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Probabilistic Ecological Risk Assessment and Effectiveness of Biochar as a Gentle Remediation Option (GRO)

A Case Study of DDT-Contamination in a Forest Nursery in Southern Sweden

Master's thesis in Infrastructure and environmental engineering

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Cover: Picture taken at the GRO site of the Kolleberga forest nursery.
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Abstract

The historical use of DDT still impacts the soil where it was once used despite a half-century-long ban, and its presence can still potentially be harmful to local ecosystems. One important area where DDT was used was forest nurseries and many are still contaminated above soil guideline values. This thesis aimed to create a probabilistic ERA model to estimate the ecological risk for top predators from DDT-accumulation through diet at the Kolleberga forest nursery in southern Sweden. It also aimed to evaluate the effectiveness of lowering the ecological risks by implementing biochar using data provided by an ongoing pilot experiment at the site. The investigated species were red kite, common buzzard, great spotted woodpecker, common raven, badger and weasel.

The thesis is a follow-up study with additional developments from a previous study in the area. The developments were dividing the area into subareas based on the former forest nursery use with different distributions of more recently obtained DDT-concentrations and incorporating home range into the model. Site-specific BAFs for leaves, grass, and earthworms (soft invertebrates) were provided from the ongoing pilot experiment. The parameters where no site-specific data was available were sourced from literature.

The results showed that there is a high probability of exceeding HC5 for many of the analyzed species. Implementing biochar lowered the BAF for all evaluated food groups, but more site-specific data is needed to evaluate the full effects of its implementation. The risk was seen as high enough to suggest preliminary remediation options. Excavation was seen as suitable for the geographically small hotspot areas while biochar can be used on the field. More site-specific data for BAFs, home ranges, and local diets of the analyzed species would be needed to get more accurate results. Suggested further research includes collection of local home range, dietary, and BAF data, implement a weighting system for home range, extending the model to include more species and performing cost-benefit analyses.

Keywords: DDT, Forest nursery, GRO, Biochar, Ecological risk assessment, Bioaccumulation, Probabilistic modelling, Home range

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We would also like to thank friends and family for being supportive throughout the process.

David Carlsson & Hugo Nyman, Gothenburg, June 2024

List of Acronyms

Below is a list of acronyms and explanation of the acronyms used in this thesis.

BAF	Bioaccumulation factor, a unitless parameter which corresponds to the ratio between the concentration of a contaminant in an organism (e.g., a plant or an animal) and the concentration in a medium such as soil.
BW	Bodyweight, the total weight of an individual.
DDT	Dichlorodiphenyltrichloroethane, an organic insecticide commonly used historically on a global scale.
DDX	Collective name of DDT and its metabolites and isomers. Sometimes referred to as "Sum DDT" in this thesis.
DS	Dry soil, parameter used to describe the bioconcentration of a contaminant within a soil when excluding the water content.
ERA	Ecological Risk Assessment.
G.O.F.	Goodness-Of-Fit, a statistical test to evaluate possible correlation from pooled data.
GRO	Gentle Remediation Options.
HC	Hazardous concentration, the concentration of a contaminant where a certain percentile of the species population is affected negatively.
KM	Känslig Markanvändning (English: Sensitive Land Use). A Swedish classification of soil quality with provided guideline values (Naturvårdsverket, 2024). Includes areas with a large exposure such as housing areas and playgrounds. The guideline value for DDT-contamination is 0.1 mg/kg DS (Naturvårdsverket, 2016).
MCP	Minimum Convex Polygon, the most frequent method to estimate home ranges.
MKM	Mindre Känslig Markanvändning (English: Less Sensitive Land Use). A Swedish classification of soil quality with provided guideline values (Naturvårdsverket, 2024). Incudes areas with a large risk of high exposure such as housing areas and playgrounds. The guideline value for DDT-contamination is 1.0 mg/kg DS (Naturvårdsverket, 2016).
NOEC	No-Observed Effect Concentration, the highest observed concentration where there are no significant effects. Used in this thesis to extract Hazardous Concentrations (HCs) for the analyzed species.
PAF	Potentially Affected Fraction, the percentile of species in the local ecosystem exposed to a concentration of a contaminant above their NOEC (Klepper et al., 1998).
POP	Persistent Organic Pollutant, organic chemicals which are harmful due to their environmental persistence, ability for long-range transport, large ability to bio-magnify and -accumulate in ecosystems and negative effects on the human and environmental health (WHO, 2020).
WW	Wet weight, parameter used to describe the bioconcentration of a contaminant using the entire bodyweight.

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1
Introduction

In 1962, the American biologist Rachel Carson released the book *Silent Spring*, which brought the use and impacts of the widespread use of DDT into public awareness (Bernes, 1998). The name of the book could be derived to the fact that the singing birds, that had brightened up the spring long before human life ever existed, now became increasingly absent, leaving a discernible sound of silence around the spring environment. In her profession, Carson had noted the increasing use of pesticides within the agriculture and forestry sectors, which was originally intended to combat and kill off insects and fungi, but which eventually turned out to have unintended but likewise devastating effects on larger parts of the fauna and especially on the birds. The increasing use of pesticides in the USA were running in parallel with a similar development in Sweden where presence of several birds quickly dropped. *Silent Spring* played an important part in an increasing political discussion about the emerged environmental problem that would eventually end much of the use of the most poisonous products, but its consequences still remain.

In a global context, there has been an extensive historical use of environmentally harmful pesticides (Swedish Environmental Protection Agency, 2012), many of which are today classified as Persistent Organic Pollutants (POPs). POPs pose a large environmental risk due to their persistence in the environment and their ability to bioaccumulate (European Chemicals Agency, n.d). One of the POPs with an extensive historical use is Dichlorodiphenyltrichloroethane (DDT) (Swedish Environmental Protection Agency, 2012). DDT is a synthetic insecticide which was initially created to protect from insectile diseases which can spread to humans, such as malaria and typhus (US EPA, 2023). This is also the explanation why DDT is still used in several places around the world as it remains a very effective cure against such diseases while still being rather cheap to use (Asker, 2011).

In later years, the use of DDT on a global scale is considerably lower than it used to be previously (van den Berg et al., 2017). In 2014, only a few countries reported usage of DDT, where the largest global user was India, with an annual usage of 3092 tons during that year and India was also the only active producer of DDT. However, the overall global trend of both usage and production of DDT decreased steadily between 2003 and 2014. In the EU, there was a partial ban of DDT in December 1978 with exceptions for minor usages (European Comission, 2003), and a final ban of DDT usage when the decisions made in the Stockholm Convention made all usage of POPs illegal in 2004.

As in many other countries, DDT was an important part of Swedish forestry and agricultural protection strategy as it was used frequently as a pesticide in these areas with a usage peak in the 1960s (Swedish Environmental Protection Agency, 2012). Due to its persistence and capability to bioaccumulate, DDT is still found in many animal species in the areas around Sweden, such as Atlantic cod and Haddock in the North Sea (Boitsov et al., 2024). The harmful effects of DDT was discovered on white-tailed eagles and different species of seals as well as the fish the seals fed on (Bernes, 1998) and in 1969, Sweden became the first country in the world to impose a general ban on the use of DDT (Turusov et al., 2002). However, forest

nurseries constituted an exception for a few years but was prohibited from 1975 and onwards (Swedish Environmental Protection Agency, 2012). The long-term ecological effects of the large historical use of DDT are still uncertain, which poses challenges in analyzing the effects on the human and ecological health in areas with large contamination.

In 2020, there was 746 forest nursery objects that were confirmed to be contaminated with DDT, with each nursery containing around 50-500 thousand tons of contaminated soil per nursery (Forsberg & Wåhlén, 2020). Apart from these, there are sites that are yet to be classified. This stresses that the contamination at the forest nurseries is a problem that should not be neglected and still could affect different species today, despite the almost half-century-long ban. However, remediating DDT is often an expensive process, and thorough investigations are important to implement measurements which can be motivated economically.

A common ecological risk connected to DDT are risks connected to bioaccumulation and biomagnification upwards in the food chain leading to secondary poisoning. Previous studies (such as Rundegren, 2019; Jongbloed et al., 1996) have investigated the ecological risks connected to DDT where Alice Rundegren have conducted a master's thesis on the Kolleberga forest nursery but without much needed site-specific information. Site-specific parameters often have a large impact on the bioaccumulation of species, which makes it important to thoroughly investigate the local site conditions to better understand the risks at each site.

1.1 Aim and Objectives

The aim of this thesis is to estimate the ecological risks due to bioaccumulation of DDT in the food chain for top predatory species at the Kolleberga forest nursery, and to evaluate the effects which the Gentle Remediation Option (GRO) biochar can potentially have to reduce the ecological risks. To achieve this, there are multiple specific objectives:

- Evaluate the DDT-contamination throughout the site and divide it into representative subareas.
- Select representative top predatory species which can be assumed to reside at the site.
- Collect and compile home range and dietary data for the selected species and incorporate it as parameters in the ecological risk model.
- Calculate bioaccumulation factors from the available uptake- and soil concentration provided from the pilot experiment at the Kolleberga site.
- Create a model to estimate the bioaccumulation through diet for top predatory species which incorporates the diet, home range, and species-specific BAFs.
- Create and format an Excel file for the probabilistic modelling of ecological risks due to bioaccumulation that can be applied in this and other studies.
- Estimate the current risks on local predatory species in Kolleberga, and which effects GRO can have on the current risks.
- Conduct a sensitivity analysis and critically evaluate which data is most important to investigate further to account for the local conditions from an uncertainty perspective.
- Suggest preliminary remediation alternatives for the site.

1.2 Limitations

There were several limitations affecting this thesis. Regarding the scope of the thesis, it only investigated top predators. An evaluation of the total ecosystem, similar to the one performed by Rundegren (2019), was not performed. Though this thesis had the opportunity to use recent data about DDT-concentrations in soil and uptake concentrations into some species from the performed pilot experiment at the site, a main limitation was the lack of other site-specific data. For some ecological parameters, such as home range and dietary distribution data, this led to a reliance on data that was created with other purposes and in other conditions and thus the results could deviate from the intended and may not be entirely representative for this thesis. The site-specific data about biochar that was used investigated a few different plant species, but these were conducted for remediation purposes and was not representative for actual diets in the area.

This thesis has been performed within a civil engineering education program, and this has potentially been a source of misinterpretation of the ecological parameters from the literature search about home range and dietary distribution data. The used sources could also contain ecological information that potentially could be subject for improving the accuracy of the model. This also goes for background information about the local ecology around the Kolleberga area such as about hard boundaries in the habitat or other relevant knowledge affecting the mentioned parameters. Interpretations of what implications data from other ecological conditions would have in the area around Kolleberga have thus not been made in this thesis.

The limited timeframe for this thesis was also an obstacle for more advanced data analysis with inclusion of more spatial analysis and data interpretation. The limited time in combination with small economic resources assigned to the thesis also made testing designated for this occasion an impossibility and that already available data had to be used. Several limitations are further described, implied and discussed later in the thesis.

2
Theory

This chapter provides a theoretical basis for the concepts, conditions, and processes that this work is based upon.

