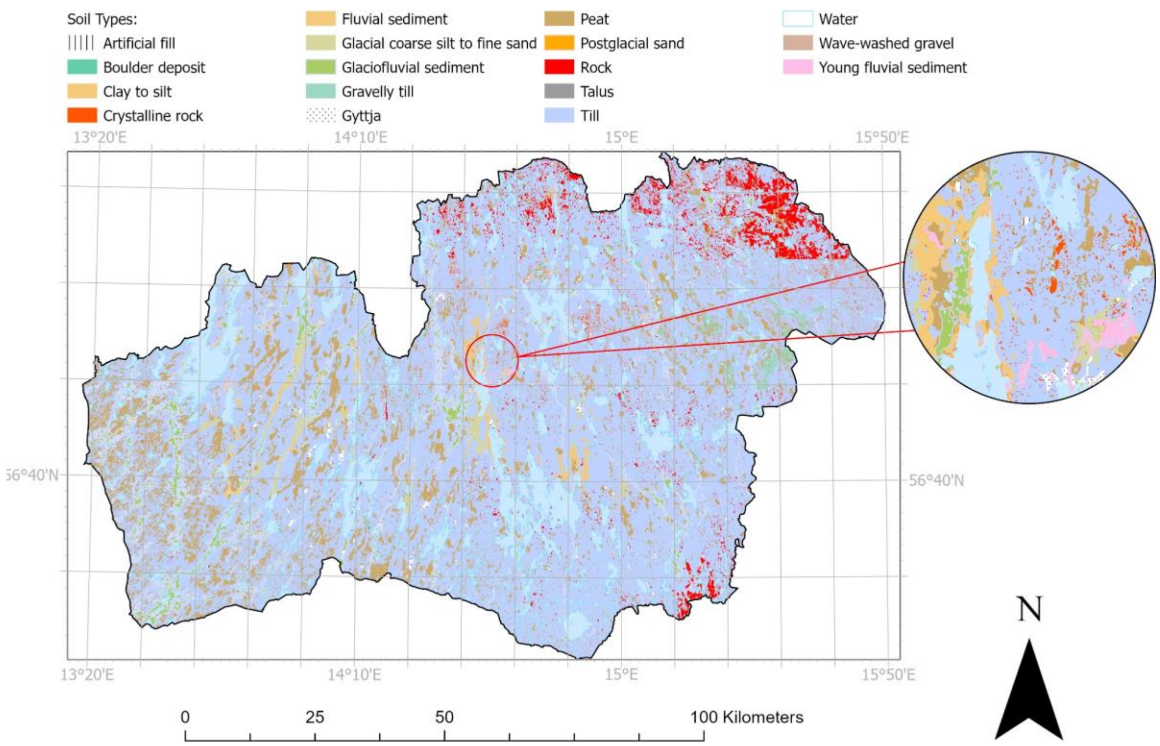

Figure 8: Soil types in Kronoberg County.

3.2.5 Analysis of Occurrence in Relation to Soil Moisture

Sufficiently high soil moisture is a stringent requirement and a strong predictor for the occurrence of *I. glandulifera* (Clements et al., 2008). To analyze its occurrence and preference for moist areas in the county of Kronoberg, observations were summarized and counted to investigate how many points were found within cells with distinct soil moisture levels. The map (see Figure 9) is a soil moisture index ranging from 0 to 100 where 0 is driest and 100 is most moist (101 represents bodies of water).

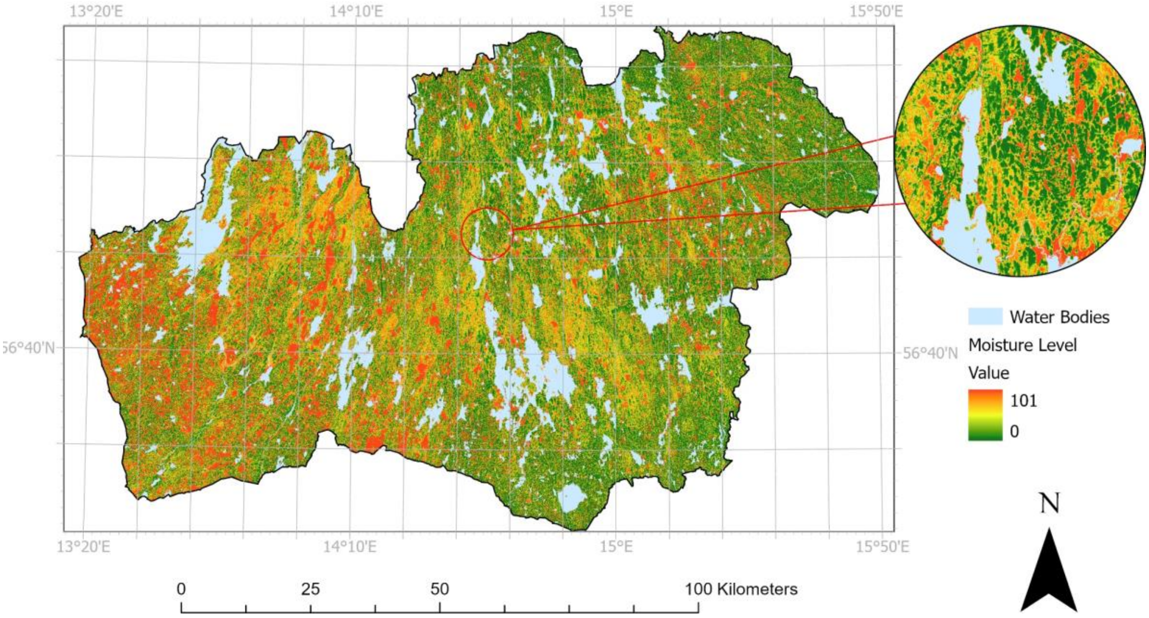

Figure 9: Soil moisture in Kronoberg County.

3.3 Reclassification and Weighted Overlay

The approach applied in this research for developing a pest risk map for Alvesta is based partially on the method for pest risk mapping mentioned in Klinken, R. D. et. al. (2015) where potential distribution and spread from existing populations are predicted, combining distribution data with input from experts regarding habitat preferences.

This study has not included the opinion from experts to influence reclassification values or weightings. Instead, the habitat and spread preferences for *I. glandulifera* has been based on the research mentioned in Chapter 2.

Most of the data used in this study was obtained in vector format. *Weighted overlay* can only be performed on raster data, requiring all vector data to be converted to raster format. For a general workflow of the data processing see Figure 10.

