UNIVERSITY OF COPENHAGEN

A Statistical and GIS-based approach to plan and manage Giant Hogweed in Vordingborg

Thematic course II: Rural landscape – Landscape management and planning

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Abstract

Invasive Alien Species (IAS) is a global issue that poses a threat to native biodiversity and human health. Globalisation and new infrastructure have increased the rate of dispersal hence allowing them to establish. In a danish context, the municipalities are obliged to eradicate invasive species by the EU-regulation. The process of creating a plan to eradicate these species can be resource consuming for most municipalities and the same accounts for the municipality of Vordingborg which is subject for this report. An existing action plan for the invasive species **Giant Hogweed** (*Heracleum mantegazzianum)* was already created in this municipality, but a high number of populations are still present within its borders. In order to test a new approach, two different technical methods are used to produce various types of probability maps. Based on different environmental variables describing the distribution of the species, a statistic-based Species Distribution Model (SDM) and a process-based GIS suitability analysis have been carried out. The key product of this report is an **upgraded action plan** that consists of a general risk map**,** a cadastral-based risk map, landscape types map and overall guidance to manage the threat of this species. As all risk scores are based in a probability, the validity of these approaches can be discussed depending on both data sources used and also the accuracy of the registered occurrence data. The products and information provided by this action plan will be useful tools for the municipal planners when making decisions about the future development of the landscape as well as when looking for more efficient assignment of resources to eradicate the Giant Hogweed.

Preface

This report deals with the consequences of an actual environmental problem: invasive alien species. The purpose of it is to explore whether the GIS and Satistical tools can help to manage, plan and fight IAS in a Danish context.

The report is part of a planning process focused on creating an **upgraded management plan** for the invader Giant Hogweed (*Heracleum mantegazzianum*) in the municipality of Vordingborg. It is written in an academic context and embedded within the course *Thematic Course II: Rural landscapes (management and planning)* at the University of Copenhagen.

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1. Introduction

Invasive alien species (IAS) are species whose introduction and/or spread outside their natural past or present distribution threatens biological diversity. Not all Alien Species are considered as IAS, as they need to pose a threat to biodiversity due to their invasive characteristics.

Globally, IAS are considered one of the major threats to native biodiversity, together with habitat destruction, pollution and climate change (Sciences, 2014). They are present in all forms of plants, animals, fungi, microorganisms, and the ecosystems associated. It is estimated that 11% of the alien species in Europe are invasive, causing not only problems to the environment but also economic and social damage; and it is expected that the rate of biological invasion into Europe will increase in the coming years (Caffrey et al., 2014). IAS are recognized as damaging to native species and they can potentially impact biodiversity, the physical environment, ecosystem functioning, recreational activities and also human and animal health (Simberloff et al., 2013).

Globalisation facilitates the spread of IAS in many different ways. *Meyerson and Mooney* reviewed the main factors that drive biological invasions and listed them as **trade**, **propagule pressure**, **disturbance** and **species interactions** (Meyerson and Mooney, 2007). The rates of invasion have increased due to international commercial **trade**, new market routes and new products. For many plant species, ornamental purposes have been the main reasons to trade alien species and it is expected to increase in the coming years.

The volume of international trade between countries has increased significantly during the last decades. The moving of species can be either accidental or intentional for a planned purpose. Most of the terrestrial species have been traded with a specific purpose. For example, the Giant Hogweed has been traded the last century because of its ornamental values.

Climate change can also be a major force driving invasive introductions. New climatic conditions can benefit IAS in many ways, for instance it can favour its life cycles, alter the competition schemes leading to a dominance of alien species over the native ones, and also provide IAS with new habitats and empty niches due to changed perturbation cycles in the ecosystems (D Antonio et al., 2001). It is also important to state that IAS such us *Heracleum mantegazzianum* in Europe or *Phragmites australis* in North-America exhibit highly plastic responses to environmental changes, which may be translated into relatively greater ability to respond to other facets of global change, such us sea level rise and increasing temperatures (Farnsworth and Meyerson, 2003).

This means that when planning takes place on a larger scale (EU or globally), these factors must be considered as they are going to shape the distribution of the IAS during the upcoming years. However, in our case, the planning will focus on a more local scale, so climate change and trade will only be considered in a future perspective, but not when assessing the actual IAS distribution in the municipality.

1.1 IAS in a Danish context

Plant and animal species that are not native to Denmark are referred to as **alien species**, even though they can also be found as introduced species, exotic species or non-indigenous species. The definitions used in a Danish planning context are taken from the **European Regulation 1143/2014** (Schulz and Della Vedova, 2014) on invasive alien species.

Despite being a small country, Denmark is estimated to be home of approximately 35,000 native plant and animal species. This is probably a result of Denmark being situated in the zones between three European biogeographical provinces: the Boreal, the Atlantic, and the Continental. The native vegetation in Denmark is then a result of a mixture of the climate characteristics of the above-mentioned provinces.

A total of **2.459 alien species** have been registered in the Danish nature over the last 300 years: 1.798 plants, 657 animals, and 4 fungi. This means that around 7% of the species that can be found in Denmark are alien species. In the last decades, the accumulated registered invasion trend (Fig. 1) has clearly raised due to globalisation, leading to inputs of new species in the Danish territory (EPA, 2017).

It is important to clarify that new species may also migrate naturally into the Danish territory, probably due to climate change and new environmental conditions. If these species spread their natural range to Denmark without human intervention, then they should not be consider as alien species. The Danish Environmental Protection Agency includes these species as native in their catalogues.

Alien species which thrive well in Denmark are typically original from territories with similar climate conditions, meaning that they have already been adapted to the climatic conditions. However, some alien species are not capable to establish themselves, but they can live long enough to have an adverse effect on native biodiversity. Therefore, they should be treated as invasive species, even though they do not meet the definition regarding the reproduction capacity.

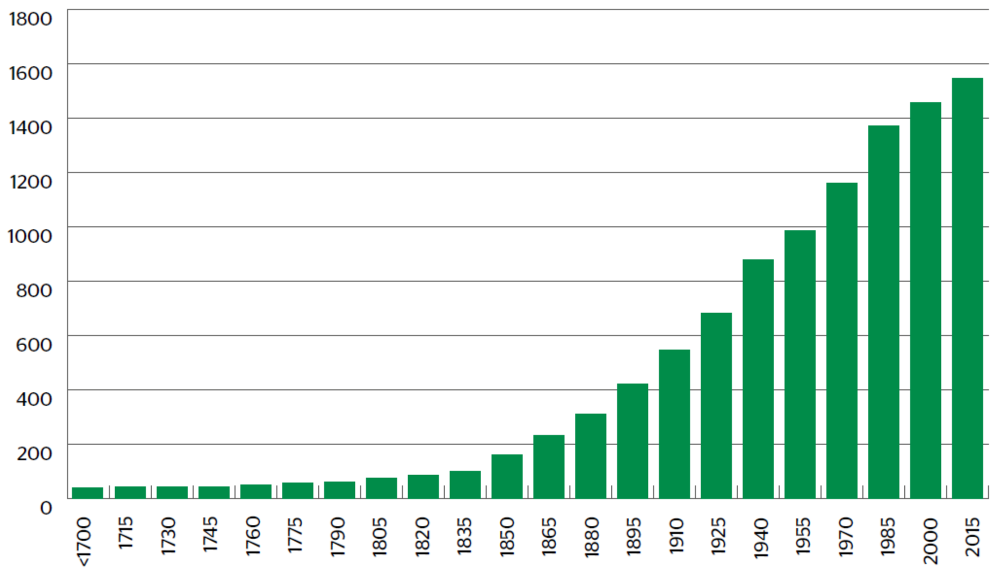


Fig. 1. The accumulated number of alien species in Denmark since 1700. It includes only the species that is known the year of their first detection (1547 out of 2459 alien species in Denmark). Data from NOBANIS.

The spread of IAS has been accompanied by many damaging effects that have been reported mainly as negative effects on **biodiversity**. Besides that, invasive species may also transmit diseases to humans and become a threat to public health, also causing economic losses in agriculture and infrastructure damages.

The Convention on Biological Diversity introduced 3 different levels when studying the effects of IAS on biodiversity: ecosystem, species, and genetic level. The effect of IAS on **ecosystems** often entails a change in the physical and/or chemical conditions. These modified conditions can allow new organisms to thrive in the area, change the species population and also lead to a physical degradation, such as soil erosion during winter. An example can be the Giant Hogweed (*H. mantegazzianum*) that replaces all the native species by blocking the sunlight (Pysek, 1994).

These effects can also be found in a **species** level, even though these ones are more common among animal invasive species. In the simplest cases, native species that are not adapted to coexist with new species will disappear, but in other cases, IAS can bring diseases or even act as vectors for parasites, that can attack directly the native fauna and flora (EPA, 2017). There can also be problematic effects in a **genetic** level, most of the times due to hybridisation between native and invasive species when they are closely related. The resulting offsprings can hybridise again with the native species leading to a significant genetic influence throughout the time.

Apart from all the negative impacts on native biodiversity, IAS are also affecting the economy, society, and human health. In 2009, the EU calculated the total socio-economic costs of invasive species in the EU to be over 15 billion of EUR. Moreover, in 2014, the Danish Economic Council reported an annual cost of 1 billion DKK due to the damage from invasive species (EPA, 2017).

The Ministry of Environment and Food of Denmark has assessed the damaging effects of IAS through a score-based index. Each IAS has been assigned a numerical score (14 - 18) depending on how adverse is the impact over the environment, economy, and health. The result of this assessment is a list of the most damaging IAS: 66 species of animals, plants, and fungi (EPA, 2017). For this project, only the terrestrial plant species have been considered due to the special focus on the Giant Hogweed.

H. mantegazzianum is considered to be the invasive plant species with the highest damaging effect in Denmark, only under the brown rat (*Rattus norvegicus*) in the overall list. This is one of the reasons why this project will have a special focus on the management of *H. mantegazzianum* in Vordingborg municipality, due to the threat it supposes to the area.

1.2 EU Legislation - Regulation 1143/2014

At the EU level, a new regulation (Schulz and Della Vedova, 2014) was agreed in order to prevent, minimise, and mitigate the adverse impact on the biodiversity of the introduction and spread of IAS. As this European Legislation is presented as a **regulation**, it is directly binding to all Member States and they do not need to transpose the law into national legislation to make it valid.

It is important to state that legally, not all alien species are strictly invasive alien species. Alien Species (AS(Schulz and Della Vedova, 2014) are any live specimen of species, subspecies or lower taxon of animals, plants, fungi or microorganisms introduced outside its natural range. It includes any part, gametes, seeds, eggs or propagules of such species, as well as any hybrids, varieties or breeds that might survive and subsequently reproduce. These AS become Invasive Alien Species (IAS) when their introduction or spread has been found to threaten or adversely impact upon ecosystem services, such us biodiversity, economical activities and human health.

The Regulation involves all the Member States in different levels of IAS evaluation. First of all, the members shall carry out a **risk assessment** of the current and potential range of IAS that are whitin the country. This means that European countries need to design **specific plans** for IAS and include the potential risk areas where the species have spread and can invade in the future. This task can be done either from a national level or the national governments can transfer the power to the regions or municipalities.

There is also an important focus on the early detection and rapid eradication of the IAS as the way of working for all Member States (Schulz and Della Vedova, 2014). Within 18 months of the adoption of the EU list of IAS, the Member States must establish a **surveillance system** of IAS which collects and records data on the occurrence in the environment by the survey, monitoring or other procedures to prevent the spread of IAS within the Union (Art.14(1)). This surveillance system also needs to used to notify early detections and then apply the eradication measures as soon as possible.

Finally, there are some provisions related to the widely spread IAS in the Member States, such as the Giant Hogweed (*H. mantegazzianum).* In this case, a **specific management action plan** should be carried out and the restoration of the damaged ecosystems should be also considered after the eradication.

1.3 Danish Legislation

H. mantegazzianum is the only invasive species regulated in Danish legislation. The regulation is found in the Article about the fight against *H. mantegazzianum* (Karsten, 2019). The current legislation has been ammended on June 23, 2017, updating the former article of June 22, 2016.

This article describes how municipalities should make an action plan concerning the fight against this specific invasive species according to the EU Regulation (Schulz and Della Vedova, 2014). The action plan is the basis for imposing owners (and users) of areas to combat the *H. mantegazzianum.* Responsibility for practical execution is placed at the owner. The eradication of the plant should be done in an efficient way according to the action plan. This means that every single plant needs to be eradicated and no single plants are allowed to reproduce. If this eradication is not done before a given deadline stated in the action plan, the municipality can give injunctions with a 14 days deadline.

If this injunction is not accommodated, the eradication may be executed by the municipality and paid by the owner. Controlling that owners comply with their responsibilities, the municipality has access to areas included in the action plan. The legislation from 2017 is giving the municipality an improved opportunity to let the landowners execute the fight against Giant Hogweed.

There is a need to comply with EU Legislation, however not all Danish municipalities have an action plan. In fact, in 2017 only 24% of the municipalities had action plans to evaluate the trend and manage of the Giant Hogweed (Suadicani et al., 2017). This can be an argument to make an upgraded action plan for Vordingborg municipality and then be used as a model for the other municipalities that still don't have a plan or want to improve their existing one.

1.4 Problem Statement

Vordingborg is located on the southeast coast of the island of Zealand (Sjælland) in south Denmark. The total area is of 621 km^2 with the longest shoreline in Denmark, of 380 Km. The most common landscape types are the farmlands and ditched farmlands, but wetlands, forests and small lakes are also important landscape features. As in many municipalities in Denmark, the Giant Hogweed is threating the Danish native flora and public health. This is why there is an urgent need for its total eradication, as stated also the above-mentioned national legislation. However, fighting against the Giant Hogweed is a resource-demanding task for the municipality. Despite the efforts to engage citizens to report the occurrences of the plant, combined with the work of municipality managers in the field, it has shown to be difficult to locate the most important occurrences and therefore also difficult to prioritise the actions. At the moment the municipality has no strategic plan that can be used as a common tool for environmental and landscape managers as an entry to the assessment of species distribution, communication, practical work, and surveillance.