2.1 Dichlorodiphenyltrichloroethane (DDT) and its Metabolites

Despite the long ban, DDT is still very prevalent in Swedish soils. Though DDT in itself is still frequent in the soil, its congeners, or metabolites, which are labelled as DDD and DDE, becomes the byproducts of degradation of DDT, which occurs in living organisms (Bernes, 1998). DDD is formed in an anaerobic process (Enell & Holmström, 2020) and is further degraded into DDA which is soluble in water (Bernes, 1998). The DDE presence is not correlated to the excretion of DDA (Chen, et al., 2009) and DDE does instead bind to the fat which constitutes the bodies of living organisms, where it poses a toxic threat towards the carrier (Bernes, 1998). DDT and its metabolites appear in two different isomer structures known as orto-para (o,p'-) and para-para (p,p'-). A figure describing the metabolic process of DDT is shown in **Error! Reference source not found.**. Both DDT and its metabolites and isomer s tructures (where the sum of their presence is commonly labelled as DDX but which are described as DDT in this thesis since no difference between DDT or any metabolites or isomers have been included in its scope) have been accounted for in the investigations that have been done at the Kolleberga site (Tyréns, 2020).

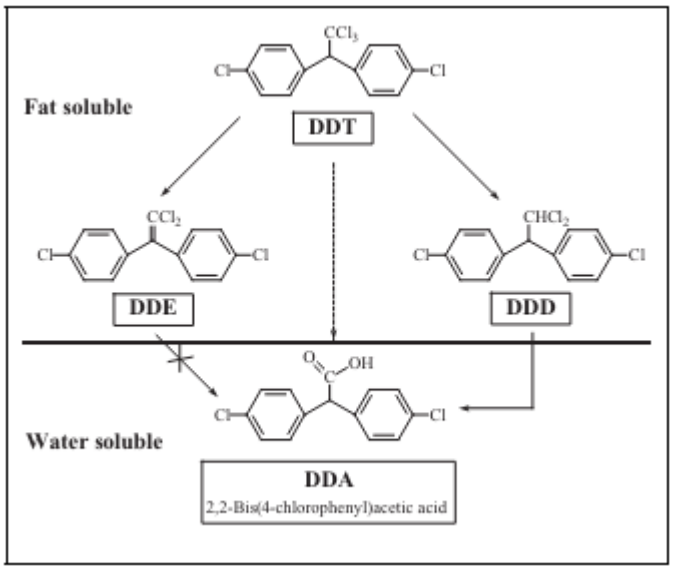


Figure 1: Figure showing the metabolic process of DDT into its metabolites. Sourced from (Chen, et al., 2009).

In Sweden, DDE has historically been particularly toxic towards birds of prey, where the peregrine falcon has suffered the worst but where white-tailed eagle, Eurasian eagle-owl, osprey, western marsh-harrier and sparrowhawk has been severely affected, which is believed

to have been caused by accumulation from poisoned smaller birds (Bernes, 1998). DDE is the most common form of DDT in the Swedish fauna today and has been directly responsible for the hormonal disorders that led to the eggshell thinning that several birds suffered from during the 1960's and 1970's which led to the eggs being crushed during incubation and thereby severely low birth rates. DDT, on the other hand is the most responsible for toxic effects on the birds' brains (Blus, 2011). An example of this is the study made by Iwaniuk et al. (2006), which showed increased DDT-levels to cause American Robins to develop smaller brain volumes, smaller song nuceli and a recuded neuronal size, causing a disturbed sexual behaviour. DDT is rarely lethal and have thus been spread without visible consequences in many cases which have facilitated its spread. A common dispersal pathway of DDT is through bioaccumulation, which means that top predators can ingest DDT through lower levels of the food chain after DDT is accumulated in the fat throughout the food chain (Bernes, 1998) despite not necessary being exposed to it at the source. Biomagnification is an extended version of bioaccumulation in which the contaminant's concentration increase (Bernes, 1998) and this makes DDT and its metabolites a much larger threat towards birds of prey (Jongbloed al., 1996).

There are several possible remediation methods for DDT, and they can be divided into biotic and abiotic remediation methods (Kumplene & Lagerkvist, 2019). Abiotic chemical methods include chemical reduction and oxidation and their combination, but that process is less effective for the metabolites. Solvents can also be used. Thermal treatment is also used where ex-situ desorption and incineration are among the methods. Most of these treatment methods are either done ex-situ or in-situ or on-situ but which require large areas of land (Wåhlén & Eliaeson, 2020). Since forest nurseries often contain large geographical land areas and have high natural values (Börjesson et al., 2022), it can be disadvantageous to perform treatment methods that include large-scale excavations. The biotic methods, that are also commonly used for general remediation methods, are thus often preferable for the soil on forest nurseries.

2.2 Forest Nurseries in Sweden

In the mid 1900's, the growing demand for products from the forest industry led to deforestation in large areas which required a systematic cultivation process of new trees which occurred in designated forest nurseries before continuing their growth on other places around the country (Nationalencyklopedin, 1995). There are around 40 forest nurseries investigated by SGU that have high confirmed levels of DDT (WSP, 2024) which was heavily used at the forest nurseries to protect them from the weevils that posed the largest threat to the small plants (Andersson, 2014) and this can be expected to be a theme for all monitored 746 forest nurseries (Wåhlén & Eliaeson, 2020). A forest nursery with historical DDT-use is often divided into different constituents such as the field where the plants were growing and "other areas" which include dipping areas, storage areas and landfills, where some are regarded as hotspot areas (Sweco, 2022). The hotspot areas often have high DDT-values to this date.

2.3 Gentle Remediation Options (GRO) and Biochar

Gentle Remediation Options (GROs) are a combination of remediation methods that can both manage the environmental risks from DDT and also do not reduce soil functionality (e.g, Cundy et al., 2016). GRO include different phytoremediation technologies but also the use of fungi and bacteria and soil amendments such as biochar (Cundy et al., 2016). GROs are applied in-

situ and aims at reducing the risk of nearby receptors from being exposed to the contaminants by different sorts of removal strategies. Another important aspect of GRO is the importance of net improvement of soil functioning which increases the ability of the soil to perform useful ecosystem services (Drenning, et al., 2022).

When it comes to phytoremediation techniques, these includes multiple different processes of using plants extract and remove harmful elements from the soil ecosystem (Yan et al., 2020). It can also be used to lower the bioavailability in the soil ecosystem. Phytoremediation is considered as a cost-effective remediation option (Greipsson, 2011), and can be divided into the sub-categories *Phytostabilization, Phytodegradation, Phytovolatilization, and Phytoextraction*. Phytostabilization covers the processes where contaminants are taken up by the plant from the soil and stabilized in the plant. This process commonly takes place within the root system (or rhizosphere) and can then also be reffered to as rhizostabilization. Phytodegradation involves the processes which takes place within the plant to break down organic compounds into less toxic substances. This can be done in different parts of the plant. When it takes place in the rhizosphere, it is also reffered to as rhizodegradation. In general, phytodegradation occures by the plants releasing enzymes which breaks down the organic compounds into less toxic substances. Further, when looking at phytovolitalization, these are processes which transforms Volotile Organic Compounds (VOCs) into less volatile compounds which then leave the plant through evapotranspiration (Greipsson, 2011). The last phytoremediation process is phytoextraction, which is the process where the plants are harvested to decrease the contaminant concentration in the soil. When harvesting the biomass, inorganic compounds which the plants cannot break down can be recovered, such as different types of metals (Greipsson, 2011).

GRO also includes different processes which can be classified as *bioremediation* (Drenning, 2021). Bioremediation can be described as an umbrella term for remdediational processes which include bacterial and funghial activities to degrade primarily organic contaminants. Although bioremediation is particularly effective within the field of groundwater remediation (Drenning, 2021), it has also shown to provide enhanced remediation for crude oil contaminated soil (Onwurah, 1999; Wang et al., 2016), pesticicide contaminated soils (Jayaweera et al., 2022), and hydrocarbons (Yergeau et al., 2009).

Another commonly used GRO method is using biochar (Drenning, 2024) which is an emerging technology in the GRO field. Biochar is the by-product that occurs after thermally degrading residual biomass in an oxygen-limited environment, and is commonly used as a soil amendment at contaminated sites. Its physio-chemical properties vary greatly depending on the type of biomass and the temperature used in its production, but general properties include a high porosity, a high organic content, a neutral to basic pH, and a high nutrient content (Drenning, 2024). When looking at the usage of biochar at contaminated sites, it can be seen as a multifunctional material. Firstly, a large portion of the carbon particles in the biochar can be seen as stable, meaning that it can be stored in the soil for long periods of time without being degraded. This provides a sustainable way of carbon storage. Secondly, its high porosity makes it an efficient material to use as an immobilizing agent for both organic and inorganic pollutants (Drenning, 2024). However, it is important to note that biochar does not break down contaminants in the soil or remove them from the soil ecosystem, but instead stabilize and immobilize them. A combination of other phytoremedation techniques are required to achieve a reduction in the soil ecosystem.

When looking at, and comparing, different GRO methods, the purpose of the implementation can dictate which methods that works for a specific contaminated site. When it comes to using biochar in remediation processes, it has been researched as a possible material to immobilize contaminants such as metals (Rodriguez et al., 2019; Lu et al., 2023), poly- and perfluoroalkyl substances (PFAS) (Sun et al., 2023), and biochemical contaminants such as DDT (Denyes et al., 2016; Drenning, 2024). In all of these research projects, the main purpose of using biochar was to make the contaminants bind to the biochar and thus become immobilized. The success rate varied depending on what contaminant was present, but the bioavailability for the investigated contaminants decreased in all of the investigations.

2.4 Ecological Risk Assessment

A common and simple definition of risk is the probability of an event happening multiplied by the scope of the consequences of the event happening (Aven, 2010) or chance and effect as described by Swartjes (2011). There are many different methods for ecological risk assessment that must be adapted depending on the purpose of the risk assessment as the site-specific conditions can vary greatly, but the source-pathway-receptor (S-P-R) approach is a common base for risk assessment modelling. According to Swartjes (2011), a good way to start an ecological risk assessment is to clearly define *protection targets.* The protection target in an ecological risk assessment can vary a lot between different cases and can include for example the soil ecosystem, specific animal species or several species.

When performing an ecological risk assessment, there are two main steps which can be taken to specify the details of the assessment; *exposure assessment* and *hazard assessment* (or *effect assessment)* (Swartjes, 2011). When translating these into the general risk assessment concept, the exposure assessment term can be seen as the probability parameter (i.e., the probability of a hazardous event happening) and the hazard assessment can be seen as the consequence (i.e., the consequences of a hazardous event would have on the protection targets). According to Swartjes (2011), combining these assessment methods can provide direct relationships between soil concentrations and the ecotoxicological effects on the local ecosystems, creating a basis for risk characterization according to the risk assessment paradigm as in Figure 2.

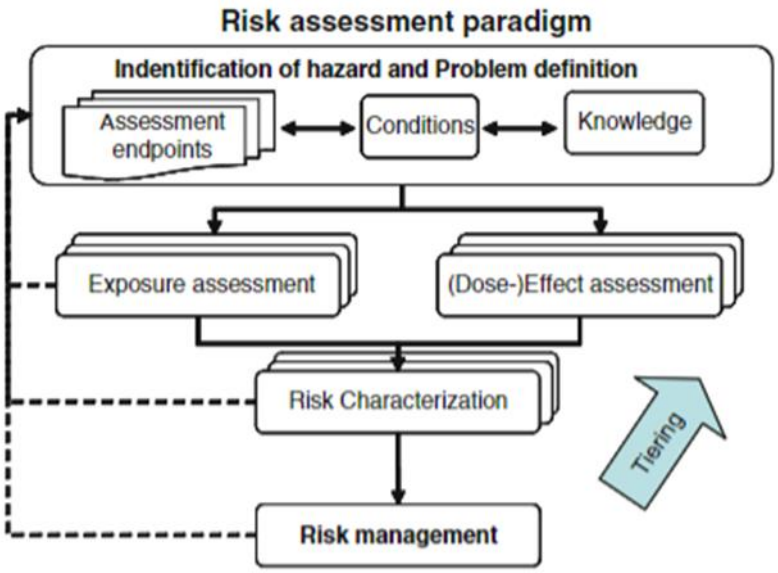


Figure 2: Risk assessment paradigm as described by (Swartjes, 2011).