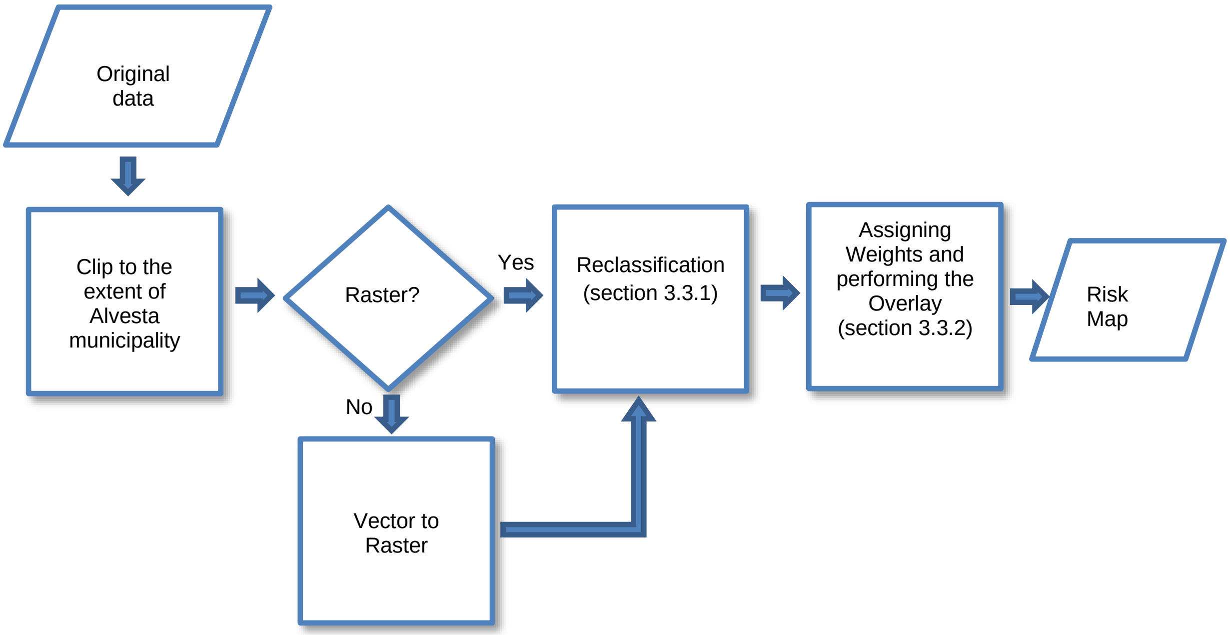

Figure 10: General workflow for elaborating the pest risk map for Alvesta municipality.

The data converted to raster format were *road buffers*, *buffers around waterbodies*, *land cover* and *soil types*. The layers were converted using ArcGIS Pro's conversion tool *Polygon to Raster*. All features were converted to raster layers with a cell size of two-by-two meters.

3.3.1 Reclassification

After conversion to raster, all raster layers were reclassified. The values assigned for the reclassification in this study are based on the interpretation of the research presented in Chapter 2 and the results from the analysis, and the argumentation supporting the selection is given next to each table.

Reclassification of distance ranges from roads and bodies of water: For roads and water bodies the reclassifications have been made based on euclidean distance from the feature, see Table 5. The highest numbers are assigned to the areas near roads and bodies of water. According to the literature consulted, invasive plant species often spread by water and roads (Dimitrakopoulos et al., 2017) (Thiele et al., 2009). *I.*

glandulifera is not an exception to this, as it is considered a weed of riparian systems being dispersed by water (Pyšek & Prach 1994) and commonly observed in roadside ditches (Clements et. al., 2008).

Table 2: Reclassification values for distances from roads and waterbodies.

Raster	**Ranges (meters)**	**Reclassified value**
Roads	<40	5
	40 – 80	4
	80 – 120	3
	120 – 200	2
	> 200	1
Water bodies	<300	5
	300 – 600	4
	600 – 900	3
	900 – 1200	2
	>1200	1

The results presented in Sections 4.1.1 and 4.1.2 coincide with the research in general and the reclassification values are therefore descending as we get farther away from the features.

Reclassification of the Land Cover Layer: For the land use layer, the reclassified values are seen in Table 3. The values have been selected based on spread studies of *I. glandulifera*. According to Bieberich et al. (2020) *I. glandulifera* benefits from changes such as disturbances or changed land use. Non-native species are repeatedly unintentionally or intentionally introduced into urban areas, making urban areas a strong predictor for invasive alien plants in general; and Clements et. al. (2008) observed *I. glandulifera* in northern latitudes in wet woodlands, forest plantations, forest clearings, urban areas and wet meadows.

Table 3: Reclassification values for the land cover raster.

Land Cover Type	Reclassification
Open Land	4
Forest	3
Urban Areas	5
Cultivated Land	1

The result from the land use analysis in Section 4.1.4 suggests the order of the reclassification values according to Table 3.

Reclassification of Soil Type Layer: For the soil type layer, the reclassified values are seen in Table 4. The values assigned are in general low, taking into consideration that *I. glandulifera* can grow on a wide variety of soil textures and structures (Beerling & Perrins, 1993). The reason for assigning higher value to areas described as *artificial fill* is that artificial fills are often seen in urban areas where a disturbance and land use change has been made, as well as movement and transportation of soils, all of which are strong spreaders of invasive alien plants (Bieberich et al., 2020). A higher value is also given to *young fluvial sediments*, taking into consideration that longer dispersal of seeds is made by water taking the seeds downstream and these should deposit and possibly grow in these areas (Pyšek & Prach, 1994).

Table 4: Reclassification values for the soil type raster.

Soil Type	Reclassification
Till	2
Boulder deposit	2
Crystalline rock	1
Peat	2
Rock	1
Glaciofluvial sediment	2
Clay	2
Clay to silt	2
Glacial coarse silt to fine silt	2

Postglacial sand	2
Gravelly till	2
Artificial fill	5
Young fluvial sediment	3

The result from the analysis presented in Section 4.1.5 support the interpretation of the research and affirms the choice of reclassification values.

Reclassification of the Soil Moisture Layer: For the soil moisture layer, the reclassified values are seen in Table 5. According to Clements et al. (2008), high soil moisture is the single most important predictor of *I. glandulifera*.

Table 5: Reclassification values for the soil moisture raster.

Ranges	Reclassification
<20	1
20 – 40	2
40 – 60	3
60 – 80	5
80 – 100	4

In Section 4.1.3, the results of the density of observations confirm Clements et al. (2008), but the density peaks between 60 and 80, thereafter a rapid decline is noted, suggesting that it might be too humid in those areas. The highest reclassification value is therefore given to the moisture range of 60 – 80.

3.3.2 Assigning Weights and Performing the Weighted Overlay

To solve a multicriteria inquiry like the one presented in this project, consisting of multiple layers and factors, each layer was provided a weight of influence. These were combined according to their relative importance according to Equation 1 (Malczewski & Rinner, 2015):

$$S = \sum_{j=1}^{n} (\mathrm{w}j \times \mathrm{v}j) \tag{1}$$

Where:

S = Suitability
j = layer number
n = number of layers
w*j* = weight of layer *j*
v*j* = value of layer *j*

The calculation is illustrated in Figure 11, where each raster is assigned a percentage of influence. The values in the cells are multiplied by the weights (0.75 and 0.25), and the results are added together and rounded to the nearest integer in the output raster (Esri, 2022).

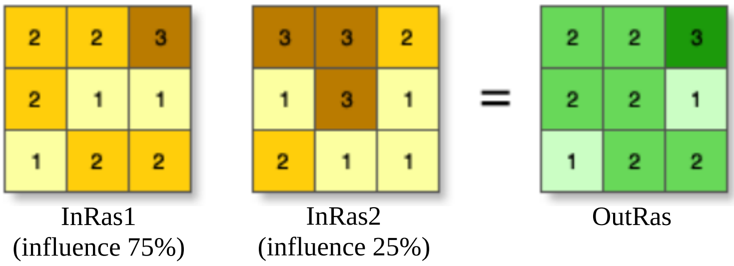

Figure 11: Illustration of the calculation for weighted overlay in ArcGIS Pro (Esri, 2022).