In this report and with the proposed Action Plan, the following points presented through questions should be covered:

What could an upgraded Giant Hogweed eradication plan consist of in order to meet the goal of total eradication in the municipality of Vordingborg?

1. How can municipal managers spot Giant Hogweed populations in a more efficient way?
2. How can communication to the landowners be linked to landscape types and propriety ownsership with high potential of Giant Hogweed occurrence?
3. Which quantitative and qualitative measures should be included in the evaluation of the upgraded action plan?

This project is delimited to investigate the factors within the terrestrial landmass and the freshwater bodies and plan within the boundaries of Vordingborg Municipality.

1.5 Objectives

The **aim** of this project therefore is to improve the existing municipal plan for the control and eradication of the invasive species Giant hogweed. The **objective** of the plan is 1) to provide the municipality operators and landowners with a practical guideline of the current and potential distribution of the Giant Hogweed and, 2) to design a management strategy to eradicate/ control the expansion of the species within the municipality.

2. Theory

2.1 The Giant Hogweed (*Heracleum mantegazzianum*)

Over 20 species of the genus *Heracleum* have been recorded in Europe. Of these, *Heracleum mantegazzianum*, *Heracleum sosnowskyi,* and *Heracleum persicum* are the ones known as Giant Hogweeds. *H. mantegazzianum* is present in central and western Europe and it is the most dominant species in Denmark.

H. mantegazzianum is the most widespread invasive hogweed species. It is originally from the western Caucasus and was introduced in Europe in the nineteenth century as an "ornamental curiosity plant" due to its impressive size (Pysek, 1994). Seeds were gratefully received and planted in botanic gardens and in the grounds of important estates. The first record of *H. mantegazzianum* was in Great Britain in 1817, recorded in the seed list of the Kew Botanical Gardens. After that, the plant began to spread fast across Europe during the 19th century. In the middle and end of 1900, the practice ceased after several warnings about the dangers of the plant (Nielsen et al., 2005).

2.2 Habitat, biology, and seed dispersal

It is necessary to know the species preferences and habitat in order to recognise the areas susceptible to colonisation and most vulnerable to the invasion of *H. mantegazzianum*. A study carried out in central Europe showed that this species preferably establishes on abandoned grassland, in ruderal places and in fringes along watercourses, woodlands, and roads, whereas areas under agricultural or horticultural use (e.g. arable crops, pastures and gardens) are unsuitable habitats. The habitat quality is also determinant for the satisfactory establishment of the individuals and its further spread. In general, *H. mantegazzianum* prefers habitats characterised by high sunlight, no active land use, human changes and disturbance to the vegetation cover, and good water availability and soil nutrient supply (Nielsen et al., 2005).

In the Danish landscape, *H. mantegazzianum* follows a similar pattern compared to the habitats preference in central Europe. It prefers rich and moist soils and can completely dominate eutrophic areas. It is usually growing in wet areas along stream banks and rivers, ditches, and riparian areas, but is also found in ruderal areas at residential properties, vacant farmland and along railways and road sides. The species is also found in wet nature areas with national protection like bogs, marshes, grazed and ungrazed meadows (Agency, 2017).

Reproduction is only happening through the production and distribution of seeds. Flowering takes four to three years and happens in midsummer where the plants are subject for insect pollination but are also self-compatible. In late summer, the plant produces a large number of seeds, in average 20,000 seeds by plant, half of them in the terminal umbel. However, individual plants with over 100,000 seeds have been reported in the Danish countryside. Although not all the seeds are viable and they will germinate, the reproductive potential of the species is much higher than any native species living in the same conditions. After the release, the majority of the seeds (95%) are present in the upper 5cm of the soil layer, close to the parent plant (Nielsen et al., 2005). But some seeds can spread further waya and they are the most important ones, as they may contribute to invasion of new sites.

The spread of seeds can happen through wind, water, and human activity. Water is an especially good pathway for dispersal of seeds because the seeds can float on water for several days. This is another reason why *H. mantegazzianum* is often found in large numbers along waterways. With climate change, the precipitation will occur in a more irregular pattern, leading to some episodes of high intensity rain (e.g. cloudbursts). These episodes can produce severe floods in the river basins and have a direct effect on the Giant Hogweed populations. As a result of the flood, this can be an important mechanism of plant dispersal to achieve large distance dispersal events (Pysek, 1994).

Despite all the natural dispersal modes, nowadays the human assisted dispersal can become predominant over the natural dispersion. The Giant Hogweed can be spread by different human activities: seeds can stick to tyres of passing cars and then be spread far from the place they were originally produced. Another example might be that some people transport the whole umbels for decorative purposes when they are dry in late summer and autumn. Cattle and sheep can also be vectors of the seeds as they can be transported in the animal fur and then enter to non-invaded sites when the animals are changed of location during the cold season (Nielsen et al., 2005).

The combination of superior natural characteristics acting at different stages of its life cycle has resulted in a remarkable invasion potential. According to the Grime’s C-S-R triangle (competitors, stress-tolerators and ruderals), the Giant Hogweed can be located between the R-ruderal and C-competitors side due to its invasive features. In combination with the natural characteristics of the plant and the human influence on seed dispersal and climate change, it comes superior to all other native species. That is why it is also called the “master-of-all-traits” within IAS (Pyšek et al., 2008).

2.3 Damaging effects of the Giant Hogweed

The consequences of Giant Hogweed populations can be analysed from their effects on the native flora and their danger to human health.

H. mantegazzianum is characterised to produce tall stems of different forms and densities. The enormous height and leaf area of the hogweed, enable individuals to overtop native plant species. When this happens, the invasive species become a strong competitor for light and it is able to exclude native plants growing under it. In dominant stands, up to 80% of the light is absorbed by hogweed plants, and other native light demanding species will automatically be suppressed due to a lack of light accessibility (Nielsen et al., 2005).

The Giant Hogweed can reach really high densities in abandoned grasslands and ruderal habitats, leading to a strong decline in the species richness of these habitats. In open habitats with light and water availability, the spread of the plant can be high and occupy the whole area, displacing the native flora that used to live there (Fig. 2).

Besides the ecological problems, the Giant Hogweed represent a serious health hazard for humans, due to its phototoxic action. The sap of the plant contains furocoumarins that lead to a relatively common type of dermatitis: phytophotodermatitis. This kind of reaction in the skin is produced when a person touches the sap and is exposed to sunlight. The reaction is not considered allergic, so anybody can be affected by it. Nonetheless, touching the plant or brushing against it, appears to be enough to induce exposure to the sap, and all the persons that come in contact with it can be affected to some extent. It is important to state that the dermal lesions created, once the photoreaction has acted, can be of a high gravity and compared to second degree burns (Derraik, 2007).

The potential health injuries that the plant sap can induce must be always taken into account when managing the species in the field. This is why, all the managerial actions including removal of individuals, must follow a security protocol for the managers and technicians (Nielsen et al., 2005).

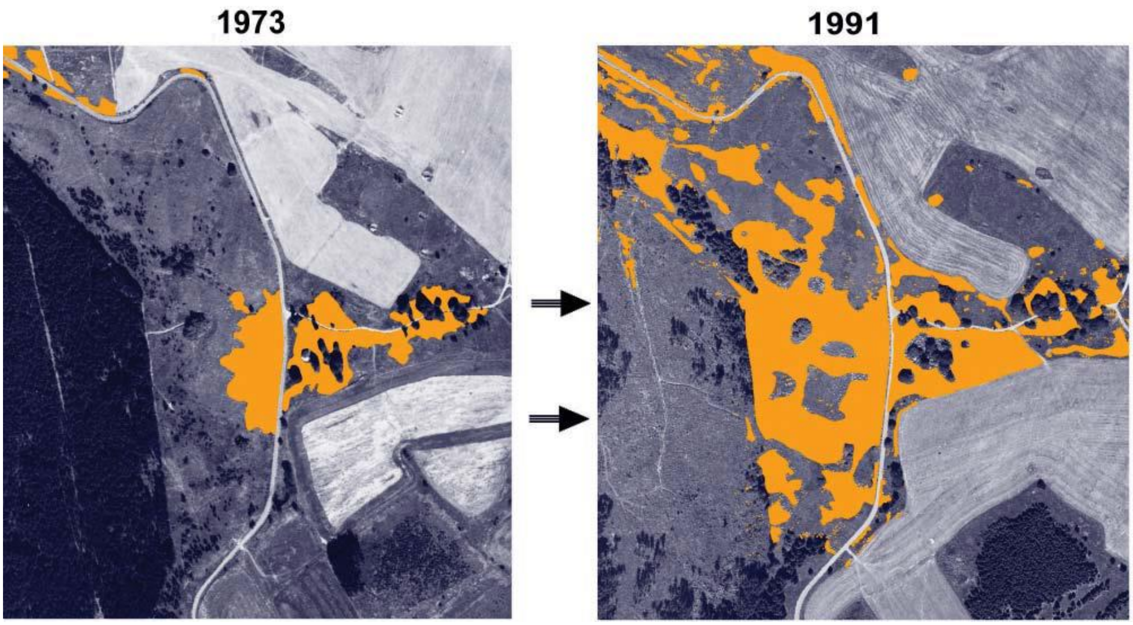


Fig. 2. Invasions of *H. mantegazzianum* in an open habitat of grassland in the Czech Republic (Source: Military Geographical and Hydrometerological Office, Dobruska, Czech Republic)

2.4 Inspirational current management plans and strategies

As in Denmark, many other northern hemisphere countries are affected by the invasive Giant Hogweed. Some of these countries have developed and implemented management strategies and plans that have served as inspiration when designing the Action Plan in this project.

A big source of inspiration for this Action plan has been the Irish Best Practice Management Guidelines on the control of the Giant Hogweed (Maguire, 2008). This guideline has been useful to structure the Action Plan in the sequential step-by-step format it has acquired as well as to design the risk alert protocol and the risk buffer around each invider stand. In both the Irish and the European Giant Hogweed Best Practice Manual (Nielsen et al., 2005) a lot of focus is put on the safety protocols as well as the isolation, dispersal control and early detection of the current Giant Hogweed stands, and this has also been included and adapted to the Action Plan this report comes up with. The idea of the landscape analysis to highlight the most problematic landscape elements within the different landscape types in the municipality was also obtained from the Irish guidelines.

The early detection by using a Risk Map as a tool was extracted from both the classic species suitability analysis used in ecology, and also from the suggestion in the Wildlife Trust Manual for the Giant Hogweed (Trust).

3. Materials and Methods

3.1 Data sources

The Giant Hogweed occurrence dataset was extracted from the Global Biodiversity Information Facility (GBIF) and consists of mainly human observations from 1996 to 2011. The sources of these human observations are i) vegetation data from protected areas in Denmark (§ 3 in the Danish Nature Protection Act), ii) vascular plants in Denmark recorded under The Nationwide Monitoring and Assessment Program for the Aquatic and Terrestrial Environments (NOVANA), and iii) Atlas Flora Danica.

For the different maps that the action plan provides with, multiple datasets from a number of different databases were required. For the production of the **risk map,** layers for city centers (*bykerne*), business (erhverv), low-rise buildings (*lav bebyggelse*), high-rise buildings (*høj bebyggelse*), roadsides (*vejkant*) railways (jernbane), forests (*skov*), tree groups (*trægruppe*), wetlands (*vådområde*), drained ditches (*afvandingsgrøft*), lakes (sø), basins (*bassin*), water courses (vandløbskant) and infrastructure (*infrastruktur*) were obtained from Geodanmark (http://kortforsyningen.dk/). The geology map 1:200 000 (Jordartskort) was obtained from http://www.geus.dk/, the Topographic Wetness Index (TWI) map was obtained from Dr. Christensen, and the topsoil property map was from the Danish Journal of Geography (M.H. Greve et. al.).

3.2 Preliminary Analysis and Data Treatment

Preliminary to the creation of the risk map, the input data had to be treated and processed so it could be used for the Risk Map production.

3.2.1 Occurrence data

The coordinates of 106 presence plots in Vordingborg included in the GBIF data set were extracted in a WGS84 datum. The Giant Hogweed cannot live in paved areas like cities and intensively cultivated fields according to the habitat preference. These layers were merged and 100 plots were then sampled randomly in the merged layer as the pseudo-absence plots. Finally, two point shapefiles of occurrence data were obtained: the 1) presence and the 2) pseudo-absence plots (Fig. 3). All the analyses and calculations were computed in QGIS environment.

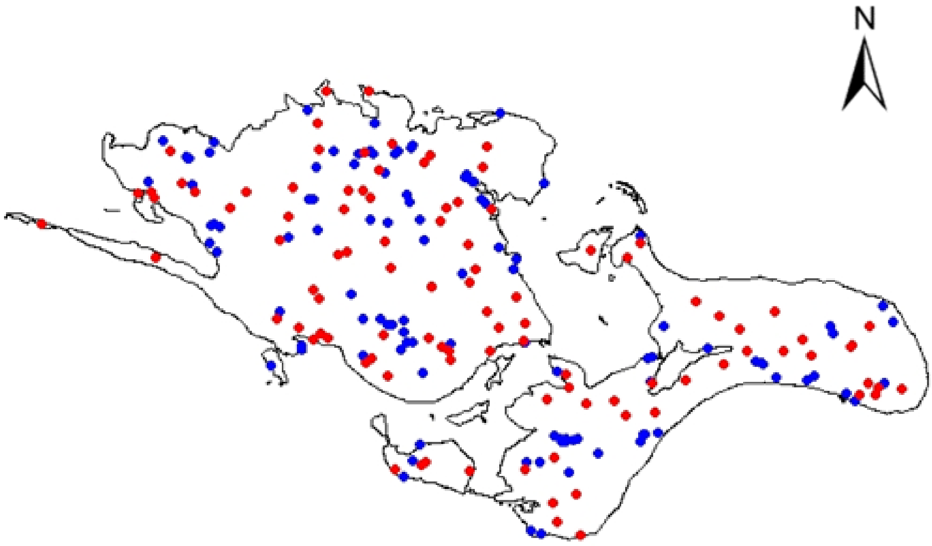


Fig. 3. Presence (blue) and pseudo-absence plots (red) in Vordingborg

3.2.2 Environmental variables

The **slope orientation** was calculated through the elevation model with aspect tool in QGIS. The threshold was from 0-360 degree. North was set as 0 degree and then giving values to the different orientations in pixel level.