2.5 Food Web Modelling

Food web modelling is a useful tool to count for the risks of secondary poisoning within the ecological risk assessment and can be particularly applicable when investigating a particular site (Swartjes, 2011). Food webs are a way to depict relationships between species belonging to different trophic levels (McKenney, 2023). The trophic level is decided by the behavioural patterns of the species in their feeding habits and the existing trophic levels can be described as follows:

- Top predators which are highest up in the food chain
- Basal species that are furthest down in the food chain
- Intermediary species that are on different levels in the food chain and thus can be predators or preys to each other.

The different trophic levels and some key features of the inter-trophic relationships are described in the simple conceptual food web model depicted in **Error! Reference source not found.**. The complexity of food web models varies accordingly to the variations in the dietary composition of the species.

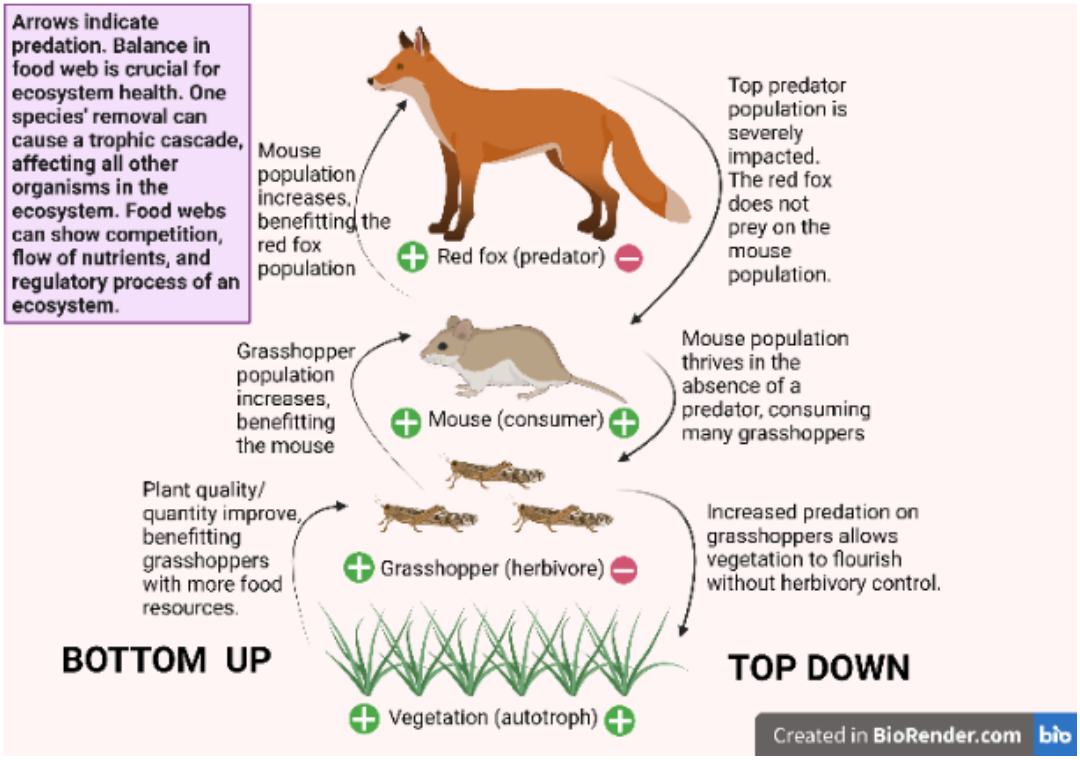


Figure 3: A conceptual model which explains the processes that constitute a food web. Sourced from (McKenney, 2023).

Ecological food web assessments are commonly built upon connectedness webs which assesses the ecological conditions at the site (Preziose & Pastorok, 2008). It typically links different species between (and sometimes within) trophic levels depending on the predator-prey or consumer-food relationships. Rundegren (2019) used species-specific food chains which can be described as a food chain with one specific species (generally a top predator) in focus continuing on its relationships with species from lower trophic levels. The assessment into different combinations of such relationships between the different species of concern in the investigated trophic levels. Though being a simplification of reality, it can be necessary to have a similar species-specific approach since a food web depicting the total ecosystem can be too complicated in assessing the bioaccumulation. Bioaccumulation as a process requires flow webs which is a developed version of a connectedness web that depicts the flows between the species in different trophic levels (Preziose & Pastorok, 2008). The inter-species relationships are commonly between adjacent levels but there are several exceptions as certain predators hunt at different trophic levels. One example is the common buzzard which hunts both different reptiles and predatory birds but also earthworms and insects (Staav & Fransson, 2007) which belong to different intermediate levels. Food webs can be limited in aiming at predicting non-linear and dynamic processes but is a recognized suitable method for toxic chemical bioaccumulation models (Preziose & Pastorok, 2008).

2.6 Secondary Poisoning and Bioavailability

When looking at the exposure throughout the food chain, an important aspect to include is the risk of secondary poisoning. Secondary poisoning can be described as when contaminants are spread from a lower level to a higher level in the food chain by indirect consumption (Gál et

al., 2008). This means that a contaminated site, such as contaminated soil, could have an impact on the entire biological ecosystem that surrounds it.

An important part of exposure assessment is to estimate the *bioavailability* of affected species (Swartjes, 2011). Bioavailability can be described as the fraction of a certain contaminant which can be taken up by a certain organism. Similarly, the *bioaccessibility* fraction determines the oral exposure of contaminants from the food chain. However, the bioaccessibility also includes the fraction of the contaminant, which is released from the digestive tracks, which makes this parameter less relevant when looking at the impact of a certain contaminant (Collins et al., 2015). When it comes to accounting for the bioavailability at contaminated sites in Sweden, the standardized method is to either use general bioavailability factors or to assume that the bioavailability is 100 % (Törneman et al., 2009). However, as the bioavailability of a certain contaminant in reality rarely is 100 %, this can often lead to an overestimation of the potential ecological risks. On the other hand, if the bioavailability factor is instead set too low, there is a large risk of underestimating the ecological risks. To have an as accurate model as possible, it can therefore be beneficial to account for the bioavailability as an unknown factor when building a model.

2.7 Home Range and Territories of Species

Within the field of ecology, it is important to define the home range of different species. The term home range was first defined by William Henry Burt in 1943 and can be described as an individual's home region (Burt, 1943). The main difference between a territory and a home range is that a territory is an area which an individual defends, for example, a bird defending its nest and its surroundings. While a territory is the area that an individual or a family defends, home ranges do commonly overlap between individuals without it being a particular concern for them. Home range should also not be confused with habitat as the habitat describes the right conditions for a species to exist while the home range is the area where an individual within a species exists in practice, though the home range naturally is a subset of the habitat.

The necessity to include home range in a model concerning bioaccumulation stems from the fact that the home range of the species can be seen as an indication of where an individual, or species, hunts for its diet. As the level of contamination can vary greatly over a large geographical area, the bioaccumulation of a contaminant like DDT can also have large variations depending on where an individual's home range is located.

According to Rolando (2002), the home range of a species, or an individual of a species, can vary greatly depending on local conditions which can make home ranges be several times higher in scarcer regions (Rossi, 2019). Rolando (2002) mentions food availability as the primary parameter deciding the home range of an individual, as individuals living in areas where the food is scarce needs to extend their home range to fulfill their energy requirements. There are also several secondary parameters deciding the home range of species. Rolando mentions the structure and type of habitat of an individual as a parameter affecting the home range size. Another important parameter is the preferred habitat structure of different species, such as forest age, tree density, and leafage size, but also the climate conditions such as humidity and temperature as deciding factors for habitat selection. Connected to home range, multiple studies have shown a positive correlation between a smaller home range and the proportion of positively selected habitats within the home range. Further, habitat fragmentation

caused either by natural causes or by human disturbance can also affect the home range as this can cause a change in the local conditions. However, this has not been proven as a general parameter affecting the home range size, but more of an indirect factor for some species. The same goes for a high population density, which can lead to large intraspecies competition for food and resources but can also depend on the abundance of resources within a geographical area. Finally, genetical parameters, such as breeding, sex and age can affect the intraspecies home range. Depending on the species analyzed, the home range has been found to be either larger or smaller during the breeding season. The same goes for the age parameter, as some species have a larger home range as juveniles as they try to find a place to build a nest while others have larger home ranges as adults. When it comes to the sex of a species, many species have low variation in home range between males and females, while others show large variations. There are also large variations between behavioural patterns of different individuals within the same species.

There are several methods to calculate home range. Minimum Convex Polygon (MCP) is the most established method for calculating home ranges and uses the location points where the animal has been spotted and draw lines between them in a polygon shape (Nilsen et al., 2007). However, it can be criticized for overestimating the home ranges compared to other methods (Huck et al., 2008) as home ranges can be irregularly shaped (see Figure 4) and thereby include spaces that are not part of the home range. The method can be said to not necessarily indicate overestimations on a systematic level but rather large uncertainties which can be argued to make MCP an unsuitable method (Nilsen et al., 2007). An alternative way that also is common practice is conducting a Kernel analysis which uses parametric probability distributions (Huck et al., 2008). There are several alternative Kernel estimators, and each of them do also have associated uncertainties, which might be a reason why this method has not been fully adopted. However, despite its limitations, Kernel estimators are also a widely accepted method to calculate home range today (Rossi, 2019).

Figure 4: Illustration of the difference between different home range estimating methods where Minimum Convex Polygon (MCP) are depicted with straight lines and no filling while the Kernel method is depicted with round contours and dots. The MCP method gives a significantly larger home range size. Sourced from: (Huck et al., 2008).

3
Case Study Area

The Kolleberga Forest Nursery is located in Skåne County in the southernmost part of Sweden as in Figure 5) and the site is in turn depicted in Figure 6. The surrounding area is characterized by a variety of forest and agricultural landscapes and between urban and rural areas and the landscape is characterized by a mixture of plain landscape and hills and ridges. The dominating soil geology at the site is glaciofluvial sediment (Tyréns, 2020). It has been used to cultivate forest plants since the 1950s but is currently in the end of a decommissioning process (Tyréns, 2020) where the site currently is in a transition phase before future use will be implemented. DDT was used continuously at the site until the total ban of DDT in Sweden in the mid-1970s. The historical use of environmentally harmful pesticides, such as DDT, at the site has led to continuous excess concentration measurements when comparing to the guideline values for DDT set by Naturvårdsverket (2016). Measurements at the site has shown that the DDT-concentrations are generally higher than the soil guideline values for both KM and MKM (as shown in Appendix A) and a major part of the DDT-contamination has been in humus-rich upper layer (Tyréns, 2020). The site is not in use as a forest nursery today and humans are only present at the site for working purposes and thus, the area is classified as MKM and the general protection value is considered low (Tyréns, 2020). In the context of the ecological risk assessment, the limited human presence at the site is a reason why humans are not considered the main receptor and thus not a main protection object at the site which instead is species living at the site and overall ecosystems. Small-scale grass management is taking place at the site today (Drenning, 2024), but replantation of new forest is scheduled in the future (Tyréns, 2020).