The weights used in this project are given in Table 6. The selection of weights emphasized the importance of water and moisture, both as a way of spread of seeds but also because of the importance it is given in the literature. The same applies for land use which has a high reclassification value for urban areas; urban areas are well known to be hotbeds for invasive alien species.

Table 6: Weights assigned to raster layers in ArcGIS Pro's Spatial Analyst tool Weighted Overlay.

Raster	**Percentage**
Roads	15%
Water bodies	20%
Soil moisture	30%
Land use	20%
Soil types	15%

The output raster from Weighted Overlay is, as mentioned earlier, an integer. The values were labeled with the following suitability levels:

1 = Very Low

2 = Low

3 = Moderate

4 = High

5 = Very High.

4. Results

The reported observations of *I. glandulifera* in Kronoberg County between September 1, 2000 and December 31, 2021 (SLU Artdatabanken, 2021) are shown in Figure 12. The findings are more concentrated in urban areas, particularly in Växjö, Alvesta, Ljungby and Älmhult. Another aspect quickly identifiable is that observations also seem more common relatively close to bodies of water.

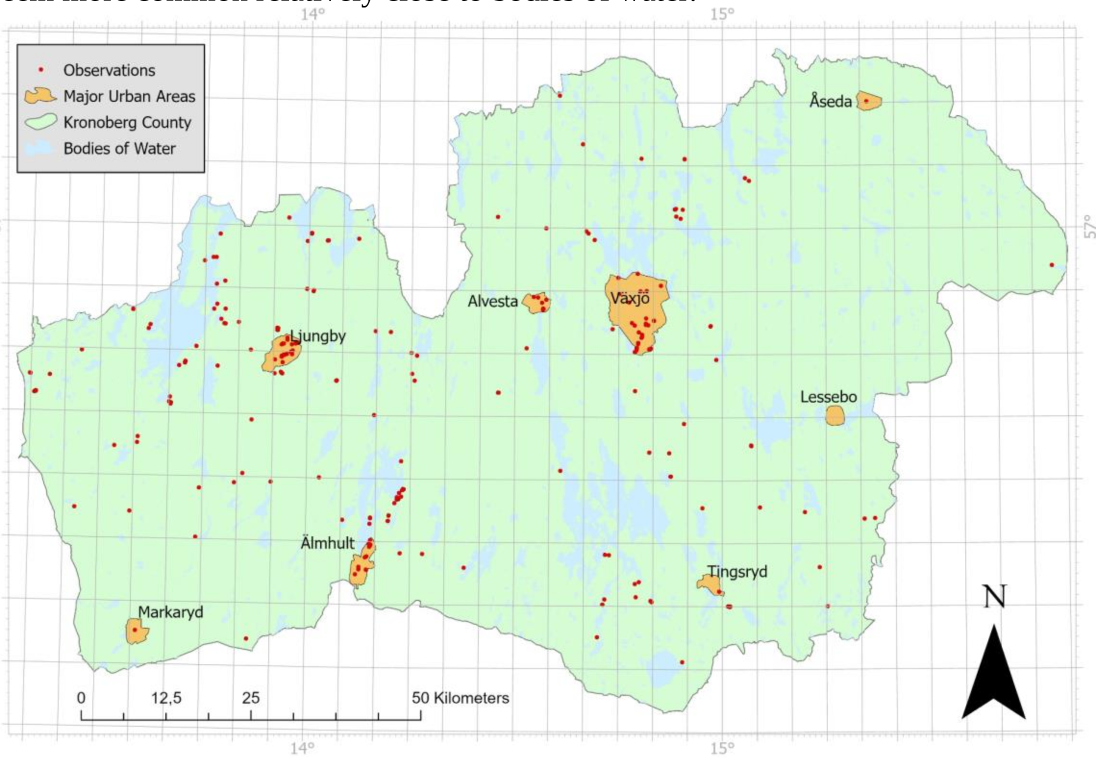

Figure 12: Observations of I. glandulifera in Kronoberg County between the year 2000 and 2021.

A total of 311 observations are considered in this study, with the largest number of reported observations in the year 2020 (Figure 13).

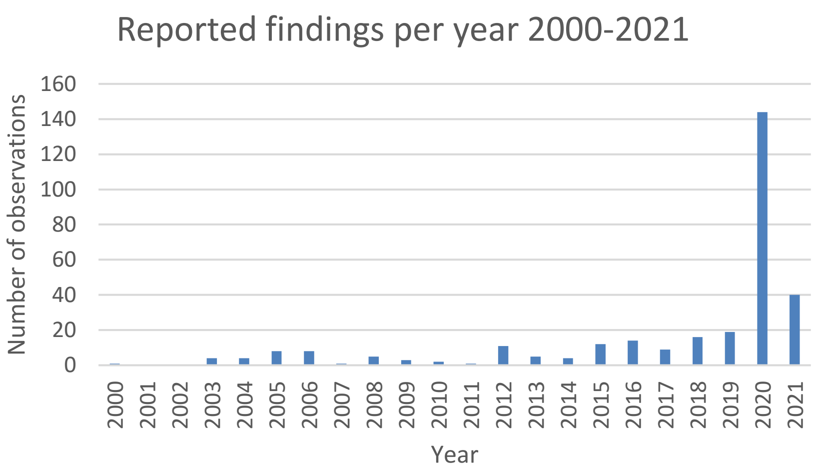

Figure 13: Reported observations of I. glandulifera per year in the county of Kronoberg.

4.1 Distribution Analysis

In the following sections, the results of the analysis made with the 311 observations are presented. Five data sets representing different abiotic environmental conditions are used to identify the set of conditions where observations of *I. glandulifera* have been made.

The five layers used are 1) Proximity to Roads, 2) Proximity to Bodies of Water, 3) Land Cover, 4) Soil Types and 5) Soil Humidity.

4.1.1 Proximity to Roads

Proximity to roads is an important factor with 75% (234) of all observations being made within 70 meters from the nearest road (Zone 1). Further, 24% (74) of the findings were made between 70 and 200 meters (Zone 2) from the nearest road and only 1% (3) findings were made at further distances (Table 7). Densities (observations per square kilometers) are also shown in Figure 14. The density is higher closer to roads and declines rapidly as we get farther away.

Table 7: Observations of I. glandulifera at different distances from roads.