The **Soil Organic Carbon** % (SOC) and **Soil Humus Content** % (SHC) are indicators of rich soil, preferred by the invader, in this case between an R-ruderal and C-Competitor according to the C-S-R triangle. This information for the top soil (0-20 cm depth) in a spatial resolution of 250 x 250 m grid cells were collected from the official Danish topsoil texture map interpolated from 45000 sampling points in 2007 (Greve et al., 2007).

The SAGA Topographic Wetness Index (TWI) layer was also used, as it is a good indicator of the hydro-morphological conditions of a specific site. It represents the surface and subsurface runoff conditions which is based on catchment area (CA) estimations. All the operations were performed in System for Automated Geoscientific Analyses (SAGA-GIS) and simulated from the elevation model, ignoring thinnest film flow.

The Infrastructure shapefile layer was rasterized in two levels: the highest 3 (0-3m) and the lowest 1 (3 - ∞m), since it is easy for Giant Hogweed to disperse along with the roads.

Giant Hogweed may also have geology preferences. The geology map represents different geology condition, e.g., flying sand in last glacial. The map was rasterized based on different conditions to check the covariance.

Since the Giant Hogweed prefers growing in humid habitats, typically corresponding to the river bank, streams, wetland areas and ponds (Pyšek et al., 2008), the distance to water (DW) was calculated as one of the environmental variables to estimate the suitability map. After rasterizing the river and lake shapefile in 40m resolution, the euclidean distance was used to calculate the distance to water for every pixel. All the calculations were performed in R.

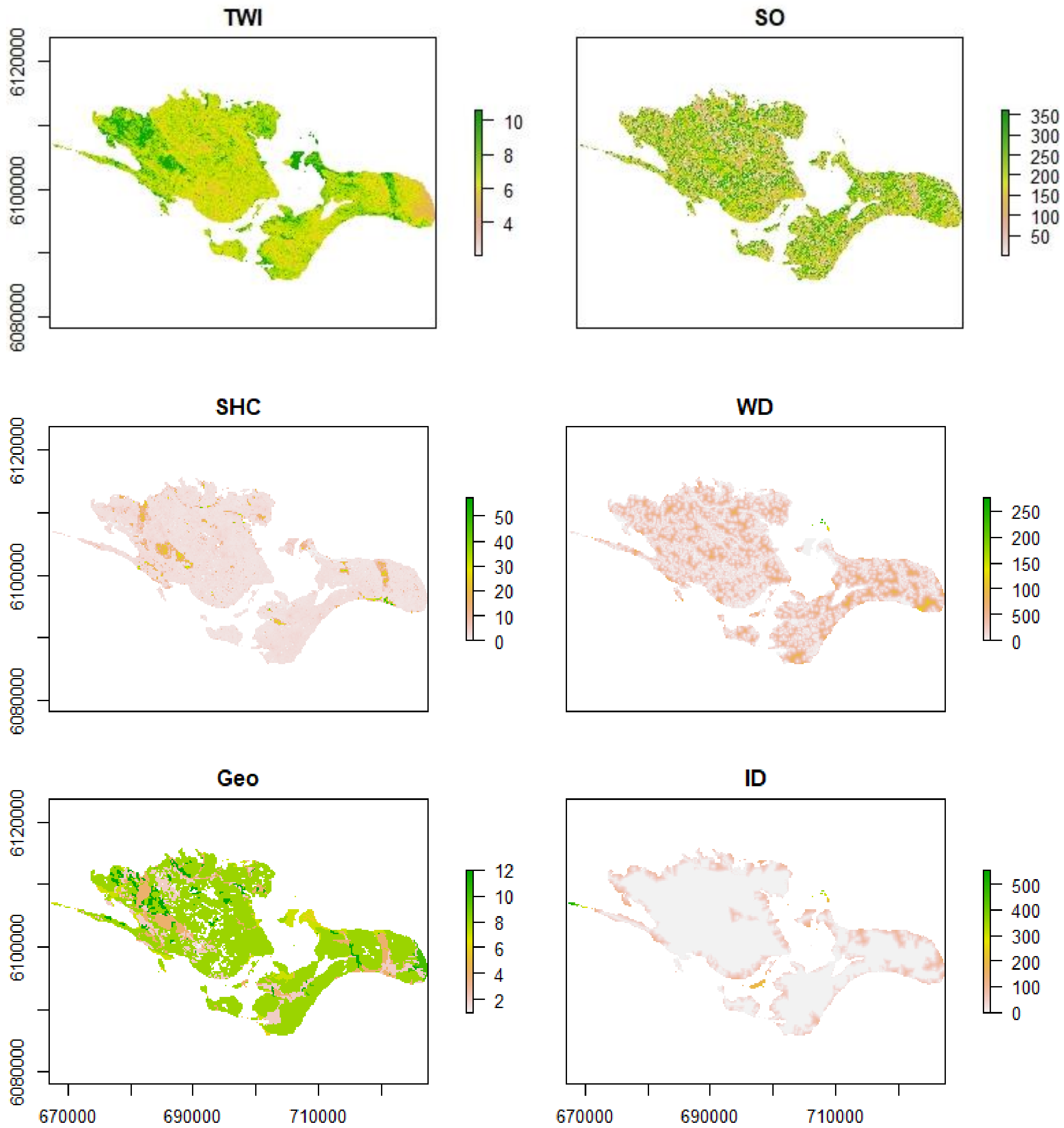


Fig. 4. Distribution of environmental variables, i.e., Soil Humus Carbon (SHC, %), Slope Orientation (SO, degrees), SAGA topography wetness index (TWI, non-dimensional), distance to water (WD, m), geology types (Geo, non-dimensional), and distance to infrastructure (ID, m)

3.2.3 Co-variance analysis

Previous to any further analysis, a covariance of environmental variables was carried out to avoid over estimation. A Pearson correlation with *ecospat* packages in R (Di Cola et al., 2017) was used, with an independence threshold of 0.7. If the correlation coefficients exceeded 0.7, the variable was deleted from the data set to avoid the overestimated assessment of the model.

3.3 Risk map

3.3.1 Statistic-based species distribution model

Statistic-based species distribution models (SDM) correlate species occurrence with site environmental variables in order to predict species habitat suitability (HS; (Guisan and Zimmermann, 2000). The R-package, *sdm*, uses individual and community-based approaches to develop new species-distribution modelling approaches by users (Naimi and Araújo, 2016). The work proceeds incrementally along with three main parts:

a. Data management and pre-processing.

Input data to *sdm* includes geographical occurrence (i.e., presence/absence) of *H. mantegazzianum* and four environmental variables rasterized at 40m resolution (Fig. 4);

b. Model development

I) Statistical models

Statistical models have best-practice applications if the goal of the model is to capture the interaction between different environmental variables (Vasconcelos et al., 2017). General linear models (GLM's) are parametric and can involve several distributions (e.g., binomial), whereas general additive models (GAM's) are non-parametric, commonly regarded as extensions of GLM's (Guisan et al., 2002). In general, GAM's are more flexible based on smoothing function in addressing nonlinear relationships between species and site data (Guisan et al., 2002). Here, GLM depends on '*stats*' package in R while GAM depends on '*mgcv*' and '*gam*' packages in R.

II) Machine-learning methods

Classification and regression tree (CART, based on the R-package, *tree*) is a non-parametric approach in response to a specified formula based on binary-recursive partitioning (Leo et al., 1984) and can be used to build predictive models directly from observations (Guisan and Zimmermann, 2000). Each prediction algorithm always minimizes the mean impurity of two previous nodes and chooses the best candidate. Random forest (RF, based on the R-package, *randomForest*), is also non-parametric using training set with key elements of CART and bagging algorithms to reduce the bias (Breiman, 2001). This approach uses a large training sets (1000 trees in this model) to find an optimal solution.

c. Assessment of model performance and analysis.

To assess the impact of different model fitting approaches on model performance for giant hogweed, 20 independent model runs were performed, which used bootstrapping approach to selecte 75% of the original dataset to build the model and rest 25% to test it each time. We assessed models in different approaches: the Area Under the (Receiver Operating Characteristic, ROC) Curve (AUC), a signal threshold-independent approach (Manel et al., 2001) which considered score > 0.80 as adequate for species distribution modelling.

3.3.2 Process-based suitability model

The process-based model was developed by expert advice, considering how the environmental variables affect the Giant Hogweed distribution. The input environmental variables were divided into six packages according to its types: DW, SOC, TWI, Infrastructure, Geology, and SO (Fig. 4.). The preference for the Giant Hogweed to each environmental package was checked and ranked acordingliy in different risk levels. Each package would eventually be assigned with a weight according to the importance of each environmental package for the SDM. Besides, a random sampling point file was produced via the QGIS sampling tool to extract information of each variables package within the whole municipality. Moreover, T-tests run by Deducer R Graphical User Interface was used to check any differences between the randomly sampled points within the municipality and Giant Hogweed occurrence points. Then different risk levels were set based on the test. The Bray Curtis Index was used to assess whether there were geology preferences for the Giant Hogweed. The geology type in each random sampling point was compared with the geology type of each occurrence point, and an abundance table was produced to execute the Bray Curtis index using PAST statistical software. Finally, SO preferences were tested by Shannon equitability test.

3.3.3 Merged Model

After producing the statistic-based SDM model and the process-based suitability model, they were both merged into the Final Risk Map. In order to check whether the models have the same pattern, a comparison was carried out, eventually merging them as a 50% proportion of each apporach to get the final risk map.

3.4 Field validation

When the Final Risk Map of Giant Hogweed was obtained, potential presence plots were sampled by calculating minimal predicted area (MPA) based on environmental element data to improve field evaluation (Guisan et al., 2006). The MPA is a binary map considering predicted values over probability threshold as 100% species occurrence in pixel level, with 0 for each pixel represents unsuitable while 1 for each pixel represents suitable. Then the MPA map was superimposed on the environmental element map (Fig. 5.), calculating the proportion of MPA in each environmental element and defining high-risk elements by comparing with the background proportion. Finally, some plots were resampled randomly in these high-risk environmental element areas. To validate the Giant Hogweed risk map, a field trip to the municipality of Vordingborg was carried out on the 27th of May 2019. During the field trip, several high risks and low risk zones were assessed to record the occurrence or absence of Giant Hogweed. The route of each spot was mapped with a Garmin GPSMAP 64S and the occurrences were mapped as points.

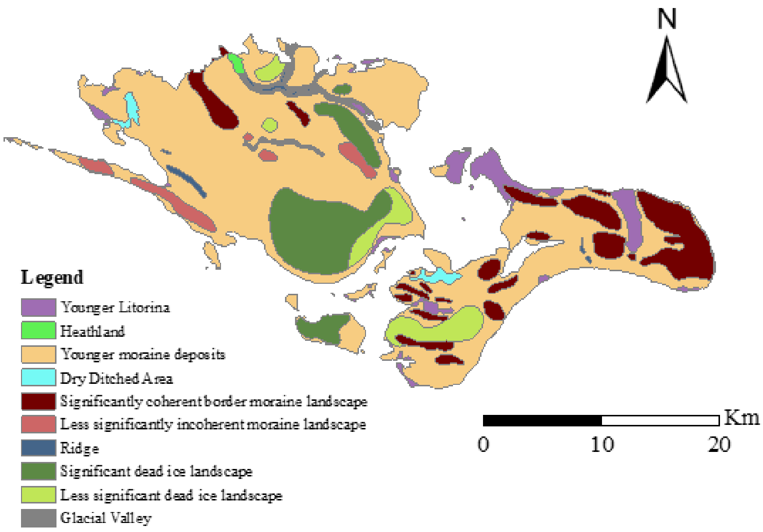


Fig. 5. Distribution of environmental elements

4. Results

4.1 Co-variance

The Pearson correlation test between geology type, SOC, humus, TWI, WD, and infrastructure shows that only SOC and humus have 100% correlation. This is because they were calculated in the same way (Fig. 6). The correlation of other variables is under 0.7 which indicates that the model will not be over-estimated by using these variables.