There is an ongoing pilot experiment by Paul Drenning and colleagues has been conducted since 2020 which has investigated how effective biochar potentially can be towards DDT-contamination. The pilot study has systematically investigated different plants representing different phytoremediation strategies (phytostabilization (salix leaves and grass), phytoextraction (pumpkin) and rhizodegradation (legumes)) with and without the addition of biochar to evaluate the remediation capacity of the different strategies on a designated spot on the field, according to a scheme showed in Figure 7, (Drenning, 2024). For the study conducted in this thesis, the pilot experiment managed to provide uptake concentrations of DDT in earthworms, grass, legumes (clover & lucerne), leaves and roots. This has provided a possibility to evaluate the efficiency of biochar as a remediation technique and how implementing it would affect the ecological risk.

Figure 5: Map showing the location of Kolleberga (Red rectangle) in southern Sweden (location in blue in the map in the top right corner) and in Klippan Municipality. © (Google, 2024a).

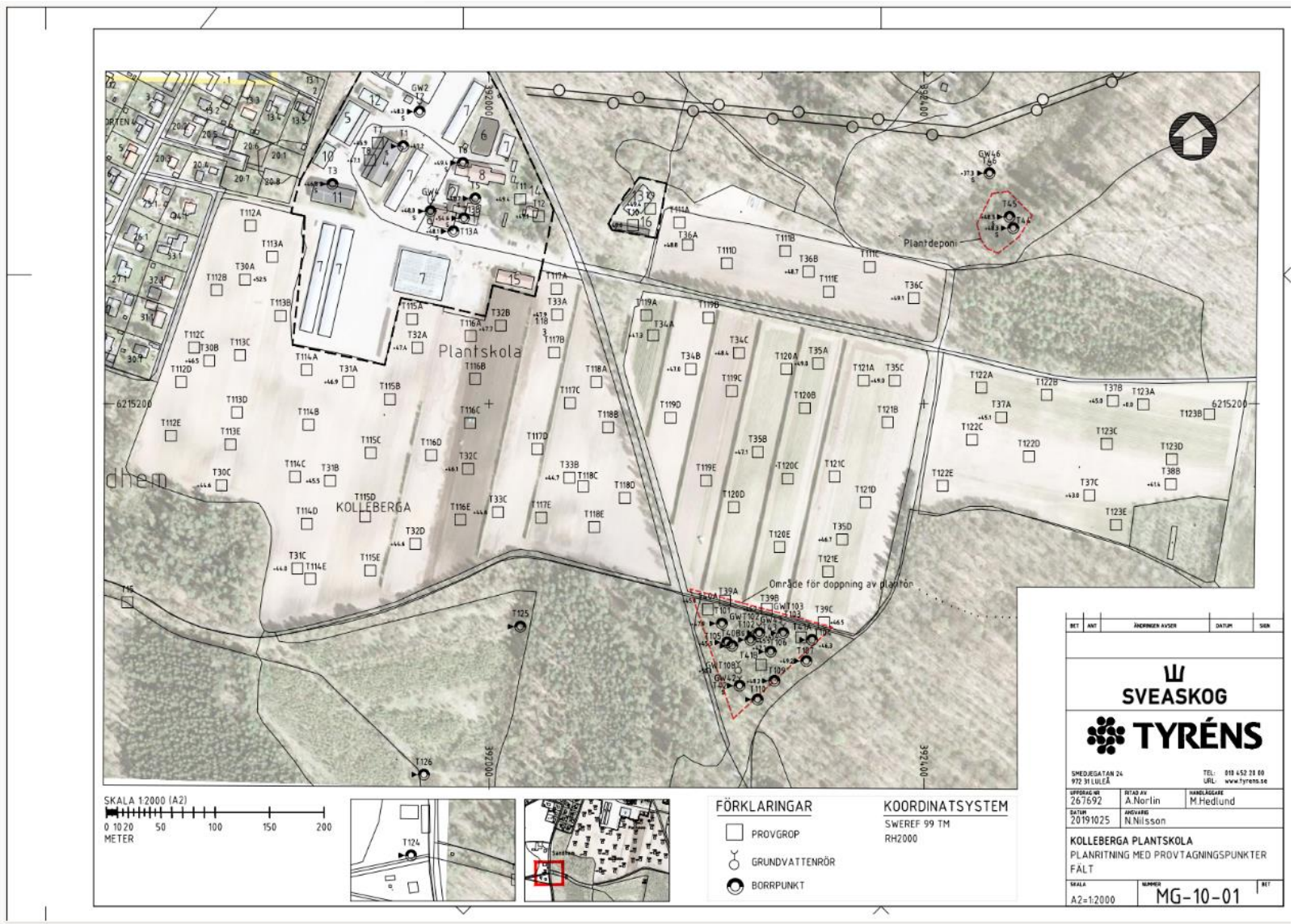


Figure 6: Map showing the area which covers the old forest nursery in Kolleberga. Sourced from: (Tyréns, 2020)

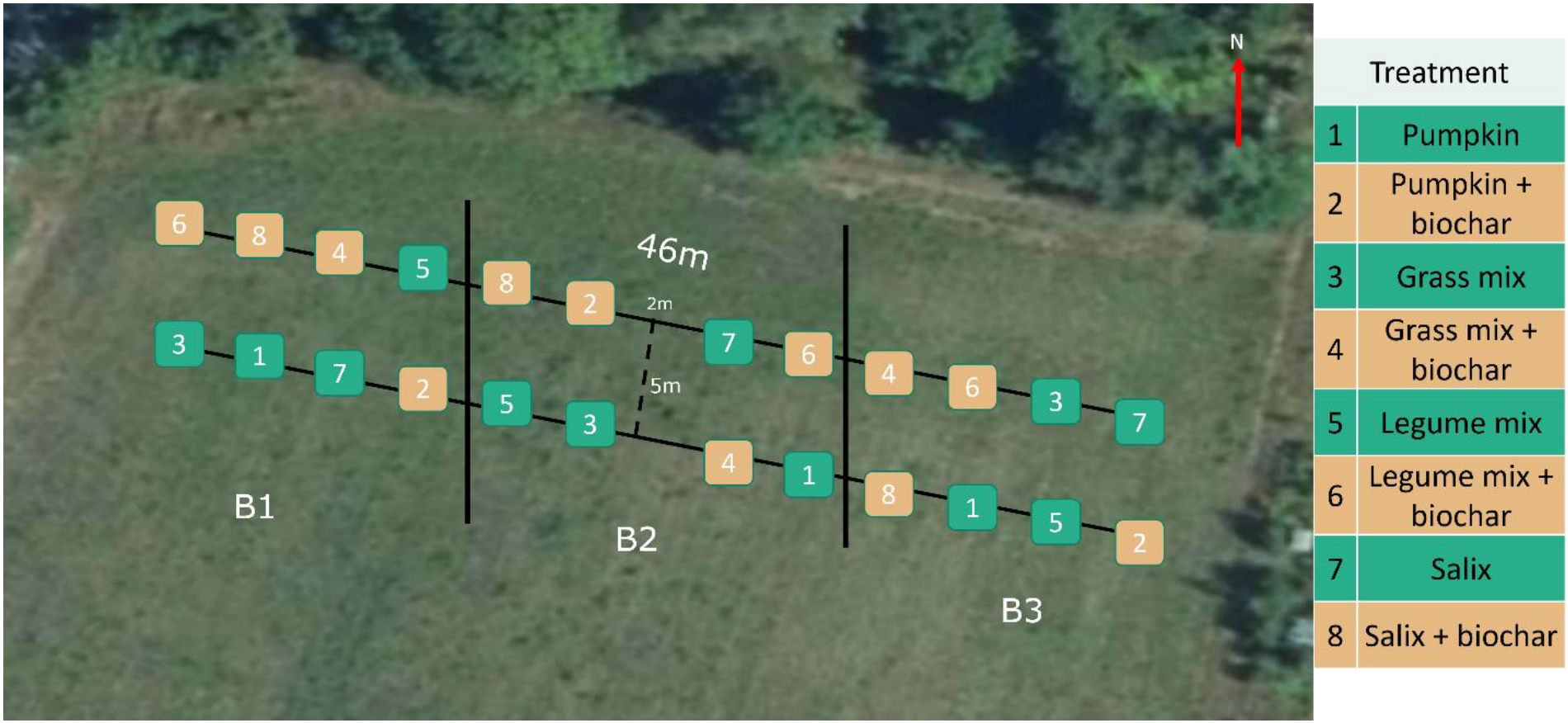


Figure 7: Overview map of the experimental area and treatments in a block design. Treatment numbers 1-8 correspond to the table, orange boxes are where biochar was mixed into the soil. Sourced from Drenning (2024).

4
Methodology

The method chapter describes the working process/methodology for the ecological risk assessment of secondary poisoning for selected top predators at the Kolleberga former tree nursery. An overview of the different steps is presented in Figure 8 and details are presented in the following sections.

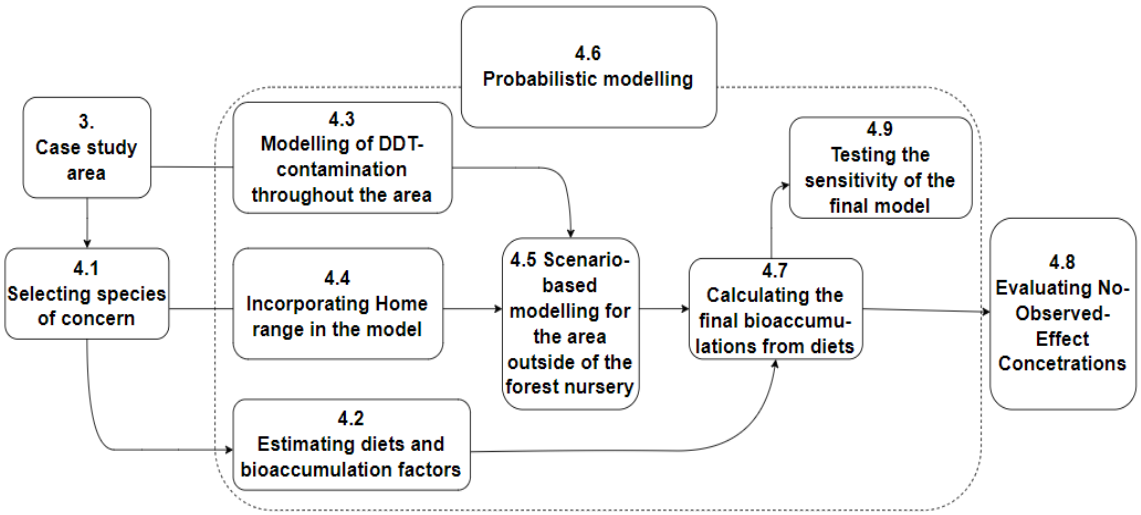


Figure 8: Overview over how the different parts of the method are divided into sections and how they are interconnected to each other.