Zone	Distance (m)	Count	Observations (%)	Area (km^2)	Observations/ km^2
1	0-70	234	75%	2973	0.079
2	70-200	74	24%	3628	0.020
3	200-	3	1%	2823	0.001
	TOTAL:	311	100%	9424	

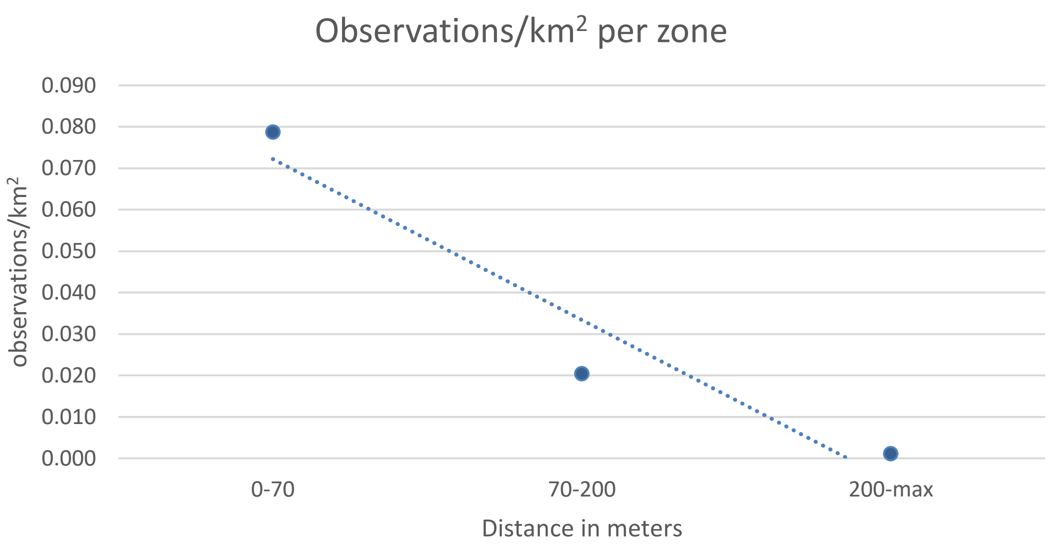

Figure 14: Observations per square kilometer at 0-70, 70-200 and 200-max meters of distance from roads and a fitted trend line.

4.1.2 Proximity to Bodies of Water

Proximity to water bodies is an important factor with 81% (251) of the observations of *I. glandulifera* made within 500 meters from the nearest water body, 10% (32) in distances between 500 and 1000 meters, 8% (26) in distances between 1000 and 1500 and 1% (2) of the findings were made at distances further than 1500 meters from the nearest body of water (Table 8). Findings per square kilometers indicates a down trending density of findings as we get farther away from water bodies (Figure 15).

Table 8: Findings of I. glandulifera at different distances from bodies of water.

Zone	Distance (m)	Count	Findings (%)	Area (km^2)	Findings/km^2
1	0-500	251	81%	5152	0.049
2	500-1000	32	10%	3039	0.011
3	1000-1500	26	8%	999	0.026
4	1500-	2	1%	234	0.009
	Total:	311	100%	9424	

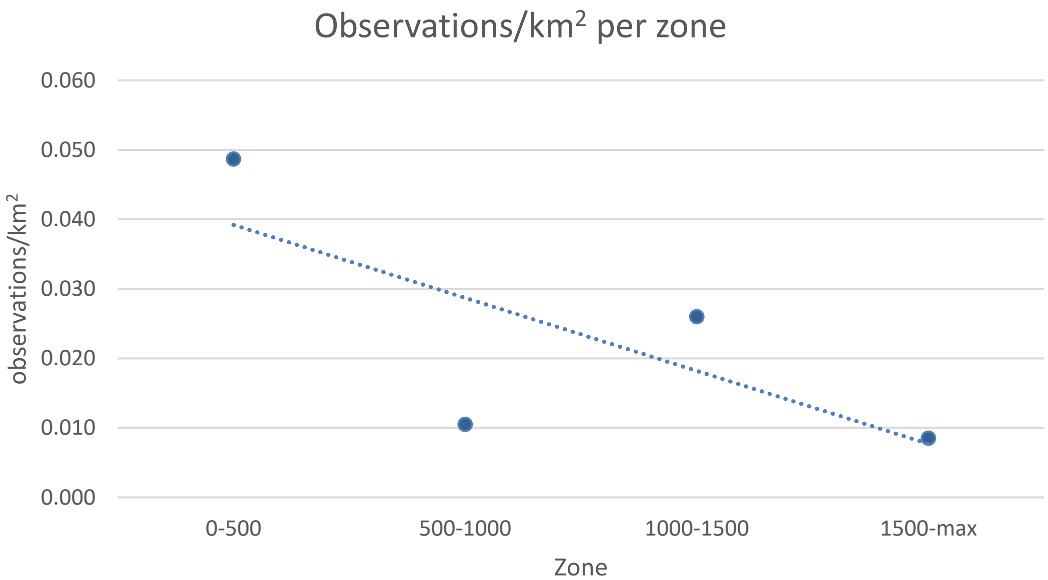

Figure 15: Observations per square kilometer at 0-500, 500-1000, 1000-1500 and 1500-max meters of distance from water bodies and a fitted trend line.

4.1.3 Land Cover

There is a noteworthy correlation between certain land cover types and the presence of *I. glandulifera* (Table 9). Approximately 40.5% (126) of the observations of *I. glandulifera* have been made in places that are defined as urban areas, followed by forest 35.4% (110), open land 22.5% (70) and cultivated land 1.6% (5).

Table 9: Count and densities of observations on land cover types.

Land cover	Count	Observations in %	Area (km^2)	Observations/km^2
Cultivated land	5	1.6%	525	0.01
Forest	110	35.4%	6908	0.02
Open land	70	22.5%	807	0.09
Urban areas	126	40.5%	243	0.52
TOTAL:	311	100%	9425	

Observations per square kilometers indicates the highest density of observations in land cover zones classified as urban areas (0.52), followed by open land (0.09), forest (0.02) and cultivated land (0.01) (figure 16).

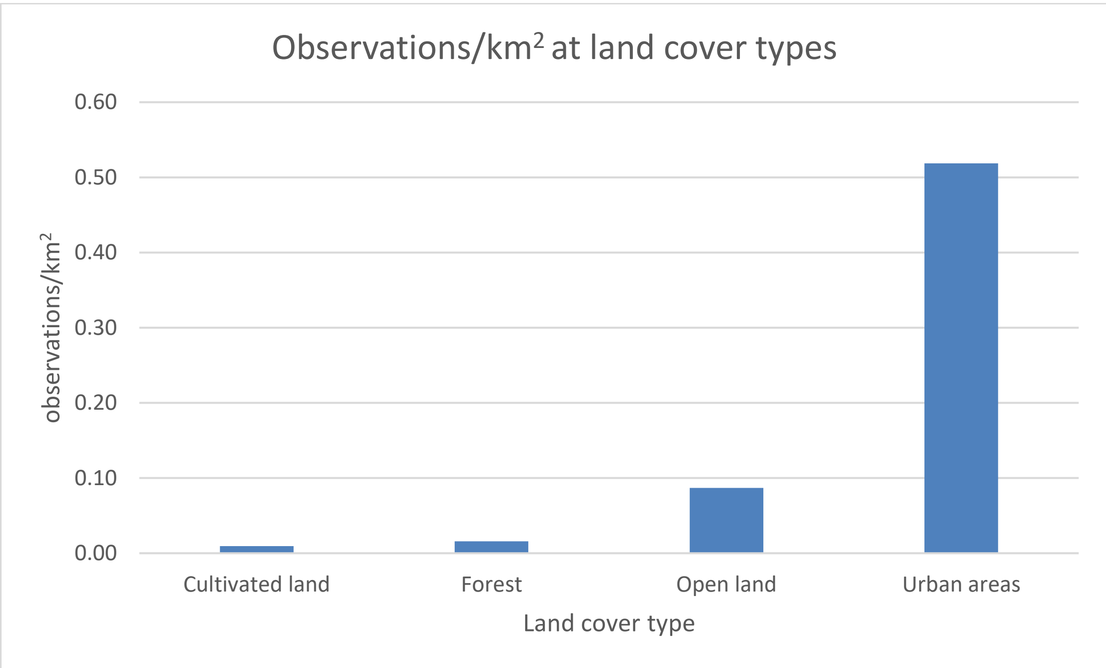

Figure 16: Observations per square kilometer on different land cover types.