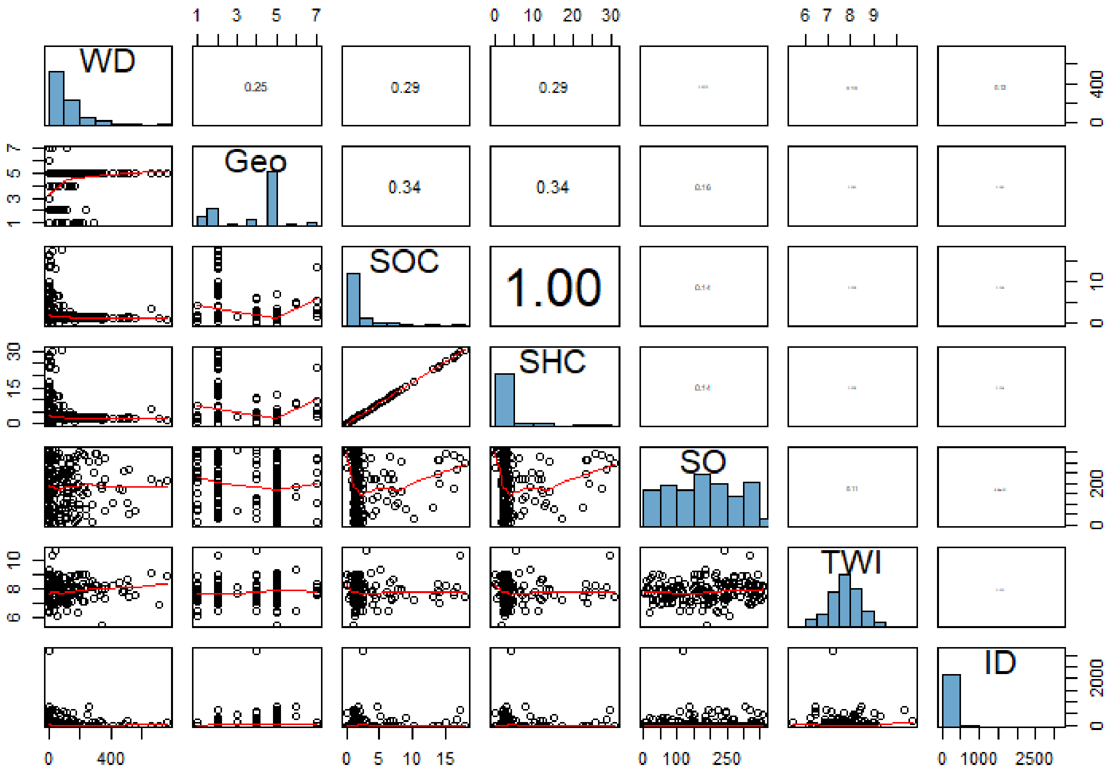


Fig. 6. Person correlation between different environmental variables. Below the diagonal are the bivariate scatter plots of matrices, on the diagonal are the histograms of frequency of each variables, and above the diagonal are the Pearson correlations, bigger size indicates higher values.

4.2 Statistic-based model

Model evaluation was based on the AUC of the ROC-curve. In general, all measures of performance revealed that RF provided the best overall performance among the four methods considered, yielding the highest overall AUC (0.884, Fig. 7). All the models except CART offered the robust (AUC > 0.8) estimation. So we used GLM, GAM, and RF to ensemble the final model.

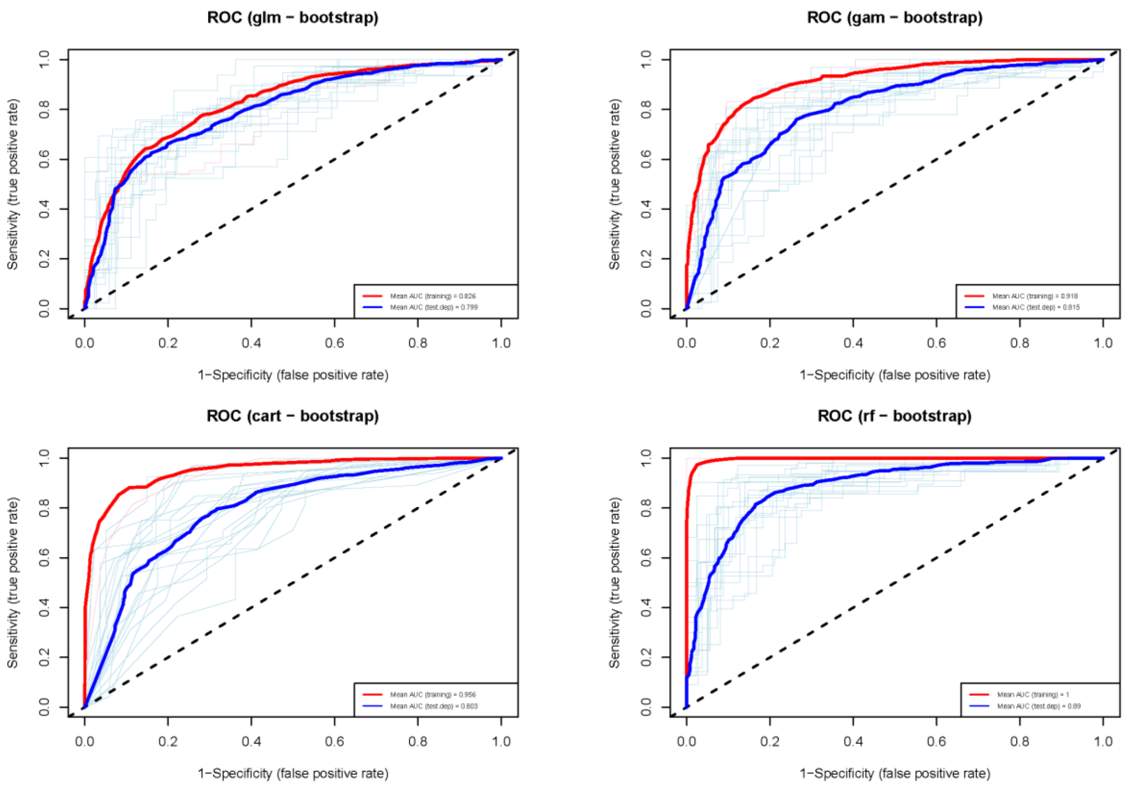


Fig. 7. Receiver operating characteristic (ROC) curves in the application of Generalized Linear Model (GLM), Generalized Additive Model (GAM), Classification and Regression Tree (CART), and Random Forest classifiers (RF). The light blue curvilinear lines correspond to ROC-curves generated by repeated application of the models by bootstrapping (n=20 replicates). Red and dark blue lines represent mean ROC-curves for the training and validation data, respectively.

According to the overall importance of variables, DW is capable of explaining a significant portion of the spatial variation in Giant Hogweed habitat suitability (Table 1). SOC is the second most important variable (Cor= 0.393 and AUC= 0.268), affecting Giant Hogweed habitat suitability. The rest variables, TWI, and slope orientation, affect less than one third of the spatial variation in giant hogweed habitat suitability map.

Table 1. Variable importance based on the correlation coefficient and AUC. Values of relative importance were obtained with the sdm package in training data, higher impact showed in higher values.

	Cor	AUC
SOC	0.393	0.268
SO	0.061	0.031
TWI	0.156	0.071
DW	0.436	0.306

4.3 Process-based model

According to the **DW** environmental package, the risk levels where designated, being 3 (0-3 m) the highest, 2 (3-52m) the medium and 1 (52-∞m) the lowest. Each risk level was later weighted using the raster calculator according to the importance of each environmental factor for the Giant Hogweed, being 0.368 the maximum value.

The T-test showed a higher value of SOC% in the occurrence points compared to the random sampling points ($p < 0.01$) suggesting that the invider preferred rich soils. From the distribution of the **SOH**% values of the Giant Hogweed occurrences points, 3 risk ranks where designated. The highest risk rank (3) was from ∞ to 5 SOH%, the medium risk (2) from 5 to 2 SOH% and the lowest (1) from 2 to 0 SOH%. Following the same procedure as with the hydrology package, the SOH% raster layer was reclassified in accordance with the three risk levels, and each level was later weighted using the raster calculator according to the importance of this environmental, being 0.332 the maximum value. The **TWI** raster ranking from 0 to1 was weighted via the raster calculator according to the importance of the TWI for the Giant Hogweed, being 0.132 the maximum value.

The **Infrastructure** shapefile layer was rasterized and included in the risk map. In this case, there were only two risk levels, the highest 3 (0 - 3m) and the lowest 1 (3 - ∞m). Later, the raster was reclassified and weighted according to the risk levels being 0.2 the maximum value. A p-value of 0.034 showed no statistical difference for geology preferences between the random and Giant Hogweed sampling sites, so this environmental factor was no longer used in the further map production. A Shannon equitability test showed no statistical preferences for any orientation (value of 0.098, being 1 an equitable abundance matrix). Consequently, this environmental parameter was not either included in the map production process.

4.4 Models comparison

The statistic-based SDM and process-based suitability model show the same pattern although they have different values of risk index. Both of them have extremely high risk level in younger litorina, significant coherent border moraine, less significant dead ice, and glacial valley landscape element (Fig. 5; Fig. 8). The statistic-based model has more variations than the process-based model (Fig. 8), however, it lacks some suitability information (hollow part in Fig. 8a) due to the lacking information in SO and SOH environmental layers (Fig. 4). Although process-based model highlights the similar highest risk area with SDM, it showed low risk area around Stege Nor (SN; Fig. 8b), and lacks some information in East semi-island (blue square, Fig. 8b).

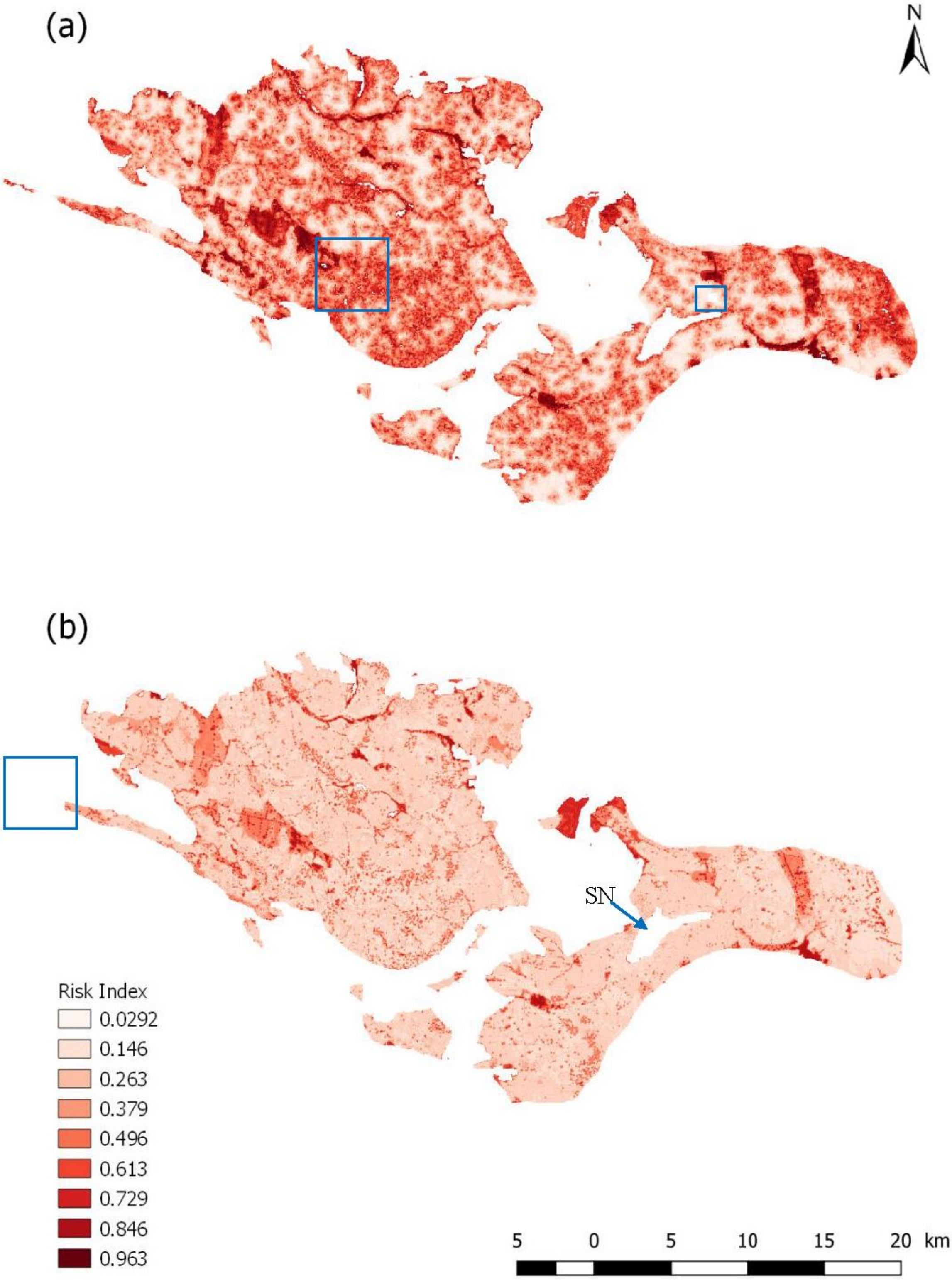


Fig 8. Distribution of suitability map across different approaches: (a) statistic-based model, (b) process-based model. Blue squares and arrows indicate the different parts of these approaches.

4.5 Final Risk Map

In order to avoid shortness of both approaches and enhance the high-risk area, a final risk map was produced. The risk map ranks from 0 to 1 in the risk index according to how probable is for the Giant Hogweed to spread or occur in a site. The final map will be presented in the Action plan in part 5.3.1.

4.6 Field Validation

All the pixels over the threshold (0.52) were considered as presence and below were considered as absence. The significantly coherent border moraine landscape, Younger Litorina, Heathland, Dry Ditched Area, Ridge, and significant dead ice landscape were considered as high-risk areas, for the proportion of presence over the background presence proportion (26.03%). A random resampling checked whether they had Giant Hogweed. During the fieldwork, seven true presence plots were found in Vordingborg and six of them in the high-risk environmental element area ("a" is close to the significant dead ice landscape, Fig. 9). These validated plots are mainly in the following element: **Glacial Valley**, which formed by the melting water beneath the ice and deposited sand; **Littorine** surfaces, from postglacial of age, have emerged from lifting the crust after melting of the ice cap; **Younger moraine** is a term that covers moraine deposits from the last ice age. **Dead ice** landscape, occurs where the ice cap retracts and leaves smaller units of ice that slowly melt, depositing in lakes and resulting in a hilly landscape was caused by edge moraine.