4.1 Selecting Species of Concern

When selecting the species of concern at the Kolleberga site, the online library Artdatabanken (2024c) was used. Artdatabanken included information about observations made within a selected area, which were used to determine the most found species within a specific radius within the area. The number of observations were analyzed for multiple different radiuses with a center in the forest nursery in the Artdatabanken Search tool (SLU Artdatabanken, 2024c). Some of the most commonly found top predators and animals of prey were chosen from the observation data. The timespan used was from January 2000 to December 2023 to have sufficient data over a long period of time. The final selection was based upon a combination between some of the more observed species in the area and already investigated species from the previous investigation in the area by Rundegren (2019).

4.2 Estimating Bioaccumulation Factors and Diets

The data of DDT-uptake and local soil concentrations from the pilot experiment was used to calculate Bioaccumulation factors (BAFs) from the site using Equation 1. The BAFs calculated

provided single-value BAFs for earthworms, a grass blend, and salix leaves, which were fitted into representative distributions. The process of fitting the data into distributions is further elaborated in Section 4.6.

$$BAF\ [-] = \frac{C_{\sum DDT,i}\ [\frac{mg}{kg}BW]}{C_{\sum DDT,Soil}\ [\frac{mg}{kg}DS]} \qquad \text{(Equation 1)}$$

Where:

- BAF is the bioaccumulation factor [-].
- $c_{\Sigma DDT,i}$ is the DDT-concentration in the analyzed species [mg/kg BW].
- $c_{\Sigma DDT,Soil}$ is the soil concentration in the area where the analyzed species resides [mg/kg DS].

4.2.1 Food Web Modelling

As some of the species selected in this thesis can hunt at multiple different trophic levels, the model in this thesis took this into account. The food web model used followed a bottom-up approach depicting contamination from food item to consumer (McKenney, 2023) and was based on a similar concept to that of Preziose & Pastorok (2008), with included integration of inter-trophic hunting that can skip trophic levels. The food webs in this model followed the basic structure formulated by Jongbloed et al. (1996) (which are shown in Figure 9) which Rundegren (2019) modified by including inter-trophic relationships that skip trophic levels according to available qualitative data. The food webs were then constructed based on the species selected in this thesis. The aim was to achieve an as consistent and accurate depiction as possible of each species' diet which provided a good overview of the chains of which DDT accumulate in them.

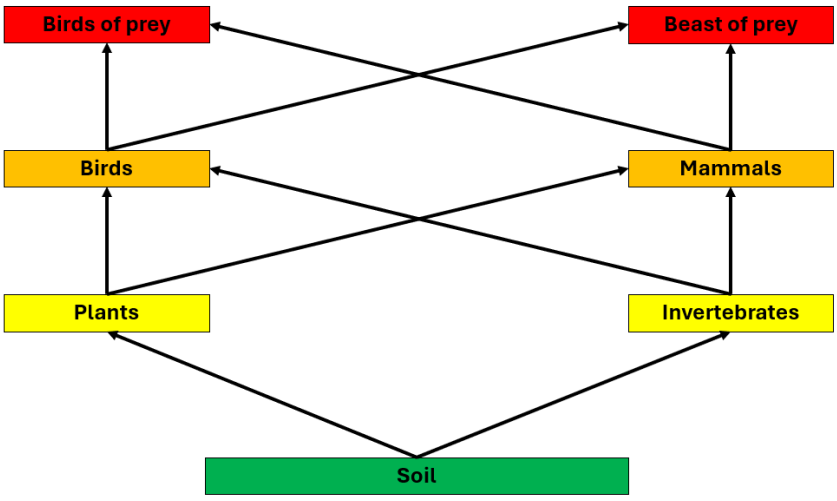


Figure 9: The general transportation chain of DDT transport throughout the ecosystem. Inspired by the model provided by the models found in Jongbleod et al. (1996) and Rundegren (2019).

To obtain an estimation of the local diets of certain species, the book *Nordens Fåglar* (Staav & Fransson, 2007) was used as a primary source for the possible diets of the different bird species, and this was also an important source for the food web modelling. The main reason for this was that it contains information about the local bird ecosystems specific for the Nordic countries. However, as this book only contains qualitative information about the different species that are incorporated within the diet of another species, representative quantitative dietary data was found through a targeted literature search. The diets found in the literature were then divided into different food groups, which were then put into the bioaccumulation model.

4.2.2 Secondary Poisoning Model

To account for secondary poisoning, the effects of multiple different diets from multiple different trophic levels were evaluated for the species of concern. The equation to incorporate this is shown in Equation 2, which is a slightly modified version of the equation provided by Traas et al. (1996).

$$BAF_{TP}[-] = BAF_{Bird} * DF_{Bird} * \sum BAF_{PB,i} * DF_{PB,i} + BAF_{Mammal} * DF_{Mammal} * \sum BAF_{PM,i} * DF_{PM,i} + \sum BAF_{LT,i} * DF_{LT,i} \quad \text{(Equation 2)}$$

Where:

- BAF_{TP} is the final bioaccumulation factor for the top predator [-].
- BAF_{Bird} is the bioaccumulation factor for birds [-].
- DF_{Bird} is the dietary fraction of birds in the top predator's diet [-]
- $BAF_{PB,i}$ is the bioaccumulation factor for each dietary group in the prey bird's diet [-].
- $DF_{PB,i}$ is the dietary fraction of each dietary group in the prey bird's diet [-].
- BAF_{Mammal} is the bioaccumulation factor for mammals [-].
- DF_{Mammal} is the dietary fraction of mammals in the top predator's diet [-].
- $BAF_{PM,i}$ is the bioaccumulation factor for each dietary group in the prey mammal's diet [-].
- $DF_{PM,i}$ is the dietary fraction of each dietary group in the prey mammal's diet [-].
- $BAF_{LT,i}$ is the bioaccumulation factor for each dietary group from lower tiers in the top predator's diet (see Figure 9).
- $DF_{LT,i}$ is the dietary fraction consisting of dietary groups from lower tiers (see Figure 9).

4.2.3 Compiling Dietary Distribution and BAF data

The purpose of the food webs and their connected dietary distributions was to enable the calculation of bioaccumulation that would be the cornerstone of the ecological risk assessment. This required quantitative data about the dietary distributions and the BAFs. Optimally, all quantitative data used should be site-specific and site-specific data has been used when it has been present, which was the case for some BAF data which is presented in Subsubsection 4.2.3.1. The quantitative data that was provided to construct the food webs rarely stated any

numbers indicating the proportions of the dietary compositions which has required data collection which are covered in Subsubsection 4.2.3.2. The rest of the BAFs which covered inter-trophic relationships involving top predators and prey species, does not exist site-specifically either and the collection process of similar data is covered in Subsubsection 4.2.3.3.

4.2.3.1 Current Pilot Experiment

For the Kolleberga forest nursery, the ongoing pilot project provided DDT-uptake concentrations in earthworms, grass, clover, leaves, and roots throughout the site. The BAF values for these were then calculated using Equation 1. Clovers and roots were excluded as these were not found to be a large part of any species' diets. These were then assigned as distributions, the process of which is further developed in Section 4.6.

4.2.3.2 Literature Search About Dietary Distributions

For the analyzed top predators, the calculation of the final bioaccumulation factors needed the dietary compositions. As the food webs only contained qualitative information of each species' dietary compositions, there was a need to obtain information about quantitative data about possible distributions of diets. This was done through a targeted literature review of previous studies which have examined the diets of certain species in different areas. The different types of food were then divided into different categories or food groups.

The aim of the model was to obtain the total bioaccumulation for the top predators and thus, it was also required to calculate the BAFs for the investigated species (see Equation 2). Apart from the collected diets for the top predators, it required representative diets from the prey species. As there was a variety of species that constituted the diets in the literature, it was impossible to include all of them with corresponding dietary distributions. Instead, it was assumed that the prey species were homogeneous enough so that their diets could be represented by single species, one representing the birds, and one representing the mammals.

4.2.3.3 BAF Data from Rundegren and Jongbloed et al.

As sufficient site-specific bioaccumulation data was missing throughout multiple food groups, these were complemented with BAF data used in Rundegren (2019). Rundegren (2019) in turn used the BAF data from the ECOTOX tool (USEPA, 2024) and the data obtained by Jongbloed et al. (1996). The distribution parameters from Rundegren (2019) were used to enable estimations BAF distributions for the different food types where no site-specific data was available. This enabled sufficient, though not site-specific, estimation data for bioaccumulation through the last parts of the food chain. The parameters defining distribution for the BAFs through different food chains can be seen in Appendix B1. The bioaccumulation factor distributions were then used in Equation 4 to calculate the final bioaccumulation factor for the analyzed top predators.

4.2.4 Incorporating the Effect of Biochar

To see how biochar could be used to reduce the ecological risks for the DDT-contamination in Kolleberga, the BAF values were calculated separately for the bioaccumulation of DDT with and without biochar based on the data from the ongoing pilot project provided by Paul Drenning and colleagues (see Appendix C1 for the raw data used from the site). This was done to see how effective the different options of applying biochar potentially could be in reducing the DDT-accumulation throughout each selected species' food chain. The results of the total bioaccumulation through diet were evaluated by comparing the percentual risk of exceeding the hazardous concentrations for each species to the results of not implementing biochar.

4.3 Modelling of DDT-Concentration throughout the area

As the provided datasets (Tyréns, 2020) for the DDT-contamination showed large variations throughout the forest nursery site, the area was firstly divided into subareas. The subareas were selected based on the area of activity during the nursery years and a brief look at the DDT-concentrations on the measurement points in the area. Apart from the available DDT-concentrations from the site, it was also assumed to be important to include the area outside the nursery in the analysis since home ranges both can exceed the borders of the nursery and be smaller. This area was included by assigning it generic scenarios of the DDT-concentration since little is known about them. This is more thoroughly explained in Section 4.5. The model was created with built-in possibilities to interchange the values depending on the available information. The model did not either take the metabolites into account and can be used on any desired measurement values

In the subareas which had measurement points with suspected non-detects (NDs), the NDs were assumed to be equal to the detection limit (ND=DL). This was to decrease the probability of underestimating the ecological risks from the DDT-concentrations in these spots. The sizes of the respective subareas were calculated by using the area drawing tool from Google Maps as the size was an important parameter in conducting a basic spatial analysis.

4.4 Incorporating Home Ranges into the Model

The home range of the selected species was incorporated into the model by assigning it as a distribution and combining it with the average soil concentration throughout the species' hunting grounds. To collect home range data, a targeted literature search was made to find information about home ranges of the selected species, and if possible additional statistical information. The literature search was conducted since there was no site-specific studies about local home ranges in the area around Kolleberga available. The literature search initially aimed at gathering home range data from preferably a relative geographic proximity to Kolleberga. This meant that reports from neighboring countries were regarded as advantageous, but since there are several factors that contribute to the home range conditions (Rolando, 2002), and that there were not an excessively large amount of sources available, sources from a variety of geographical conditions were collected and used.

The collected sources depicting the home range for the species of concern were very heterogenous. One important aspect was the techniques used to estimate the home ranges. Of the studies that mentioned the method to estimate home range, most of them used Minimum Convex Polygon (MCP) and these were used as often as possible to increase the consistency in the compilation. The 90th or 95th percentile MCP (MCP90 or MCP95) were preferred ahead of MCP100. The average home range values were used when specified and if only a home range interval was mentioned, the average value within the interval was used (which was not a totally reliable assumption based on the reports that specified both but considered the most reasonable option for this compilation). The reports which investigated the behaviour of species during the breeding season were generally only considered if they mentioned the home range during non-breeding seasons as it commonly deviates from the usual home range (Rolando, 2002).