4.1.4 Soil Type

The most common soil type of the county, *till*, has most observations of *I. glandulifera*, 63.3% (197), followed by *glaciofluvial sediment* 14.1% (44), *peat* 5.8% (18), *artificial fill* 4.8% (15), etc. (Table 10).

Table 10: Observations of I. glandulifera on top of soil types.

Soil Type	Count	Percentage	Area (km^2)	Observations/km^2
Till	197	63.3%	5995	0.03
Crystalline rock	3	1%	65	0.05
Peat	18	5.8%	1304	0.01
Rock	1	0.3%	300	0.00
Glaciofluvial sediment	44	14.1%	486	0.09
Water	N/A	N/A	962	N/A
Clay to silt	9	2.9%	70	0.13
Glacial coarse silt to fine sand	12	3.9%	93	0.13
Postglacial sand	3	1%	8	0.38
Artificial fill	15	4.8%	6	2.5
Young fluvial sediment	9	2.9%	8	1.13
TOTAL:	191	100%	9423	

The two soil types with the highest number of findings per square kilometer are artificial fills with 2.5 findings per square kilometer and young fluvial sediment with 1.13 findings per square kilometer (Figure 17).

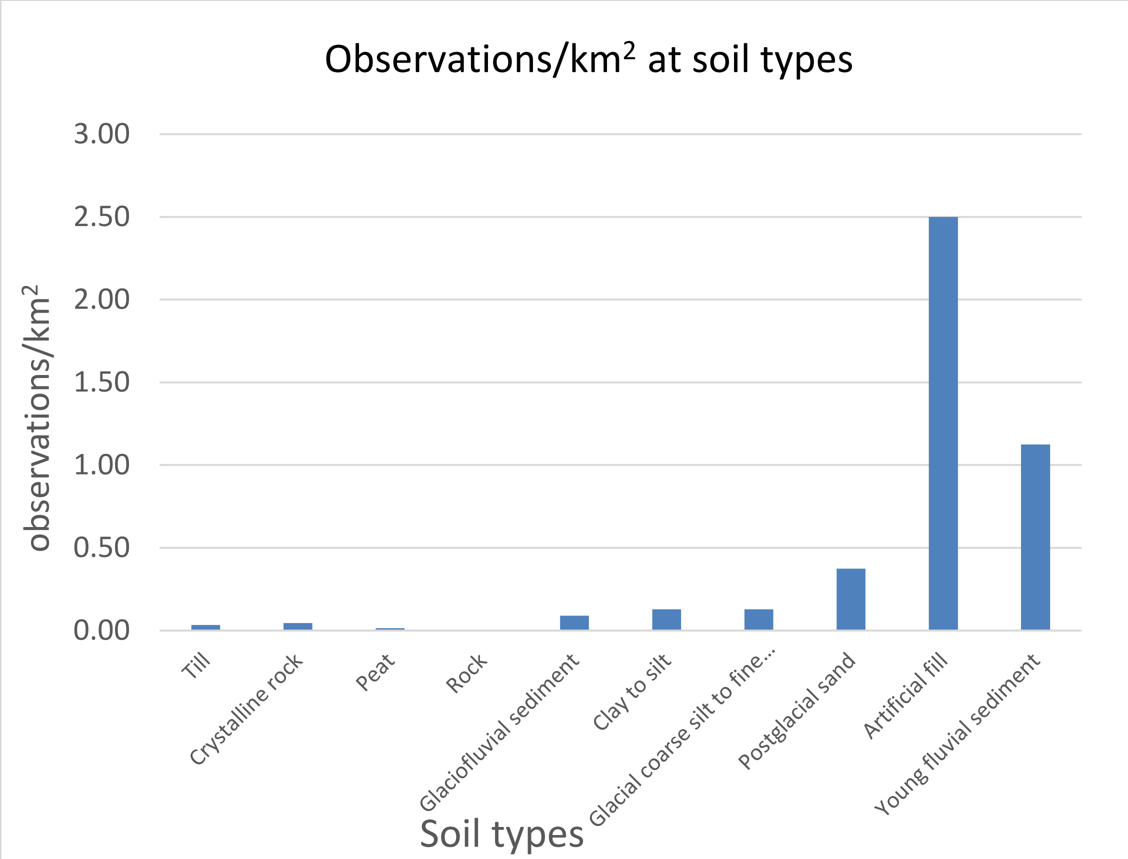

Figure 17: Observations per square kilometer on different soil types.

4.1.5 Soil Moisture

The soil moisture data which range between 0-101 where 0 is driest and 100 is wettest (101 is water) has been classified into 10 ranges. Most findings have been made in the dryer half, counting a total of 165 observations in the soil moisture range 0-50 and 146 observations have been made in the soil moisture range 51-100. A quarter of the observations (25.4%) were made in the driest range of the soil moisture data (0-10) (Figure 18 and Table 11).

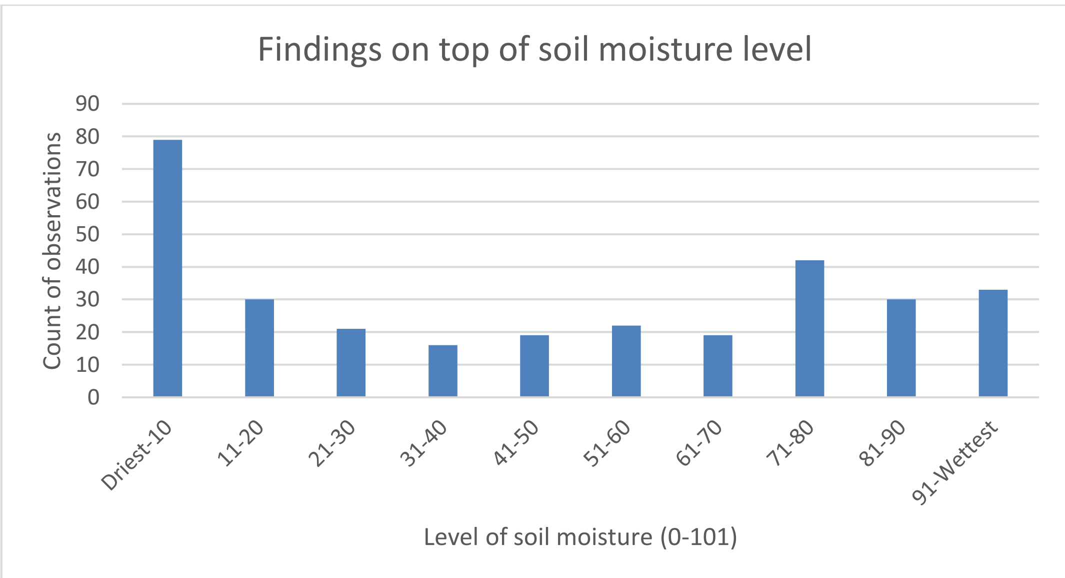

Figure 18: Count of observations in ten classes of soil moisture.