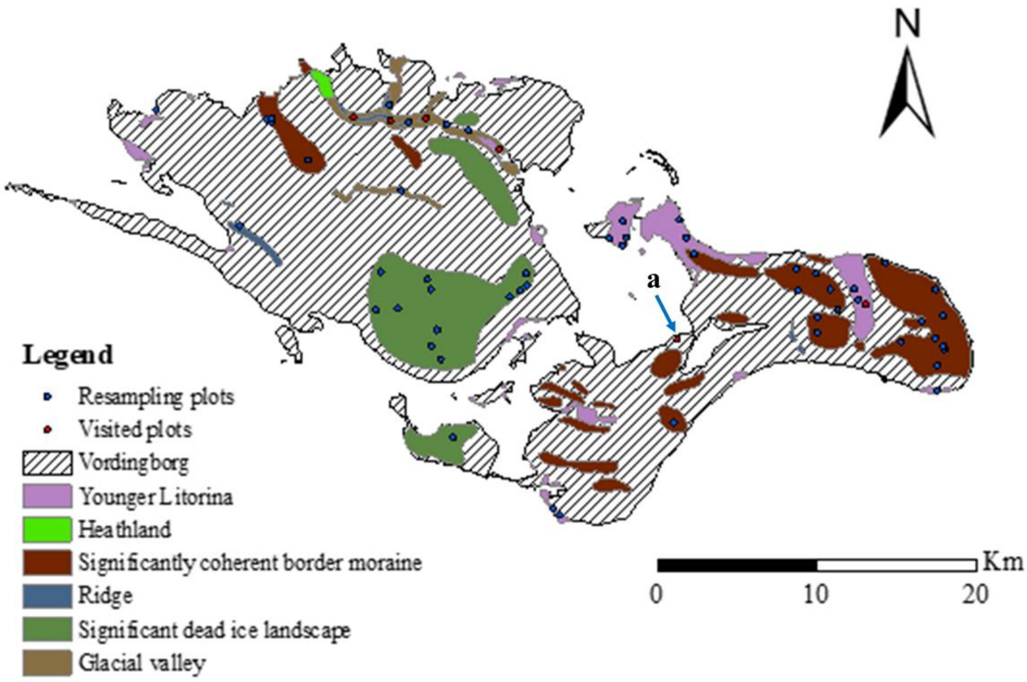
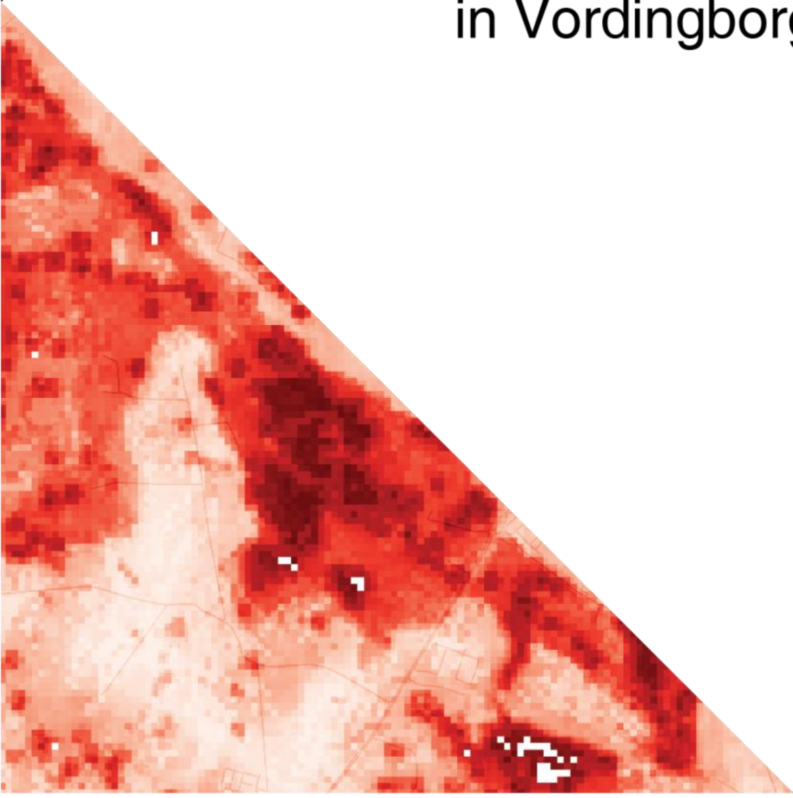


Fig. 9. Resampling-based on high-risk environmental elements, 'a' represents the true presence plot but not within a high-risk environment element.

Action Plan for Giant Hogweed

in Vordingborg Municipality



5. The Upgraded Action Plan for the *Giant Hogweed* in Vordingborg Municipality

The action plan to fight the Giant Hogweed consists of several sequential steps that need to be followed for effective management of the invader Giant Hogweed.

1. Security protocol
2. Distribution map based of previous data
3. Communication and education
4. Distribution map renewal, population characterization, and preventive actions
5. Risk network and infection routes
6. Specific management plan
7. Monitoring, reporting, and evaluation

5.1 Security Protocol

As mentioned before, the sap of the Giant Hogweed can remain active for hours after the plant has died and produces Phyto photodermatitis that can be compared to second degree burns. Therefore, it is extremely important that everyone operating in areas infested with Giant Hogweed is aware of the associated issues and health risks. Any activity that involves bruising, cutting or touching the foliage may result in toxic skin reactions. The following recommendations should be followed when treating with Giant Hogweed:

- All body parts must be covered with protective synthetic waterproof materials and long-sleeve globes and protection glasses must be used when treating with the plant
- In case of exposure to plant sap, one should immediately wash the skin with soap and water and keep the area away from the sunlight for at least 48 hours
- Sun cream should be used for the sensitive areas during the months after the reaction
- Topical steroids to reduce severity and ease discomfort will help during the early reaction
- If any sap goes into the eyes, rinse them with water and use sunglasses
- Visit the doctor in any case and especially after intensive contact

5.2 Distribution Map base on Previous Data

Prior to any other action, it is important to spot and localize the current populations of the Giant Hogweed within Vordingborg municipality. As already mentioned, the participation and commitment of not only the municipal team but also the landowners, visitors and in general citizens are key for the success of this control plan. **Three tools** with different types of information are provided in order to spot the current populations of this species.

- The **Risk Map:** provides not only the municipality members but also the owners with the habitat suitability for the Giant Hogweed in a municipal level
- The **Landscape Analysis:** its main objective is to link high risk areas with landscape type and to provide with information about which landscape elements are more sensible to colonization
- The **Cadastral Map:** will assign each property a risk value

5.2.1 The Risk Map (Hotspot analysis)

In order to assess the habitat hotspots for the Giant Hogweed within Vordingborg Municipality, a suitability analysis was carried out. A habitat suitability analysis pretends to determine a species' probable occurrence based on different parameters such as information about occurrences as well as environmental variables (Fig. 10).

By selecting the most important environmental factors that explain the distribution of the Giant Hogweed in Vordingborg municipality and by taking into account former and current occurrence data, a risk map was produced. The risk map ranks from 0 to 1 in the risk index according to how probable is for the Giant Hogweed to spread or occur in this site.

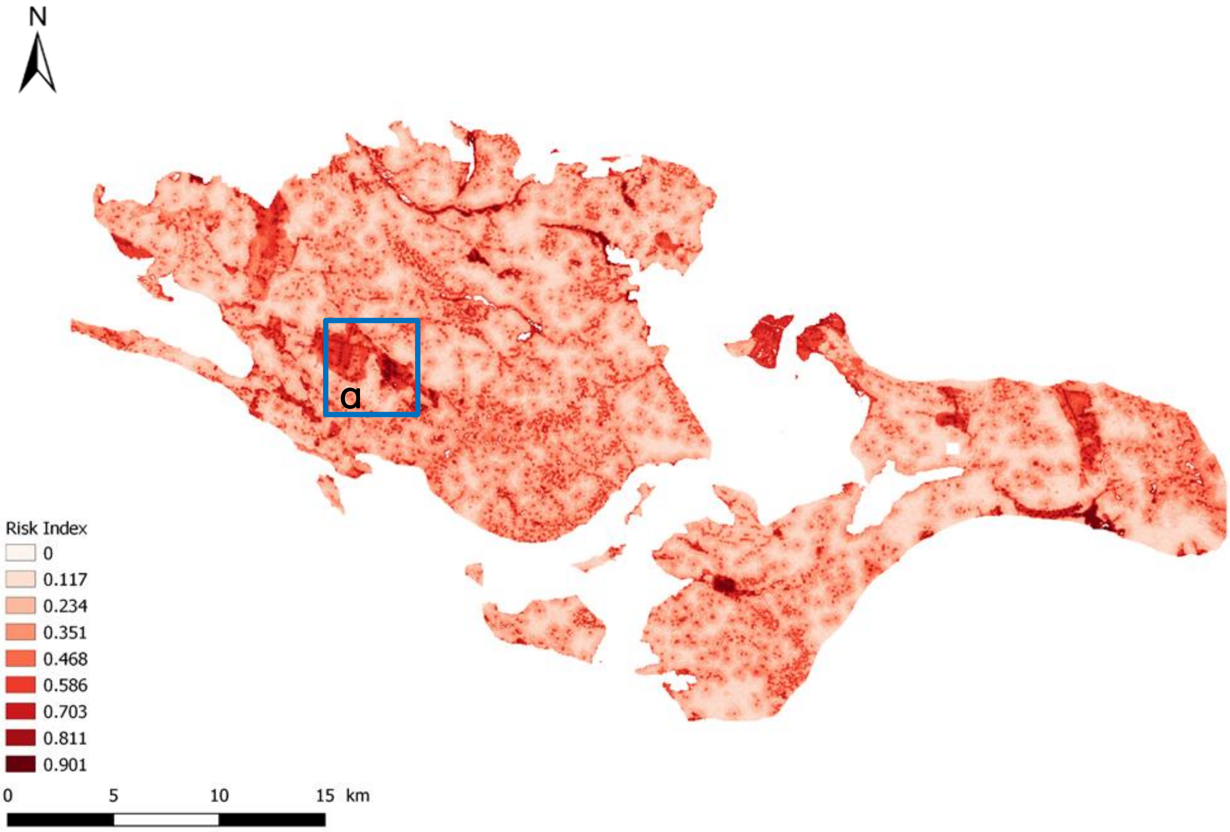


Fig. 10. Probability risk map of occurrences of Giant Hogweed

5.2.2 Landscape Analysis of High-Risk Areas

To ease the interpretation of the Risk Map for both the municipal managers, planners and landowners, a landscape type map focusing only on the high-risk areas was created. As the landscape element map (Fig. 9) used in the validation process is maily based on geology types, a landscape analysis based on the land cover was needed. A high-risk landscape cover map was manually developed based on the *patch-corridor-matrix* model. Pattern types analysis is a good tool to identify each landscape cover, as each element will generally follow the same spatial pattern.

Following the *patch-corridor-matrix* model, the landscape **matrix** in Vordingborg Municipality is the farmland, generally with a relatively low risk index value. However, immersed in this low-risk matrix, some patches and **corridors** can be recognised, generally scoring the highest risk index values.

The big high-risk **landscape character types** correspond to wetlands, heavily ditched farmlands, and lakes, while the small ones correspond generally to forest clearings, basins, small ponds, tree groups or small lakes immersed either on the agricultural matrix or within other patches (e.g. forests). There are other landscape types corresponding to the corridor landscape elements such as river valleys, big roads and highways, ditches, and dirt roads (Fig. 11).

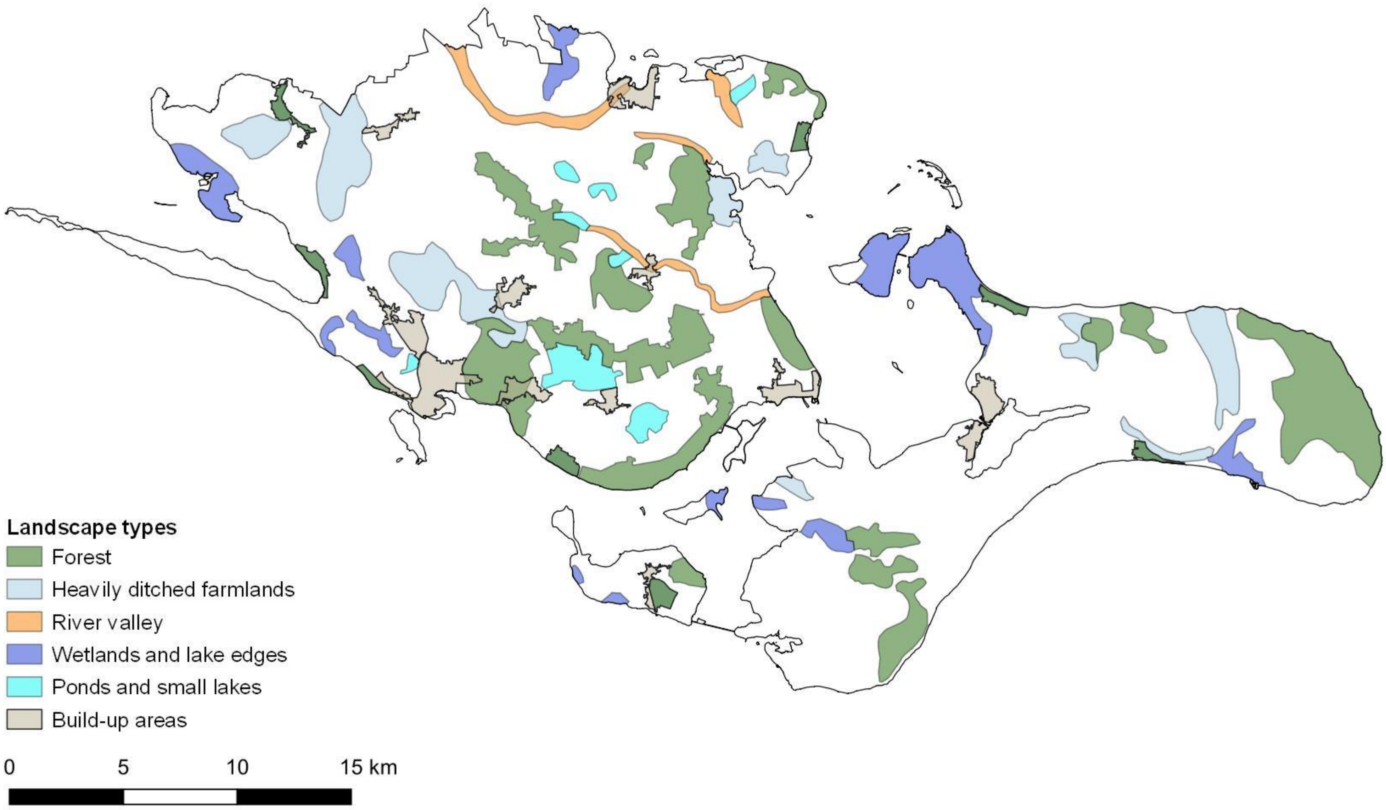


Fig. 11. Landscape type map

5.2.3 High Risk Landscape Types

Heavily ditched farmlands – Due to the usually high soil organic carbon content, high water table level, and the presence of water corridors that can act as contamination routes (e.g. ditches), there is a naturally high risk for the Giant Hogweed to occur in virtually any part of this landscape type. However, the heavily ditched farmlands are usually intensively tilled and in rotation, which prevents the establishment and germination of the Giant Hogweed. Still, some small-scale elements that are less managed are extremely suitable for the Giant Hogweed to happen. <u>Special attention to any uncultivated, fallow and set-aside areas, as well as crop margins, fringes, edges of streams and ditches, and fences.</u>