4.5 Scenario-Based Modelling for the Area Outside of the Forest Nursery

The home range data of the investigated species were used to calculate how large part of the home range of each species that the Kolleberga forest nursery constituted compared to the areas outside of Kolleberga. To limit the probability of underestimating the ecological risks, the center of home ranges was therefore put in the center of the forest nursery. The reason for this was that the Kolleberga area could be assumed to have much higher DDT-concentrations than the surrounding areas. As the DDT-concentration outside of the forest nursery was unknown, scenario-based modelling was used for the outside concentration. Three different scenarios for the DDT-concentration outside of the forest nursery based on the Swedish soil guideline values (Naturvårdsverket, 2016) were tested. The fourth scenario was a scenario where the home range was limited to the Kolleberga area, and the DDT-concentration outside of the nursery was therefore not considered which was done for comparison purposes with Rundegren's thesis (2019) which made that assumption. The scenarios are summarized in Table 1. The reason for including this scenario was to evaluate the possible ecological risks if an individual only resides at the forest nursery. The different scenarios were evaluated both with and without the effects which implementation of biochar.

Table 1: Differences in outside concentration between the four scenarios for the scenario-based part of the model.

Scenario	**DDT concentration outside nursery**
1	1 mg/kg DS (Limit value for MKM)
2	0.1 mg/kg DS (Limit value for KM)
3	0 mg/kg DS (No DDT-concentration)
4	Entirely on the nursery.

To test the effectiveness of remediation, two different types of remediation were tested. Both scenarios included excavation of the dipping point and the plant landfill and implementing biochar at the site, and a concentration outside of the forest nursery of 0.1 mg/kg DS. The difference between the scenarios was the effectiveness which biochar could have on hard bodied invertebrates, as this was the most critical food group for DDT-accumulation through diet according to Rundegren (2019). The scenarios are summarized in the following bullet points:

- Excavating the dipping area and plant landfill and implementing biochar at the entire forest nursery site. The effects from biochar were assumed to be none for the food groups where no site-specific data was available.
- Excavating the dipping area and plant landfill and implementing biochar at the entire forest nursery site. The effects from biochar for hard bodied invertebrates were assumed to be 50 % similarly to the effects on soft bodied invertebrates.

The DDT-concentrations and the collected home range data was used to calculate an average soil concentration on the species' hunting grounds using Equation 3. It should be noted that the use of this equation assumes that the food intake is equally distributed throughout the whole home range area. Though individuals do not extend their home range without a reason that most often is connected to food availability (Rolando, 2002), the food intake could still be concentrated to a few local dietary hotspots located in the center of the home range which is based on the local conditions.

$$c_{mean,soil}\ \left[\frac{mg}{kg}\right] = \sum_{i=1}^{n=3} \frac{A_{Subarea_i}\ [ha]}{A_{Home\ Range,Total}\ [ha]} * c_{Subarea_i} + \left(\frac{A_{Home\ Range,Total} - A_{Kolleberga}}{A_{Home\ Range,Total}}\right) * c_{outside} \quad \text{(Equation 3)}$$

Where:

- $c_{mean,soil}$ is the average DDT concentration in the soil on the species' hunting grounds. The letter *i* represents the different subareas (i.e. the field area, the dipping and landfill areas, and the built area) of the Kolleberga forest nursery [-].
- $A_{Subarea}$ is the area of the subareas of the Kolleberga forest nursery [km^2].
- $A_{Home\ Range}$ is the area of a specific species' home range [km^2].
- $A_{Kolleberga}$ is the total area of the Kolleberga forest nursery [km^2].
- $c_{Kolleberga,i}$ is the concentration of each subarea of the Kolleberga forest nursery [mg/kg DS].
- c_{outside} is the scenario-based assumed concentration in the area located outside of the forest nursery [mg/kg DS].

The mean soil concentration was then multiplied as a variable into the final equation for the bioaccumulation (see Equation 4) to estimate to what extent the DDT-contamination in Kolleberga could affect the health of each species.

As the home ranges varied a lot throughout the literature, the home range data for some of the species were found to have very large variations. To adjust for this, a weighting was performed by excluding the statistically outlying values as they affected the statistical output on a large scale in a disturbing way. The weighted values were also compared to the original unweighted value to evaluate the difference it made. The excluded values are marked yellow in the compilations of the home ranges which are found in Appendix D.

4.6 Probabilistic Modelling

To estimate the total bioaccumulation, some parameters were included by applying Monte Carlo simulations. The parameters that were simulated in such a process were bioaccumulation throughout all parts of the food chain, i.e., the estimated BAFs for different food groups, the

home range of the investigated species, and the DDT-concentration at the forest nursery. These parameters were defined as probability distributions where the home range parameter was added compared to Rundegren (2019) and the other parameters (DDT-concenctration, some of the BAFs and dietary distributions were modified since then. The process started by performing a Goodness of Fit (G.O.F.) test in the software ©ProUCL 5.2. which tested the values for normal, gamma, and log-normal distributions to see if the values could be fitted to any of these distributions. The G.O.F. generally and consistently showed a high statistical correlation for lognormal distribution for the DDT concentrations and their statistical parameters were thus chosen for the assigned distributions for all subareas. The same process followed for the home range distributions, which showed large variations in distribution between the different species. The dietary fractions were analyzed as point values since the literature was limited and reported large variations in dietary compositions for the species of concern which would make a more detailed statistical test redundant. The dietary fractions were then chosen from the mean values of each food group and rounded to obtain a sum of the dietary fractions totaling to 100 %.

@RISK is a software that accounts for uncertainties in fields involving risks (Palisade, 2024) and the fit tool in @RISK fits values into representative distributions. The bioaccumulation factors (BAFs) were run in the fit tool in for the site-specific values provided by Drenning (2024), Rundegren (2019), and Jongbloed et al. (1996) to obtain the most suitable distribution which were then combined with the point values of the dietary compositions to obtain total BAFs for the top predators. The different statistical parameters that were obtained from the different statistical analyses were used as input values through an input file in Excel. The distributions were assigned as input cells and simulations were then run combining all parameter values as an output cell in @RISK and running a Monte Carlo simulation combining all parameters with 100,000 iterations which obtained distributions of the total bioaccumulation through diet for all analyzed species (see Equation 4). This provided a distribution of the total bioaccumulation for analyzed species which was then used to evaluate the total ecological risks from the forest nursery.

4.7 Calculating the Final Bioaccumulation from Diets

When all the different parameters were incorporated, the final model was set up. The model used to calculate the total bioaccumulation through diet for each food chain is shown in Equation 4.

$$Bioaccumulation_{TP,final}\left[\frac{mg}{kg\ diet}\right] = BAF_{TP} * c_{mean,soil} \quad \text{(Equation 4)}$$

Where:

- BAF_{TP} is the bioaccumulation factor calculated for each top predator [-].
- $c_{mean,soil}$ is the mean soil concentration on each species' hunting grounds [mg/kg DS].

4.8 Evaluating No-Observed-Effect Concentrations

When estimating the No-Observed-Effect Concentration (NOEC) for the selected species, the American knowledgebase ECOTOX (USEPA, 2024) was firstly used to find representative

NOEC values for birds and mammals. To extend the quantity of data for NOECs, the NOEC values provided in Jongbloed et al. (1996) were also added into the NOEC dataset. The process for finding representative NOEC values followed the same procedure as the one in Rundegren (2019). The NOEC data collected from ECOTOX (2024) and Jongbloed et al. (1996) was then fitted into a representative distribution using the fit tool in @RISK and run through a Monte Carlo simulation with 100,000 iterations (like in Section 4.6).

To minimize the probability of underestimating the ecological risks at the site, species-specific correction factors were calculated in the same way as described in Traas et al. (1996). The final correction factors were calculated by correcting for the energy requirement (EMR), the caloric intake of food from different food groups (CC) and the food assimilation energy (FAE). The EMR was provided as a point value while the CC and FAE parameters were estimated by multiplying the dietary fraction of each species of concern with the corresponding correction factor for each dietary group provided in Traas et al. (1996). This provided a specific correction coefficient for each category. The final Correction factor was then calculated using Equation 5. The correction factors for all food groups can be seen in Appendix E.

$$CF_i = CF_{EMR} * CF_{CC} * CF_{FAE} \qquad \text{(Equation 5)}$$

Where:

- CF_i is the final NOEC correction factor for a species [-].
- CF_{EMR} is the correction factor for energy requirement [-].
- CF_{CC} is the correction factor for caloric intake of food [-].
- CF_{FAE} is the correction factor for food assimilation energy [-].

The correction factor was multiplied with extracted values from percentiles of the NOEC concentrations, creating representative values for Hazardous Concentrations (HCs). A standard to evaluate the ecological risks is to use the protection of 95 % of a species population as a threshold (i.e., a HC5 where 5 % of the species population is affected negatively) (Klepper et al., 1998), which was used in this thesis to analyze the ecological risks at the site. The ecological risk in this thesis was evaluated as the probability of exceeding the HC5 for the species analyzed.

4.9 Testing the Sensitivity of the Final Model

As the model included multiple uncertain parameters, a sensitivity analysis was made on the final bioaccumulation distribution to evaluate the parameters too see how much they contributed respectively to the final output for each species and scenario. The sensitivity analysis was made by analyzing the Spearman Rank Coefficients provided directly in the output cell in @Risk. The main objective of performing the sensitivity analysis was to evaluate which parameters that had the largest effects of the results and thereby also achieving an estimation of where more data collection might be needed.

5
Results

This chapter shows the results and sub-results that was obtained throughout this thesis work. The sub-results of selected species and selected subareas are presented in Sections 5.1 and 5.2 respectively. The calculated results from the exposure assessment and hazard assessment are show in Sections 5.3 and 5.4 respectively followed by a sensitivity analysis in Section 5.5.

5.1 Selected Species

The species that were selected were red kite, common buzzard, great spotted woodpecker, common raven, badger and weasel. The birds were chosen due to that they were commonly observed in Artdatabanken (2024c) and had varying dietary habits and interesting characteristics while the mammals were assumed to be less visible, making the observations less reliable. Instead, they were chosen accordingly to the mammals investigated by Jongbloed et al. (1996) and Rundegren (2019) in combination with confirmed presence in the area. The selected species are presented in this section along with some important characteristics.

The chosen prey bird representative was the great tit as it had already been noted to be commonly occurring in the area around Kolleberga. For the mammals, the bank vole was chosen as their representative. This was due to that the rodents had been recognized as a main part of the diets of the investigated top predators and that the bank vole was one of the more commonly featured rodents in the Kolleberga area according to Artdatabanken.

5.1.1 Red Kite *(Milvus Milvus)*

From the taxon lists from Artdatabanken, it was obtained that red kite was the most observed species in the area which was the primary reason for including it as a selected species. It was also the species that Rundegren (2019) added to account for the Kolleberga conditions in comparison to Jongbloed et al. (1996), and the only bird that were present in both Rundegren's thesis and this thesis. The red kites are prevalent in Southern Sweden during the whole year and are thus potentially highly exposed to the contaminated environment in the Kolleberga area. The red kites are known for adapting the diet to what is available where birds have been a slightly more common prey than mammals (Génsbøl, 2006). It can also steal prey from other birds of prey and eat from slaughterhouse waste. When they eat insects, they mostly pick them from the ground.