Table 11: Count and densities of observations on top of soil moisture levels.

Soil Moisture classes	Count	Area in km²	Observations/km²:
Driest-10	79	2685	0.03
11-20	30	765	0.04
21-30	21	528	0.04
31-40	16	447	0.04
41-50	19	423	0.04
51-60	22	438	0.05
61-70	19	490	0.04
71-80	42	592	0.07
81-90	30	747	0.04
91-Wettest	33	1338	0.02
Water		972	n/a
	TOTAL:	9425	

There is an increase in density of observations as the soil gets more moist (Figure 19). The observations decrease rapidly after the humidity level 80.

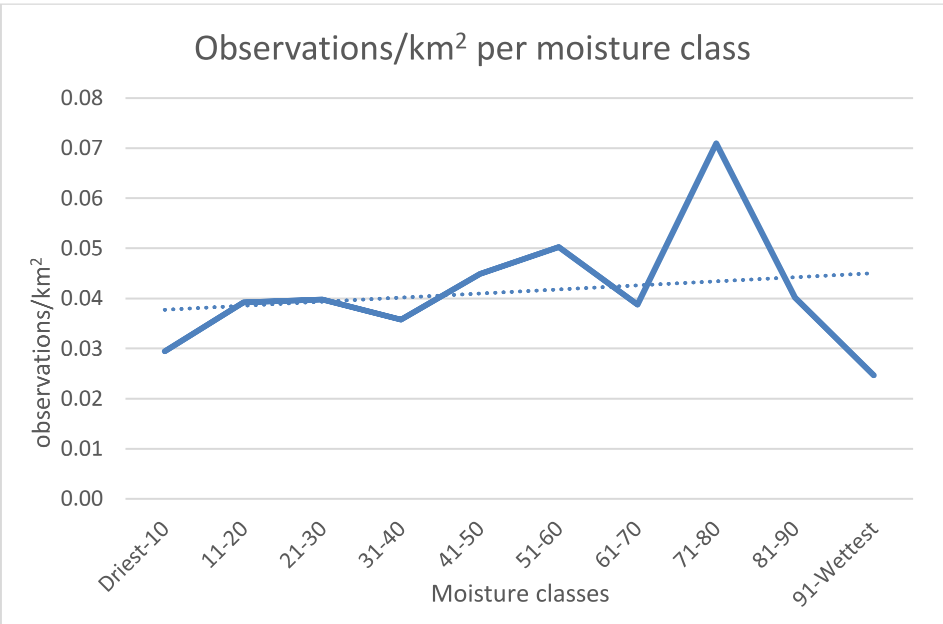

Figure 19: Observations per square kilometer within different soil moisture classes.

4.2 Pest Risk Map for Alvesta Municipality

The pest risk map (Figure 20) depicts areas where it is more probable that *I. glandulifera* occurs (thrives and spreads). The map is created with a weighted overlay and where the weights were assigned based on the research about habitat and spread preferences as well as on the results from the distribution analysis in this study.

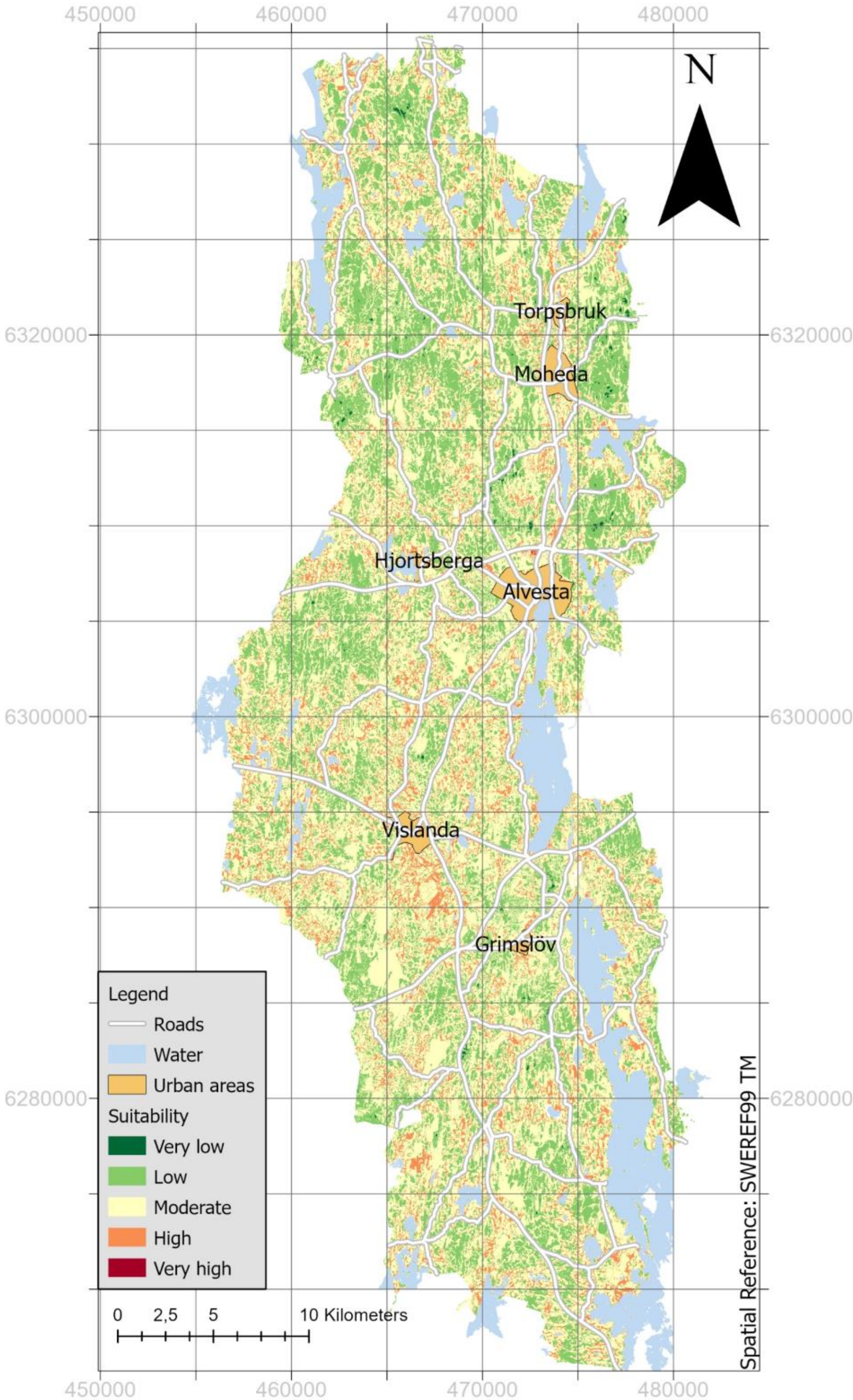

Figure 20: Pest risk map for I. glandulifera in the municipality of Alvesta.

The most common class is *moderate* with 57.38% of the area, followed by *low* with 30.01%, *high* with 12.35%, *very low* with 0.18% and *very high* with 0.07%. The percentage of areas belonging to the different classes can be seen graphically in Figure 21.