Wetlands and lake edges – Due to the high soil organic carbon content and the high water table level these landscape types are ranked as high-risk areas. As they usually correspond to non-ploughed, uncultivated areas because of the difficult hydrological conditions, is the perfect undisturbed habitat for the Giant Hogweed. In some cases, these areas can be mowed or grazed by cattle or sheep, which can eventually reduce the Giant Hogweed establishment. <u>Special attention to: anywhere + on the non-grazed/mowed sites+ special focus if the Giant Hogweed is reported upstream in the catchment area.</u>

River valleys – Due to the proximity of water and sediment build-up, river valleys are also high-risk landscape types. As lake edges and wetlands, river valleys are usually non-cultivated areas where the Giant Hogweed can occur virtually anywhere. <u>Special attention to: anywhere + special focus if Giant Hogweed is reported upstream in the catchment area.</u>

Farmland and urban settlement – Farmlands and urban settlements are the landscape types with the lowest risk index value. This is because of the intensive management and aggressive land use these areas are characterized by (e.g. intensive tillage, impermeable surfaces, build up areas). However, within this landscape character types, some high risk hotpots can be found, corresponding to some small landscape elements. <u>Special attention to tree groups, crop margins, basins and ditches in the farmland. Margins in creeks, ponds, and roads, unbuild urban surfaces, wastelands and even private and public gardens in the urban settlements.</u>

Forests – Forests are generally non-suitable landscape types for the Giant Hogweed. Despite having suitable nutrient levels and hydrology conditions for the Giant Hogweed to establish, light limiting factors. It is only in some illuminated areas or extremely wet places where the Giant Hogweed can outcompete native species. <u>Special attention to ponds, ditches, forest and road edges, forest clears.</u>

5.2.4 Cadastral Map

Cadastral risk maps differentiate from the general risk map and the landscape type risk map in many ways. The difference between this map and others is found in the utility for landscape managers. The purpose of the cadastral map is to provide landscape managers with a map that links cadastral references to the maximum pixel risk score.

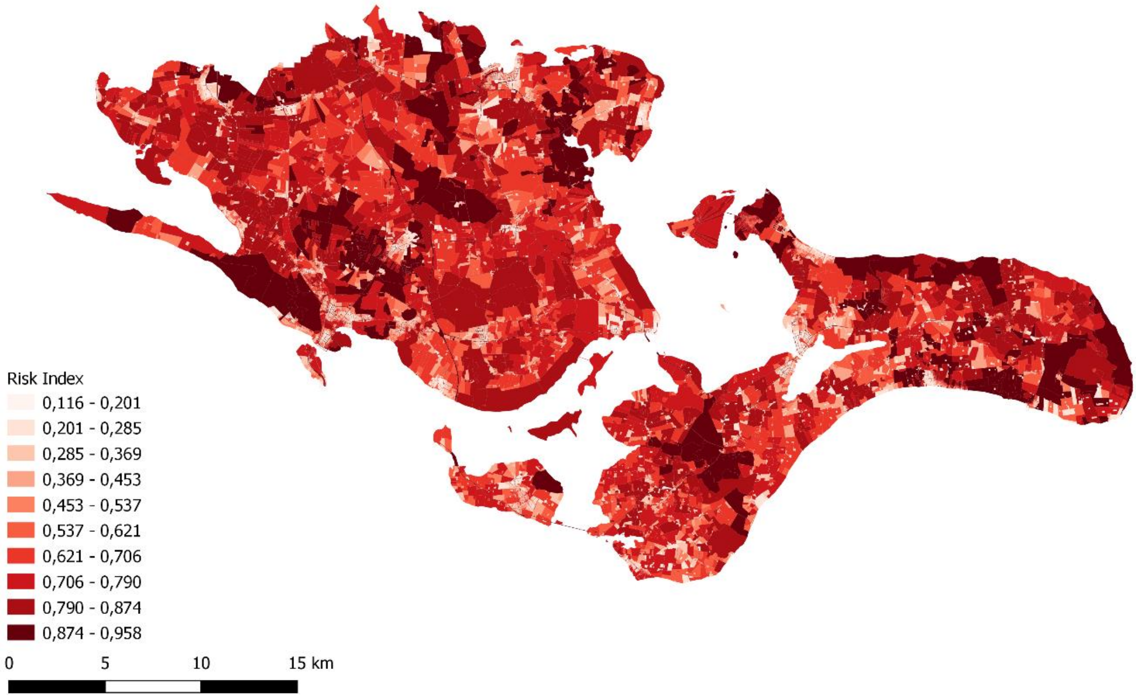


Fig.12. Cadastral-based risk map.

5.3 Communication and Education

5.3.1 Educative materials

Owing to their large size, stands of tall invasive hogweeds are very catchy and visible for most of the year, both alive and dead. It is therefore relatively easy to determine the species distribution at a local scale. This combination of characteristics also makes it particularly suitable for involving citizens in locating stands through a public awareness raising campaign.

A focused programme of awareness raising needs to be developed to get cooperate with the citizens having important local knowledge. Awareness raising should be targeted at key groups, e.g. road and river managers and companies deliberately or inadvertently transporting soil. Groups involved in outdoor activities, such as fishermen, farmers, hunters, environmental groups, hiking, and cycling clubs, can be directly targeted. The public needs to be aware (or easily able to find out) where their observations should be reported. The medias that can be used to distribute the information campaign ranges from the official website of the municipality, local tv, radio, and newspaper, posters and leaflets to social media (etc. Facebook).

5.3.2 Web map

A digital version of the risk map should be available for citizens within Vordingborg Municipality. This will improve the level of information about dispersal and occurrence of Giant Hogweed and raise public awareness. Several options could increase public access to these digital resources. One option is to make the risk map available online as a raster file. This solution would only be relevant for citizens with GIS experience. Another communicative solution is to generate a Web Map Service solution (WMS). A WMS solution consists of a digital map that can be accessed by normal HTML connection. An HTML connection would comply with the existing digital sources found on the municipality's webpage.

5.3.3 Informative campaigns

An important part of the plan is also the communication of the current status of the species in the municipality and the efforts that are being carried out. To do so, the municipality is mainly using the **Facebook** page to do some informative posts in order to engage the citizens to report new findings of the species. It has been proved that it is a very useful tool for the municipality due to the high number of occurrence reportings after publishing on Facebook.

Besides using social media as an informative tool to engage the citizens, when the control season starts, the municipality should increase the efforts to inform about the problem. The **local newspaper** or the plan’s **website** could also be used to enhance communication and raise awareness about the municipal efforts to fight the Giant Hogweed. These tools could result in an increase of the citizen's reportings, but could also engage landowners to eradicate the species, before the municipality sets the deadline protocol.

Another problem that faces the municipality is the citizen's lack of knowledge about the invasive species *H. mantegazzianum*. Ignoring this can lead to a wrong identification and reporting of individuals and also focusing the eradication efforts in another species. A useful and engaging way to increase the knowledge within the local population would be the realisation of **workshops**. The workshops could be done during late winter and early spring to let citizens and landowners know about the species before it develops during spring and summer. The content of the workshops should be decided by the municipality depending on their requirements or issues that had the last year. A proposal to the learning aim of the workshop is competencies in species recognition, making management plans for your own property and in collaboration with your neighbours, assessing the most efficient eradication method.

5.3.4 Direct communication

Once the hot spot risk analysis and the management strategy has been planned according to the different landscape patterns, there is the need to communicate this risk to the municipality inhabitants. Within the municipality borders, we can distinguish between state owned areas and private property. The public lands can be administered at a national level or by the municipality, but the private land needs to be managed by the landowners, becoming the ones responsible to fight the Giant Hogweed in their properties.

In order to communicate the risk level that each property has, the **cadastral maps** have been combined with the risk map. Then, the average risk has been estimated for all the properties in the municipality.

A form of direct communication is needed to make the landowners know about the new plan and their tasks related to it. It needs to be a practical and automatic form so the municipality can be self-sufficient in the communication process, relating the cadastral properties with the risk level and sending automatically the form to all the landowners.

In this case, the form of communication will be a **formal correspondence** (Fig. 13) sent by email (or E-Boks) to the landowners. The formal letter will include a presentation from the municipality where the owner will be informed about the new assessment made for the Giant Hogweed in the areas. The risk level of the property will be presented later in a range from 0 to 1, being 0 the lower risk and 1 the higher, so the owner can identify how vulnerable the land is to the spread of the species.

To illustrate the risk level, two maps will be attached in the letter, first a topographic map with the property limits and street names to help the landowner locate his land and then the same limits embedded in the risk map. After informing the owner about the risk in his property a recommendation of management will be addressed, and it will be forwarded to the WebMap where the specific management actions for each landscape character types can be found.

5.3.5 Automatic atlas generation QGIS

Generation of maps can be time-consuming. A proper map that visualizes both cadastral references and giant hogweed risk zones is a basic communication tool that should be included in all letters to landowners within the giant hogweed high-risk zones. In order to make this process more efficient, automatic generation of multiple map layouts covering different cadastres can be a useful tool.

Automatic atlas generation processes make communication to landowners easy by generating maps from information such as cadastral owner, type, number, etc.

Information about the Giant Hogweed

To:

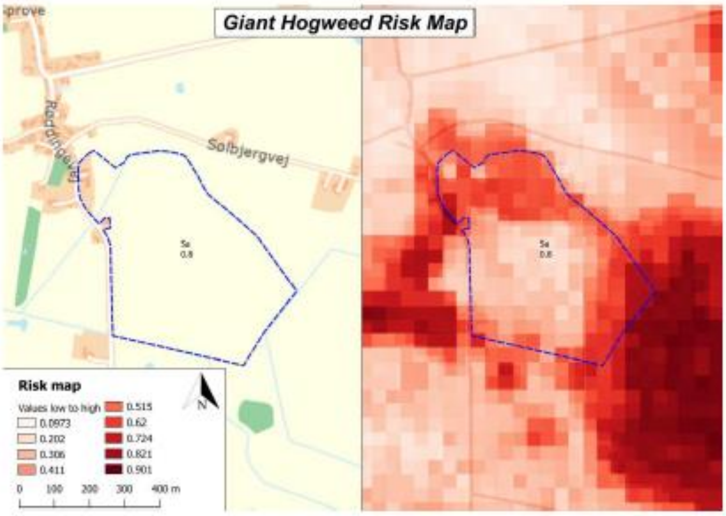
Landowner Landownersen

Hogweed road 21 – 4760 Vordingborg

Giant Hogweed and your property

The Municipality of Vordingborg has carried out a landscape analysis in order to map potential habitats of the invasive plant species Giant Hogweed (Heracleum mantegazzianum). According to the Giant Hogweed action plan of Vordingborg municipality you as a landowner are obliged to eradicate individual plants and colonies of Giant Hogweed at your property before the 1st of June. A quick way to search for Giant Hogweed at your property would be to plan a route along streams, edges and wetlands. Areas with a high level of disturbance could also be included.

Some parts of your property are found to be suitable for this invasive plant species. The part of your property with cadastral reference 5a, Damsholte Sogn scored a risk value of 0.8 on a scale from 0-1. This means that you as a landowner should pay attention to occurrences of this species. To get more information about the Giant Hogweed and eradication methods please visit our homepage or concact the municipal official responsible for Giant Hogweed. (www.Vordingborg_Hogdeath_now.dk).



Best regards Vordingborg Municpality

Fig. 13. Example of letter to landowner

5.4 Updating Distribution Map, Population Characterization and Preventive Actions

Once a population or plant is reported, the GPS location needs to be registered in a common database available for the municipality members and citizens. The objective is to build a distribution map of the current occurrences of Giant Hogweed in Vordingborg Municipality. A 4-metres radius around the plant or population will be denominated ad "seed fall sites" as they might be potentially contaminated soils. In areas where the plant is accessible or might be potentially a risk for children or other people (road margins, public green spaces), warning notices and fences must be put up.