5.1.2 Common Buzzard *(Buteo Buteo)*

Common buzzards were also discovered to be one of the more commonly observed top predatory species at the Kolleberga area. They do not necessarily stay in the area during the whole year (Génsbøl, 2006), but are present enough in the area for being an interesting study object and it is also generally one of the more common birds of prey in Europe. Buzzards

generally eat rodents but are also omnivores with a preference for mammals. They also occasionally pick earthworms from the ground in a field environment (Staav & Fransson, 2007).

5.1.3 Great Spotted Woodpecker *(Dendrocopos Major)*

The great spotted woodpeckers were also commonly found in the area from the taxon lists. Unlike many other birds of prey, the great spotted woodpeckers receive most of its food from trees in the form of insects and larvae (Staav & Fransson, 2007). They also eat seeds and occasionally juvenile individuals of small birds.

5.1.4 Common Raven *(Corvus Corax)*

The common ravens were also among the more commonly occurring birds of prey in the area. They are known for being omnivorous with changing diets depending on the availability of food, which also include human waste in residential areas but also sometimes insects (Staav & Fransson, 2007). Since ravens have such a variety in their dietary compositions, they will also have very complex food webs. This means that the characteristics of the compositions are very condition-specific and largely depends on the local prey availability.

5.1.5 Badger *(Meles Meles)*

Badgers were among the species that Jongbloed et al. (1996) investigated and which Rundegren (2019) continued to investigate. Badgers are generally nocturnal and shy towards humans and that is probably the reason why they are not as observed by humans as many of the birds tend to be. Badgers' diets generally consist of vegetable parts and earthworms, but they also tend to be omnivorous with very varying diets (Nationalencyklopedin, 2024).

5.1.6 Weasel *(Mustela Nivalis)*

Weasels were existent in the area but have not been very discovered by human observations listed in Artdatabanken. Weasels were also chosen based on presence in Jongbloed (1996) and Rundegren (2019). Though they are considerably smaller than badgers, they are still a very large-scale predator with a very varying diet. They mainly eat rodents and rabbits and also smaller birds (Britannica, 2024).

5.1.7 Great Tit *(Parus Major)*

Great tit was chosen as the representative bird species and is thus significantly smaller than the other investigated birds. Great tits are commonly found in the area around Kolleberga, and they mainly eat caterpillar and other larvae and insects, as well as seeds (Staav & Fransson, 2007), which are along some of the detected food chains. The total bioaccumulation was not examined for the great tits.

5.1.8 Bank Vole *(Clethrionomys Glareolus)*

Bank voles were also investigated since they were assumed to be a representative prey mammal. They mainly eat seeds, fruits, herbs, and other plant parts but also invertebrates and hazelnuts (SLU Artdatabanken, 2024b). They live in different types of forests and mostly on the ground but do occasionally consume their food in trees. The total bioaccumulation was not examined for the bank voles either.

5.2 Site Area Division

An overview over the different subareas is shown in Figure 10 and important characteristics are shown in Table 2. The yellow area corresponds to field area which is the largest part of the nursery and where the tree cultivation occurred. It was considered as a suitable subarea based on its relative homogeneity, which was also noted in the results, where the concentrations of DDT were equally much higher than the limit values for MKM (Tyréns, 2020). The red area corresponds to the dipping area where the preparations for the subsequent pesticide spraying have occurred, as well as a landfill area, where the DDT-concentrations varied but were occasionally very high. The highest DDT-concentrations were located within these two areas, and they can be defined as hotspots. The grey area equals the part of the nursery where there are buildings and where parts of it has been part of the field earlier. The values there were on average lower than on the field (see Appendix A) but almost every measured point still gave higher values than the limit value for KM and MKM. The loam soil in the area has previously been removed which is an important characteristic of the site and the scale of DDT use in that area is not yet sufficiently documented (Tyréns, 2020). The green area is a generic definition of the area outside of the nursery which was considered as a subarea as it constituted a considerable part of the home range of some species and was thereby important to include in this study.

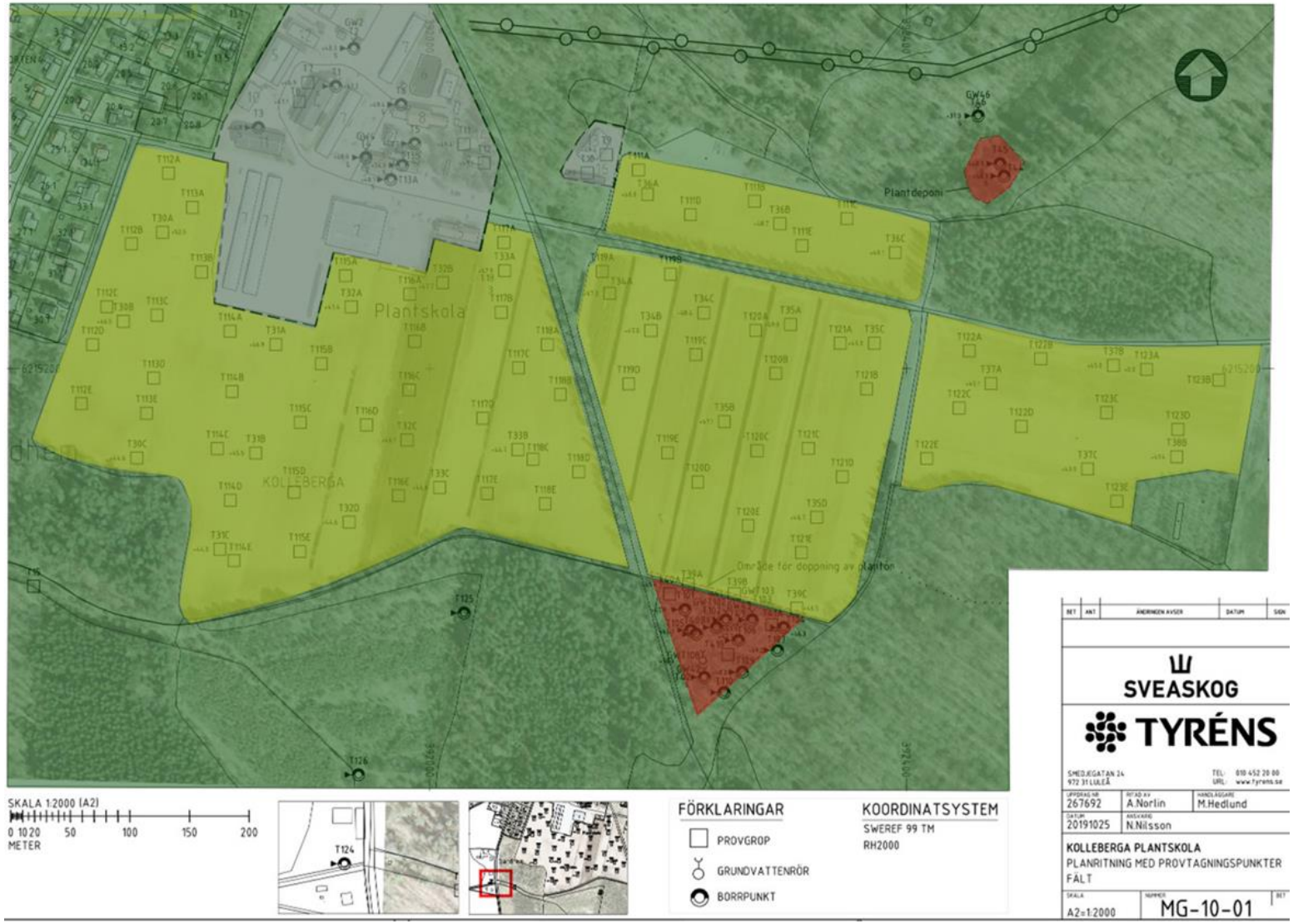


Figure 10: Map based on Figure 6 which depicts the subareas that the area has been divided into. Red is the dipping area (triangle) and landfill area (relative circle). Yellow is the fields. Grey is the area around the buildings that belong to the nursery area. Green is the area outside the nursery.

Table 2: List of the subareas along with their respective area type, size and colour in Figure 10. The area calculations are listed in Appendix F.

Subarea	Area type	Size	Colour
1	Field	0.222 km^2	Yellow
2	Dipping area and landfill	0.010 km^2	Red
3	Built environment	0.051 km^2	Grey
4	Outside area	-	Green

5.3 DDT-Distribution Throughout the Area

The DDT-concentrations were found to have large variations between the different subareas of the forest nursery. The cumulative frequencies of DDT-concentration for all subareas are shown in Figures 11-13. A full list of the defining parameters used to define the DDT-distribution is shown in Appendix B2.

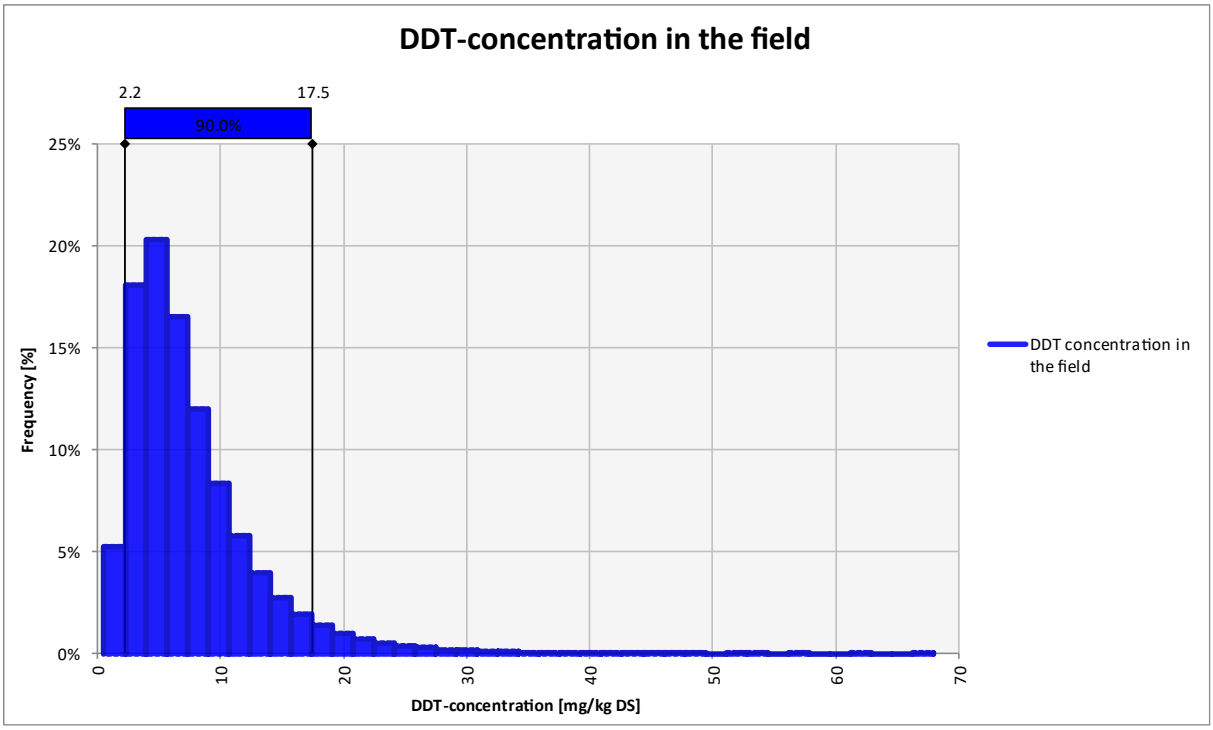


Figure 11: Distribution of the DDT-concentration in the field displayed as the relative frequency of occurrence graph. The figure also shows the values for the upper and lower confidence intervals, marked as point values.