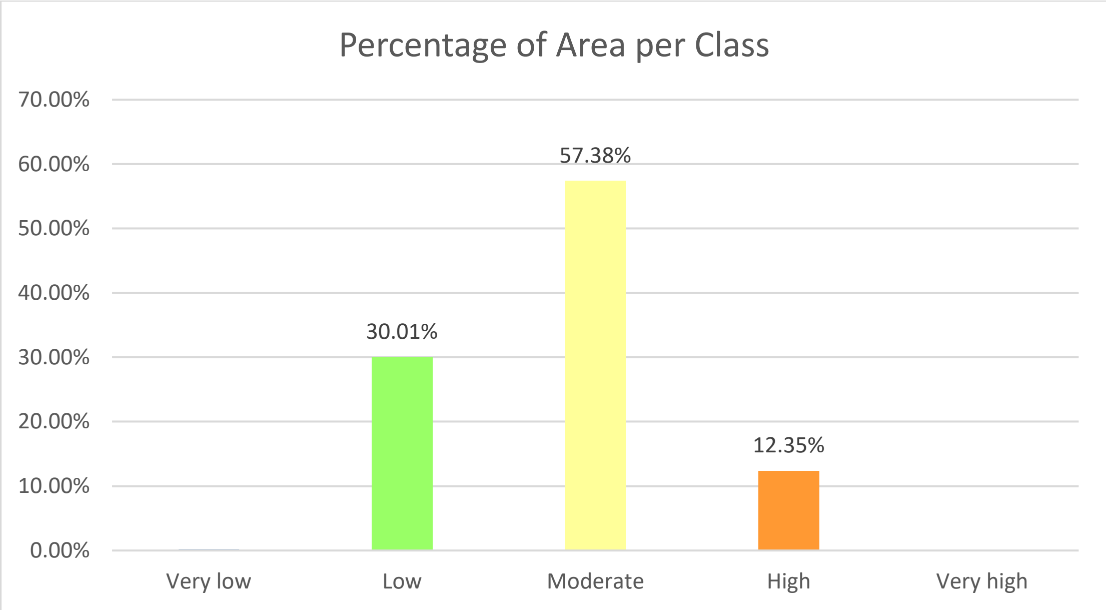

Figure 21: Area in percentage of the five different suitability classes.

The total area of Alvesta Municipality is 974 km^2 (1074 km^2 including water bodies). The areas (in km^2) of the suitability classes are *very low*, 2; *low*, 292; *moderate*, 559; *high*, 120; and *very high*, 1. The distribution is seen in Figure 22.

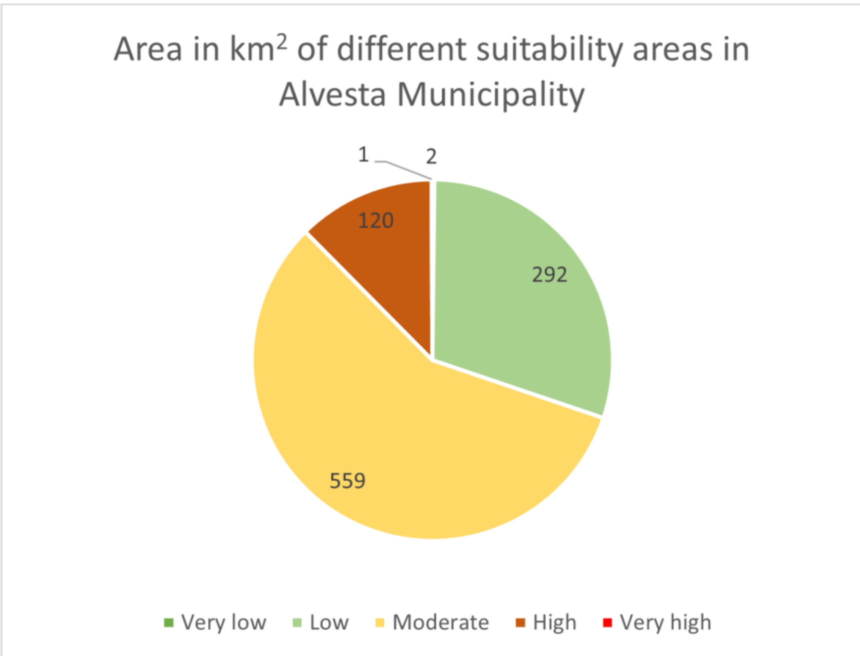

Figure 22: Area in km^2 for the five different suitability classes.

Actual locations of observations in the urban area of Alvesta (the seat of municipality with the same name) are seen in Figure 23. Seven out of nine observations have been found in areas labelled as either *very high* or *high*. The pest risk map is preferably presented at a large scale, as seen in Figure 23, showing a smaller amount of area with a greater amount of detail.