It is primordial to establish the length of time that Giant Hogweed has been on the site, as long-standing infestations over many years will have a larger seedbank and also will be more resistant to any kind of eradication method.

What to do if there is no Giant Hogweed in a high-potential site?

The fact of not spotting Giant Hogweed in a high-risk area does not necessarily mean that the plant is not present or that there is no risk for the plant to establish. Despite its big dimensions, it is sometimes difficult to access the potential areas because of hydrologic conditions. Also, the typically adjacent vegetation such as nettle (*Urtica dioica*) and reed (*Phragmites australis*) might sometimes hinder its detection. This is why, in order to make sure that any Hogweed plant is reported, there should be frequent detection sessions throughout the year.

In places where the Giant Hogweed cannot be found, efforts should be put in place to prevent the species arrival (see Step 4).

5.5 Risk Network and Infection Routes

The risk network creation and infection routes control are key elements for the action plan to work. It is strictly necessary to prevent the spotted populations of Giant Hogweed from spreading anywhere else. As already reviewed, in order to colonise a new area, seeds of Giant Hogweed have to reach the site by natural or human-assisted mechanisms.

A **risk network** surrounding each Giant Hogweed detection site will be created in order to avoid its spread. It is important to keep in mind that virtually every type of landscape may be suitable for the spread of Giant Hogweed from a seed source point. However, a good way to detect the most vulnerable spots is by using the Risk Map. In high-risk areas surrounding the current detection sites, the landscape parts more prone to be reached by seeds for the dispersal are:

- Within wind dispersal distance of existing stands not protected by barriers (e.g. hedgerows, forests)
- Within the flood zone of water courses where the Giant Hogweed has reported upstream
- Road or railway border within 2 km of a current Giant Hogweed occurrence point along the border
- Adjacent to gardens in which the Giant Hogweed is cultivated

Once the most vulnerable areas to be colonized are detected, there must be an accurate identification of the landscape flows that may contribute to the seed or plant dispersal, acting as infection routes. The most typical dispersal drivers are:

Combining the vulnerable areas and the infection route information, there will be a **risk alert** creation to enhance the communication between landowners and people doing any kind of activity within the risk network. This risk alert must be done in a case-by-case basis, as each Giant Hogweed populations and landscape flows are unique.

- Importation of infected soil with either rootstocks or seed
- Contamination on vehicles and equipment
- Adhesion to car tires and motor vehicles
- Colonisation from upstream areas seed wash-out

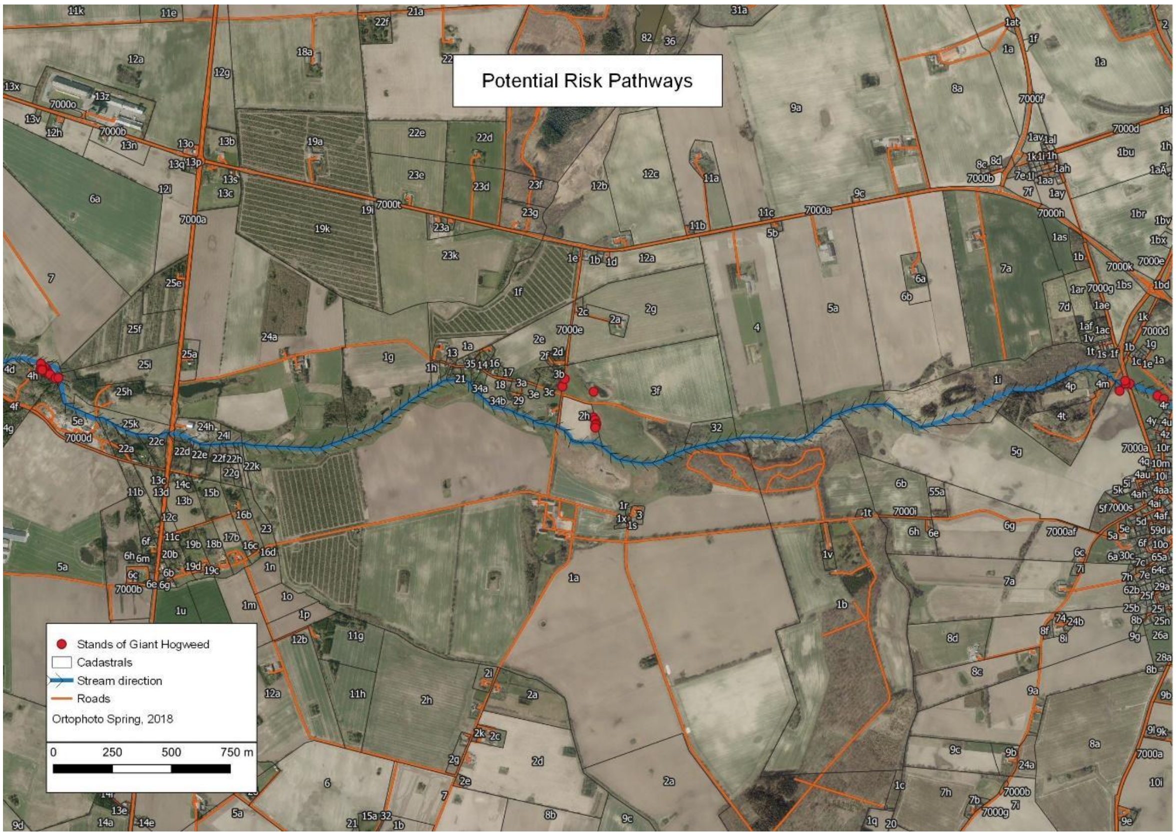


Fig. 14. Risk pathways based on landscape elements

5.6 Specific Management Plans

When designing the specific management plan and deciding the eradication or control methods, an economic study of the cost must be done. The aim of this is to identify if sufficient resources are/will be available to complete the work within the planned timescale.

5.6.1 Eradication methods

The aim is to perform an effective action against the Giant Hogweed. Effective control is defined by all individual plants dying and when stands are eradicated. Where the stands are massive the fight shall be performed for several years. The landowner is responsible to ensure that no further seed dispersion from existing plants is happening. For detailed descriptions of the eradication methods please visit the methods catalogue (former action plan). The municipality will provide guidance and will find solutions fitting each problematic situation if required by a landowner.

The tables underneath are based on experiences regarding the practical combat against Giant Hogweed (Hedeselskabet, 2009). The 'smiley/sad faces' represents the trade-offs between resources used, work environment, efficiency, and negative environmental effects. The table can be used as guidance to compare different methods in different landscape types.

	Manual methods				Machine methods			Changed maintenance	
	Root cutting	Mowing	Umbel removal	Spraying	Soil preparation	Mowing	Spraying	Re-cultivating	Grazing
Individual plants and small stands									
The edge streams, 2-meters of fringe, fences, depots etc.	🙂	😐	😐	😐	☹️	😐	☹️	☹️	😐
Meadows and nature areas	🙂	😐	☹️	☹️	☹️	😐	☹️	☹️	🙂
Agricultural land	🙂	😐	☹️	🙂	🙂	😐	🙂	🙂	😐
Large stands									
The edge streams, 2-meters of fringe, fences, depots etc.	😐	😐	☹️	😐	☹️	😐	☹️	☹️	😐
Meadows and nature areas	😐	☹️	☹️	☹️	☹️	😐	☹️	☹️	🙂
Agricultural land	☹️	☹️	☹️	🙂	🙂	😐	🙂	🙂	🙂

Table 2. Practical eradication methods

5.6.2 Annual cycle of actions

To reach a successful eradication against Giant Hogweed, it is preferred to start the planning of next year's actions in late summer. It is also important to perform surveillance and actions early in the growth period and repeat the whole process.

Late summer – It is recommended for the landowner, to start the surveillance in September where flowering plants are dead and large stands are accessible. This is done to get the status of actions performed this year. Actions and results should be reported to your municipality, so more occurrences can be included in the strategic action plan which

Autumn and winter – When entering the autumn and winter month it is time to explore the risk maps. The risk map is a visualization of the potential risk for Giant Hogweed to establish. The risk map can provide information about where to prioritise the search for new stands and plan to avoid further spread of the species. For more information about the risk, map read part 5.2.1. A web version of the risk map can be accessed at www.Vordingborg.dk/example

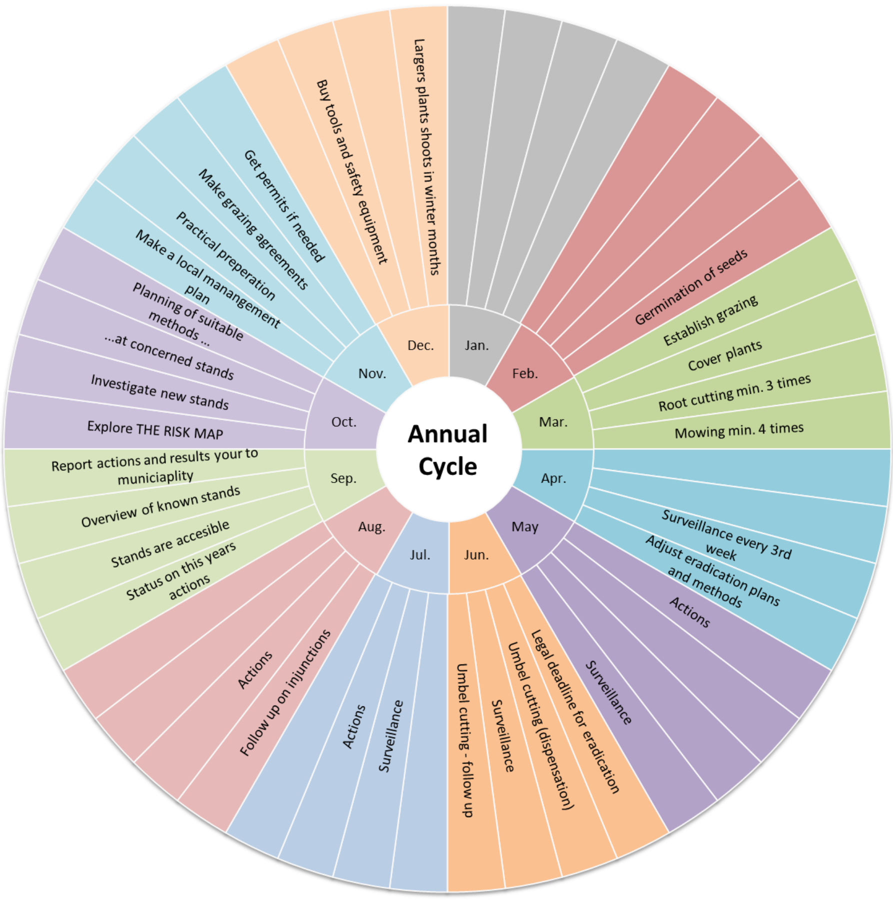


Fig. 15. The annual cycle of Hogweed eradication activities

Depending on where stands are located in the landscape, suitable methods should be selected. An assessment of suitable methods can be carried out by the guidance in part 5.6. Along with the assessment of methods, it is preferred to make a local management plan for the actions that need to be performed in the forthcoming year. Tools and safety equipment can also be bought in advance.

Early spring and summer – Some larger plants may already have shot in mid-winter, but the germination takes place at the end of February. It is crucial to start actions early in the growth period. Therefore, eradication actions should be established in March and carried out through the growth period. The umbel cutting has shown to be most effective in mid-June, this means that a dispensation is needed if this method is preferred due to the specific landscape element.

In the ongoing process of applying the methods, there needs to be parallel surveillance going on. It is recommended to survey stands 14 days after actions have been carried out and other known stands every third week in the growth period. The surveillance can give information for the manager to evaluate eradication plans and methods and thereby adjust the actions.

5.6.3 Follow-up

After the deadline of performed eradication, the municipality will follow up on known stands of Giant Hogweed. The purpose is to survey to what extent the landowner -including authorities- had fulfilled their responsibilities of total eradication of the stands. If the requirements are not met, the municipality will have two options.

1. If it is the first time for the landowner to be contacted, the municipality will start a dialog with the landowner to communicate the importance of the fight against Giant Hogweed. The dialog should include guidance of the most effective eradication methods that can be applied to a specific landscape type at the landowner's property.

2. If a dialog has been already established and the requirements are not met, the municipality will have to give an injunction. The injunction should state a new deadline 14 days in advance. If the injunction is not followed, depending on the situation, the municipality can perform the actions needed to eradicate stands to avoid further spreading. This action is paid by the landowner.

5.7 Monitoring, Reporting, and Evaluation

The last part of the plan includes the **surveillance**, **monitoring**, and **evaluation** of the success. This is necessary in order to assess which of the objectives have been met, what can be done to improve the functioning of the plan, which parts of the plan are the ones are problematic and to keep the species track within the municipality borders.

Once the action plan is settled and the communication tools have been sent to the landowners, the municipality planners must continue with the monitoring part of the plan. One thing that can be done is a **registration of occurrence** when dealing with the management of the species. Meaning that if a new occurrence spot of Giant Hogweed is found, it should be added to the database of Giant Hogweed, to increase the pool of occurrences. The registration should include information about several physical factors defining the specific stand of Giant Hogweed. This information can be organized in the following attributes:

Table 3. Recommended attributes to include in the surveillance protocol

Locating	Eradication
• Coordinates (UTM, 32N) • The total affected area (m2) • Number of plants (0-10, 11-100, 101-1000) • Date of finding (dd-mm-yyyy) • Responsible landowner (name/organisation/company)	• Date of eradication initiated (dd-mm-yyyy) • Selected eradication method (tekst) • Area on which control or eradication work has been carried out (m2) • Evolution after performed actions (new polygon)

The registrations can also be done by the landowners if they spot non-registered plants within their properties. In this case, a form of communication between the owners and the municipalities should be established to ease the transfer of information. Public participation GIS (PPGIS) can be used to monitor the species by citizens and landowners, as it has been done, but the municipality must make sure that the strategy is known and used widely by the local population.

The **surveillance** of the plan application needs to be done by the municipality, who has to make sure that the landowners with Giant Hogweed presence eradicate the plants before the

3 stated deadlines. If after that, the person responsible for eradicating the plant has not followed his obligations, the municipality will perform the eradication and the bill would be sent to the landowner.

To **evaluate** the efficiency of the Upgraded Hogweed Action Plan, a benchmark would be preferable. Such a benchmark doesn't exist for the municipality of Vordingborg as the prior management activities are described as ad-hoc tasks by the officials of the municipality. A proper evaluation of the upgraded action plan should focus on qualitative data from landowners and officials from the municipality. A checklist to examine the effect of the upgraded plan could work as input for the final evaluation. The checklist should cover the following topics i order to be used for the final evaluation, and should be answered both by municipality officials and landowners:

1 - Risk level: Have the upgraded Hogweed action plan provided you with information about the current risk level on a local and regional level?

2 - Biology: Have the upgraded risk plan increased your knowledge of the plant biology and dispersal strategies?

3 - Landscape elements: Can you identify landscape elements of importance for the Giant Hogweed in the landscape based on information found in the upgraded action plan?

4 - Methods for eradication: Can you select a proper method to eradicate different sizes of populations from the information found in the action plan?

5 - Communication: Did the upgraded action plan improve communication about management and legislation between you and the municipality/landowner?

6. Discussion

6.1 Data accuracy

For the map production, different data sources have been used. As a result of that, different qualities of mapping are being used and this can lead to some inaccuracies in the data set. Also, for the occurrence data, 106 recordings have been used to represent the actual distribution of the Giant Hogweed within the municipality. This sample is too small to represent a real distribution and in a long time scale (e.g., 1996 – 2018), meaning that the oldest data could not reflect the occurrence even though they have been used during the analysis due to the small amount of data available.

6.2 Risk Map

The risk map provided in part 5.2.1 of the Action Plan is a probability-based map, merging from statistic-based and process-based suitiblity maps. As already mentioned in the theoretical review of the plan, the *Heracleum mantegazzianum* is a euryoic species, meaning that it can tolerate a wide range of environmental and stress conditions. This is why it is recognized as a competitive specie in Grime's pyramid. Despite being true that there is a higher probability for the Hogweed to occur on the high-risk areas, other lower risk areas can easily be colonized by it. Another point that needs to be taken into account is the map pixel resolution. As the risk map was designed to be used as a detection guideline tool in a municipality scale, each pixel is relatively big in cell size (e.g., 40 m) expressing the mean risk value. Consequently, the microhabitat scale and other smaller landscape elements that can serve as perfect habitats and dispersion sources for the Giant Hogweed are not included in the risk map. It would therefore be a mistake to focus the management efforts only on the high risk areas; hence the importance of an effective preventive and early detection through the engagement and public collaboration.

A good way to cover this weakness would have been by creating a more accurate map with a smaller pixel cell size. Also, it would have been interesting to include dispersal sources such as urban settlements, or current occurrence points. However the purpose of the plan was to provide the municipality members and citizens with a tool on how to fight the Giant Hogweed in a municipal scale, hence small landscape elements, micro habitats, and dispersal sources were left aside on the risk map production process to make it more simple and intuitive.

Moreover, the different data quality (e.g. the wetness index vs. SOC%) together with the course time limitation under which the project was carried out limited the final risk map.

The assumptions that was assessed during the Risk Map production could also affect its result. In the GIS-based approach, some assumptions where done when working with the infrastructure package according to the group's criteria and field trip observations. To start with, any distance map to infrastructure was created as a difference to the water bodies, where a WD layer was produced. This is because the resolution in which the final Risk Map was produced is not high enough to express the small-scale effect of infrastructure over the overall risk index. This is why the infrastructure polygon layer was treated binomically, meaning that the highest risk values (3) where within the road polygons and the lowest risk values (1) out of it. Also, as the infrastructure weight was not calculated through the SDM approach, it was assumed to have a weight of 0.2 according to the field observations and to the weight of the other environmental packages.

The risk map is not taking fjords and other seawater bodies into account. The variables considered in the analysis is only found within the boundaries of the terrestrial land and fresh water. Factors related to marine environments are excluded. But through field validation, it was discovered that occurrences are found near a little closed bay called Stege Nor. These occurrences i possibly a result of the seed dispersal through seawater. The dispersal through seawater is outside of the delimitation of this project. This should be improved in the development of a future action plan. To include bays and fjords in the analysis can be especially useful in a place like Vordingborg Municipality where several of these shores are found.

6.3 Model development and Field validation

For statistic-based model, the model accurrancy may decrease due to pseudo-absence plots. Although these plots based on our previous knowledge, it is still possible that these plots were true presence plots. For process-based model, the importance variables are based on statistic model which is not show the completely expert advise which means that the comparison of the two approaches are not completely objective. In field validation, we did not visit all the environment element types due to lack of time, escapically for the significant dead ice landscape (Fig. 9) and the west Vordingborg (blue 'a' square in Fig. 10). Besides, the threshold defined is only based on the statistic-based model since both two models have similar ranges and it is hard for process-based model to define a threshold.

6.4 Cadastral map

The weakness of the cadastral risk map is that cadastres with the same reference-value are joined. With this decision follows that the map is very useful when starting a communication process with affected landowners, but not as useful when assessing the risk score at a landscape level. As the risk score applied to the joined cadastres is a max risk score, all fields of a landowner with a single high score pixel would get a high a risk score value that equals the value of the highest pixel risk score.

The above-mentioned technical decisions make the cadastral map a perfect tool to help to establish preventive targeted actions such as information campaigns. With a limited budget, this map can increase the cost-benefit of communication as the risk score of joined cadastral references can be sorted from low to high.

A solution to counter the issue of high single pixel values would be to work with the cadastral map and the risk map in parallel. It that way it would be possible to visually combine the results of the cadastral map with the risk map, and thereby identify the cadastral within true high-risk zones.

6.5 Landscape analysis

Apart from the risk map and its application into the cadastral map, a **landscape analysis** was also done in order to see the bigger picture and to summaries, the high-risk areas joined with the landscape types. This landscape map has a broader scale in comparison with the risk map. Even though the accuracy of it can be lower, it is easier to distinguish the different landscape types according to the risk associated. For instance, with this analysis, we can easily locate the river valleys that are more prone to be invaded by the Giant Hogweed.

The matrix of the landscape type map corresponds to the agricultural fields, all of them categorized as low risk due to its high level of management. This means that all the matrix has not been taken into account on the map as a risk element. It is important to state that even though it has a low risk value, it can be really sensitive to future landscape changes, both originated by agricultural practices or broader planning projects.

In this case, this landscape type map can also be used by the municipality as a really powerful tool for **planning**. Protected areas, climate change adaptation plans, creation of new corridors or wet areas can be potential projects that the municipality will face in the future, and to do so, the risk landscape type map should be taken into account when planning. For example, if the municipality plans a new wetland area in the "low-risk matrix" could seem that the probability to be invaded by Giant Hogweed is low. However, it is not the case, because all new places without a vegetation cover can be susceptible to the arrival of new seeds. Also, when planning new corridors and enhancing nature connectivity in the municipality, the high-risk areas must be considered, becausewrong planning may lead to increased dispersal routes for the Giant Hogweed. This is why an approach closer to planning by management it is recommended, always considering the products created and the level of management and land use when planning new projects in the area.

6.6 Landscape changes and the rate of dispersal / Trade-offs

Landscape changes in the municipality will alter the risk map created and lead to higher inaccuracies in it. The longevity of the map so can be sensitive to these changes in the land use. Agricultural activities are relatively dynamic and, in a few years, the type of crops, areas of fields and properties can experience large changes on a local scale. This is why the actual map produced can be seen as a static view of the risk but may not reflect the future spread of the species. In fact, a probability map shows the higher-risk areas as the ones that may be invaded in the future but does not mean that all of them are already colonised by the Giant Hogweed. Despite the annual changes in the land use, the map reliability should be still high some years after its publication.

However, there will be a need for an update of the map, specially because the agricultural land use may expand their range in some area and reduce it in others. It can be discussed how often the map should be updated but also there is a need to consider the economic costs that a new production of the map would suppose to the municipality. Therefore, a **trade-off** of both aspects will need to be considered by the municipality managers to find out how often they will need an updated map.

6.7 Improving landowner's engagement

The essential aim of this action plan is to improve engagement of landowners fight against the Giant Hogweed. The purpose is that the plan will provide the tools needed to motivate enough to get the landowner to take the first step in the fight.

The Cadastral Risk Map is providing information about a specific property and the potential risk in these. The data used to produce this map is public. But the landowners may feel that they are being subject to systematic **surveillance** with this tool. If this leads to a reduction in their incentive to cooperate with the municipality it would be reluctant to the aim of this plan. To avoid this situation if would be necessary to explain how the analysis was carried out. It is important to explain that there's no ongoing remote surveillance of the property (ect. via drones). Presenting the origin of the data used to produce the risk map could appease the fear for surveillance of the citizens. The in-field visits by the municipality, to follow-up on that the landowner's obligations comply, should be explained in that way they always have been carried out due to the legislation.

The municipality has the possibility to fine landowners that are not fighting Giant Hogweed if the municipality is performing the actions by themself. But at the moment the legal limitation on the amount is too low (3.81 DKK/m2) compared to the resources needed to perform the eradication on large colonies. There is a need for the engaging landowner to perform a proper eradication.

The potential negative influence on landowners willingness to cooperate should be investigated. In the best possible worlds, a bottom-up approach would be preferable to look at the problem from the landowners perspective and to deal with the different interests and conflicts of the eradication of Giant Hogweed. There should be an in-depth evaluation of the efficiency of the plan. The evaluation should include how to adjust to landowners wishes.

7. Perspectives

The fight against invasive alien species is a global affair that will compromise the natural values of many regions in the nearest future. Invasive species such as the Giant Hogweed can pose a threat to native biodiversity and also bring problems to governments such us economic costs and public health hazards. Therefore, **strategic action plans** and specially local ones will be needed to manage the invasive species in the most effective way.

Nowadays these plans are more necessary than ever due to the big land use change the Danish landscapes are experiencing. For instance, the restoration of many ditched forests and land into wetlands and also reclaimed lakes are increasing the wet area in the countryside. This can lead speed up the dispersal pathways of the Giant Hogweed and other invasive species related to moisture creating stepping stones in the landscape. These new changes demand updated local action plans to fight more effectively the invasive species.

In this project, a specific action plan to fight against the **Giant Hogweed** has been proposed to the municipality of Vordingborg. Even though being a plan designated for a specific species and it focuses all the efforts in Vordingborg, it can give some guidelines for creating new strategic plans in the future. For instance, those municipalities who still do not have an action plan to fight the Giant Hogweed or those who would like to improve their actual plan would be candidates for using the product that has been created in this project. Moreover, the same materials and methodology used to create the maps could also be used for making a risk analysis of other invasive species such us the **Japanese Rose** (*Rosa rugosa*) or the **Japanese knotweed** (*Fallopia japonica*), major invasive species in Denmark at the moment (EPA, 2017).

Fighting invasive species is often highly demanding in terms of **economic costs** and **resources** for public institutions. Nowadays the public agenda for nature-related projects is growing with topics such us climate change mitigation and adaptation, creation of green corridors, biodiversity oriented practises in productive land, etc. This means that the fight against invasive species may not get enough funds as needed to achieve an effective eradication of these species. Therefore, in a Danish context, it may not be possible to carry out the management plans for all invasive species. The importance of other nature-related problematics will need to be discussed when deciding on which areas should the resources and the efforts be focused.

Another point that has to be considered is the **future effects** that the plan will have on the area. Most of them may be positive, leading to a better collaboration of the landowners to fight the species and a more effective way of management by the municipality thanks to the new risk maps. However, after publishing the improved action plan, including the tools representing the risk score on a local scale, it can affect specific properties and areas. There is a probability that the finding of large Giant Hogweed stands may reduce or affect negatively house or land prices. That is why it is suggested that the specific local maps with the risk values should be confidential for the municipality and can only be sent to the specific landowners for managerial purposes.

8. Conclusion

As demonstrated in this report it was found possible to create different versions of Giant Hogweed risk maps based on a number of digital datasets. The risk maps were found useful for identifying areas with a high probability of occurrence. It is important to note the word probability, as a high score on the risk map didn't necessarily equal the occurrence of a Giant Hogweed. Furthermore, it was found that a landscape element map could be produced based on the general risk map. The landscape element map makes it possible to include the risk of dispersal into a general landscape planning context.

The tools developed in this project is mainly based on visual maps which have the purpose of improving the communication in the action plan. The tools can both be used at a strategic level on a larger scale, but can also be useful in direct communication with the landowner. In addition to the visual maps, concrete guidance should be provided to engage the landowner in the local planning, as well as in the practical actions at the property. This form of strategic communication can work as a preventive tool to mitigate further dispersal.

When publishing the risk map the municipality should be prepared to assume its responsibilities in terms of communicating the process of risk map generation to the citizens. Citizens could easily feel monitored and imagine UAV's mapping their property.

With the tools in the hand, the manager is now having a communication platform that can be used to establish a dialog in a more structured way than before. The communication process can be prioritized by ranking properties based on the risk score.

Overall the management tools are making it possible to reach an increased cost-benefit of the management. The fact that the upgraded action plan is not implemented yet in the management practices of the municipality leaves the evaluation of the efficiency of the plan as one unanswered question. With this improved action plan, we hope that it will contribute to a more effective fight against the Giant Hogweed.

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