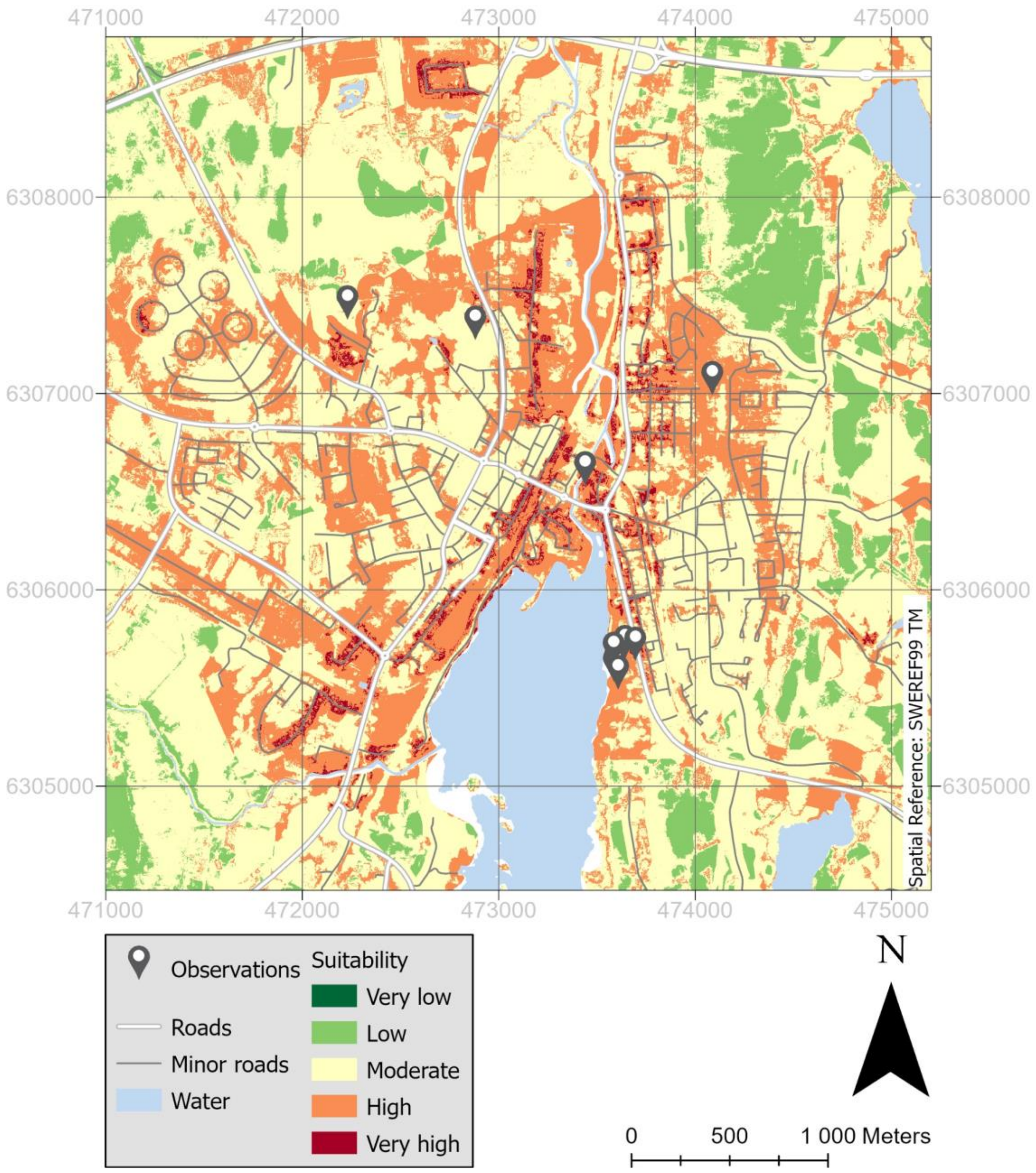

Figure 23: Observations in the urban area of Alvesta.

A total of 16 observations in the entire municipality of Alvesta have been made. Of these, 10 are in suitability area *High* (62.5%), 5 in *Moderate* (31.25%) and 1 in *Very High* (6.25%).

5. Discussion

The aim of this project was to make a distribution analysis of the accumulated observations of *I. glandulifera* in Kronoberg County, in order to identify relationships between environmental features and the observations, as well as to make a comparison with results from earlier literature and spread studies. The results together with earlier research were thereafter combined into a pest risk map to identify potential risk areas that should be prioritized for control to prevent the further spread of *I. glandulifera* in Alvesta municipality.

The results obtained from the analysis indicate that there are certain environmental features or conditions where *I. glandulifera* prefers to grow, or is more easily spread. The results coincide with the literature and the methods used for obtaining the results were inspired by similar studies. The results in general should be considered to be trustworthy.

The key data used for this study has been gathered and uploaded by the public through the Swedish portal for invasive species (*Artportalen*), a kind of crowdsourcing where people upload coordinates, pictures and species names. As seen in the beginning of Chapter 4, the number of reported observations of *I. glandulifera* have increased in recent years, with a peak in 2020. The interpretation of this increase is that the rise of reported observations may be due to reasons other than an actual rise in the number of specimens of *I. glandulifera* that are present. A possible speculative explanation which I have considered for the peak in 2020 is that the Covid-19 pandemic forced many to find an outdoor activity which they could do alone or at distance from others. It may be that searching and reporting invasive alien species is such an activity.

The results indicate that the strongest indicator of presence of *I. glandulifera* was the soil type *artificial fill,* followed by the land use type *urban areas*. These environmental conditions are well identified as areas more likely to contain seeds of invasive plants, as well as full grown specimens (Clements et. al., 2008). Particularly *artificial fills* that are often composed of soil, gravel, mulch, and other organic matter which can contain seeds or parts of invasive species. These kinds of soil masses are often moved or disturbed propagating invasive plants to new areas (County Administrative Board of Kronoberg, 2022; Helmisaari, H., 2010).

Furthermore, it was shown that the spread of *I. glandulifera* tends to concentrate along communication routes, nearby urban areas. A reason for the overrepresentation of reports on these sites could simply be due to more people walking on sidewalks, bicycle lanes, recreation paths, etc. rather than in the forest or rural lands, thus increasing the probability of people reporting at these particular sites. Still, many studies and organizations emphasize that roads are natural channels of distribution and dispersal of seeds and should therefore be considered when planning and counteracting the spread of invasive plants (Clements et. al., 2008; Swedish Environmental Protection Agency, 2022; Trafikverket, 2021). The results presented related to distance from roads can therefore also be considered in line with other earlier studies and reports.

Proximity to water was also shown to be an important predictor of *I. glandulifera*. Many observations were made around lakes. As was the case in proximity to roads, the reason for more reports closer to bodies of water can potentially be due to people roaming for recreational purposes on paths near a lake, instead of inside forests or rural lands where there are no roads or paths. Still, even in this case, we find support in the literature for invasive plants thriving close to water, especially *I. glandulifera*, which according to Pyšek & Prach (1994) disperse its large number of seeds by water.

For the observations located within several different soil moisture classes, a surprising result was that most observations of *I. glandulifera* were made in the drier half of the moisture data. The soil moisture data was therefore analyzed on more than one occasion, once removing the areas corresponding to urbanized zones, and for the final analysis the unclassified data was used instead of the pre-classified version (available at SLU’s database). The reason turned out to be that the area corresponding to the drier half was bigger than the area of the moister half. When calculating the density of the observations on different classes of moisture, the results coincided with the literature. According to Clements et al. (2008) the single most important predictor of *I. glandulifera* is soil moisture, and the densities of observations on top of the ten moisture classes corroborated that we get higher density of observations in the moister range, specifically between 60 and 80.

The results of the study have answered the research questions and fulfilled the objective of this project. Larger scale presentations of the pest risk map can be used to depict, at greater levels of detail, areas with a need for stricter control, particularly in the urban areas of the municipality. Further analysis can be done with the produced map; for example, a selection by location to highlight property polygons on top of the areas with greatest probability of occurrence. This can be useful since the regulation clarifies that the responsibility of prevention and control corresponds the property owner.

Further studies related to the spread of *I. glandulifera* and other invasive species could be focused on potential spread from existing plant populations instead of occurrence of plants. That is, this study focused on the occurrence and distribution of *I. glandulifera* and relationship between the occurrence and environmental variables. A study of potential spread from existing populations would require more knowledge of the plant’s biology and focus more on means of dispersal. The spatial distribution of the plants, where each individual plant is represented by a point, can be thought of a starting point. The invasive nature of *I. glandulifera* leads to the assumption that each plant can spread its seeds and initiate the growth of new plants around it, and each of those individuals will spread its own seeds at smaller or larger distances, creating multiple nodes of invasion (Pysek & Hulme 2005). Based on this assumption here are some examples of further studies could be focused on: Dispersal and transportation of seeds by nearby water streams, dispersal of seeds by animals, or focused on anthropogenic dispersal: transportation routes for garden waste, handling of garden waste in recycling centers, etc. are all potential studies of value.

6. Conclusion

The objective of this project was to analyse the distribution of *I. glandulifera* in the county of Kronoberg and use the results, together with earlier research, to create a pest risk map for a smaller area, covering the municipality of Alvesta. The results of the distribution analysis coincided with earlier spread and habitat literature, and a pest risk map for Alvesta Municipality was created.

The distribution analysis indicated that observations of *I. glandulifera* are more common in urban areas, close to bodies of water and roads. The number of observations decrease as we get farther from roads and waterbodies. The analysis also indicates that observations are more common in areas with higher soil moisture. It is important to note that the soil type *artificial fill* has the highest density of observations of all the analysed environmental factors.

A pest risk map depicting suitability classes was developed based on the above-mentioned results and earlier research. The resulting map is, at larger scales, useful to identify areas with a higher probability of occurrence of *I. glandulifera*, and can be used by decisionmakers as a tool for the control and eradication of the plant.

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