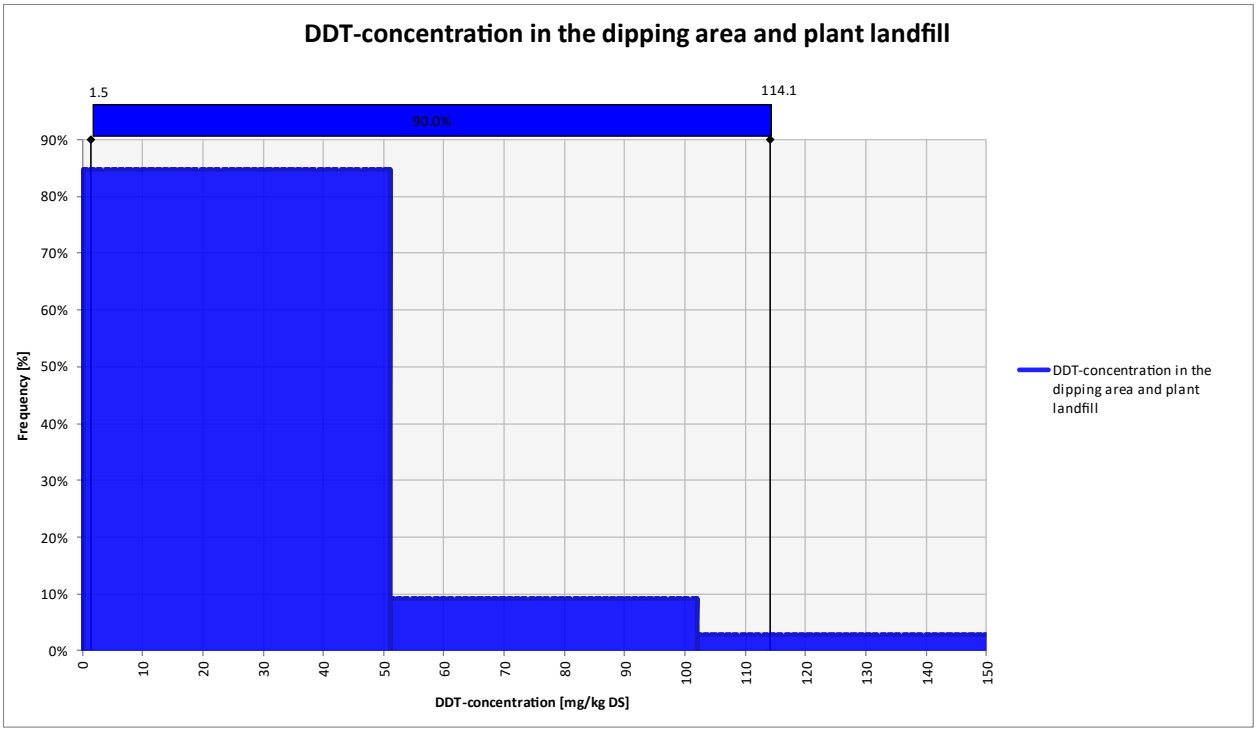


Figure 12: Distribution of the DDT-concentration in the dipping point and landfill, shown as the relative frequency of occurrence graph. The figure also shows the values for the upper and lower confidence intervals, marked as point values.

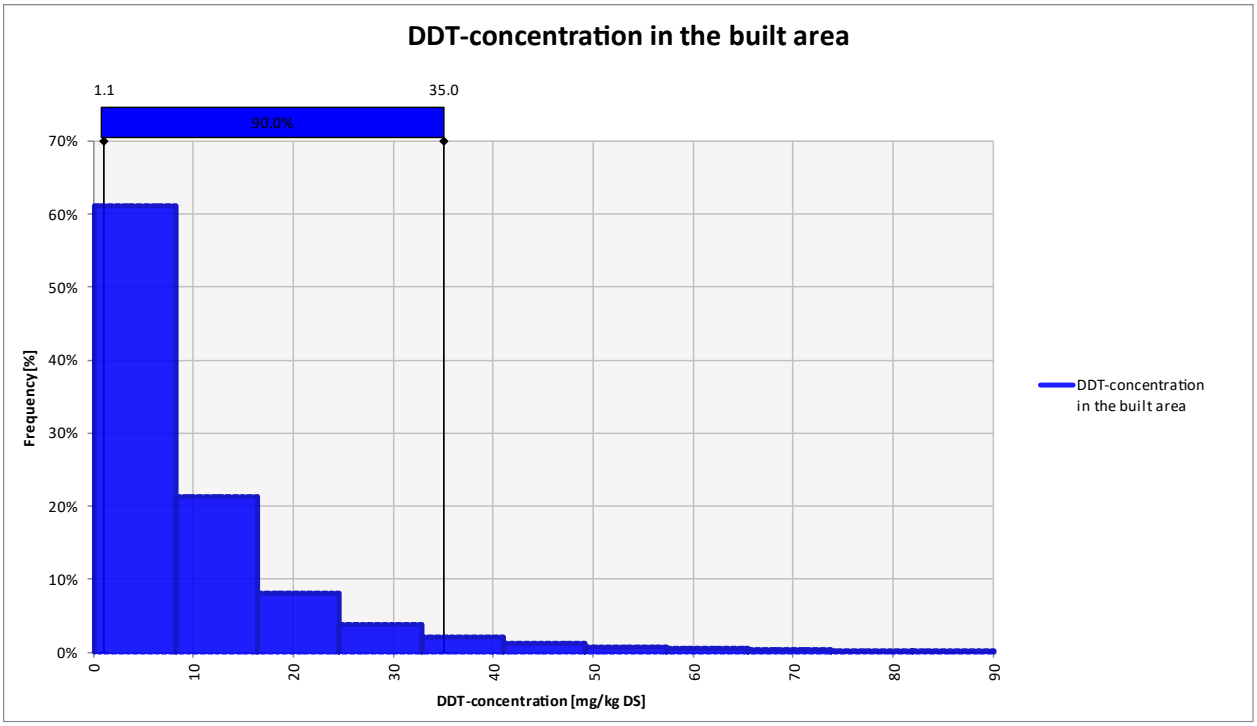


Figure 13: Distribution of the DDT-concentration in the built area displayed as the relative frequency of occurrence graph. The figure also shows the values for the upper and lower confidence intervals, marked as point values.

5.4 Hazard Assessment

This section shows the results of the parameters evaluated in the hazard assessment.

5.4.1 Dietary Distributions

The dietary data showed large variations depending on where the studies were made. They were initially based on the constructed food webs and a complete food web for the common raven is shown in Figure 14. The food web for common ravens does best incapsulate how complicated species-specific food webs can be as ravens have a varying diet from different trophic levels. The food webs for the other investigated species are shown in Appendix G. The calculated average dietary fraction for all the selected species is shown in Table 3. A full list of the data collected from the dietary literature search is shown in Appendix H.

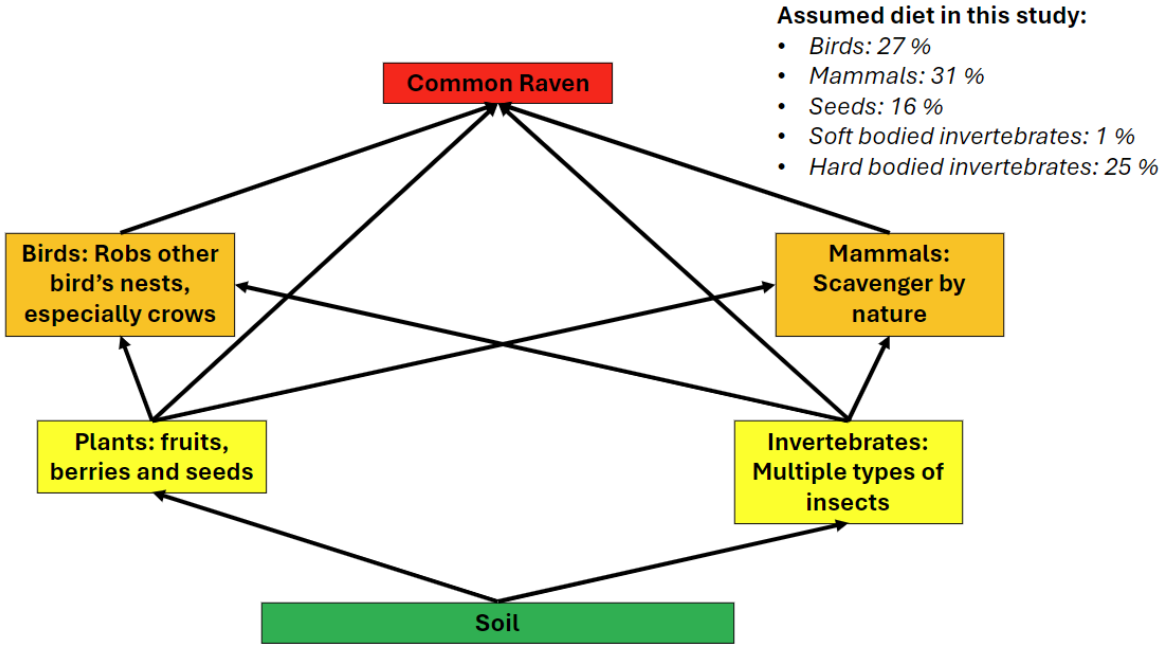


Figure 14: The DDT transport throughout the food chain for a Common Raven (Corvus corax). Qualitative data sourced from: (Staav & Fransson, 2007). Quantitative dietary data estimated from the literature review of dietary compositions (see Appendix H).

Table 3: Final dietary fractions [-] for the selected species, sourced from the literature study shown in Appendix H. The rows marked "lower tier for birds" and "lower tier for mammals" are the assumed dietary compositions from the prey species. The dietary groups which are marked with an asterisk (*) have local BAF data from the Kolleberga site. The assumed dietary fractions for the prey species are marked in italic.

	Badger	**Common Buzzard**	**Common Raven**	**Great Spotted Woodpecker**	**Red Kite**	**Weasel**
Bird	0.03	0.29	0.27	0	0.46	0.1
Soft bodied invertebrates, lower tier for birds*	*0.65*	*0.65*	*0.65*	*0*	*0.65*	*0.65*
Hard bodied invertebrates, lower tier for birds*	*0.35*	*0.35*	*0.35*	*0*	*0.35*	*0.35*
Mammals	0.06	0.71	0.31	0	0.5	0.89
Leaves, lower tier for mammals*	*0.46*	*0.46*	*0.46*	*0*	*0.46*	*0.46*
Grass, lower tier for mammals*	*0.46*	*0.46*	*0.46*	*0*	*0.46*	*0.46*
Seeds, lower tier for mammals	*0.08*	*0.08*	*0.08*	*0*	*0.08*	*0.08*
Grass	0.21	0	0	0	0	0
Seeds	0.18	0	0.16	0.03	0	0
Soft bodied invertebrates*	0.39	0	0.01	0.41	0	0
Hard bodied invertebrates	0.13	0	0.25	0.56	0.04	0.01

5.4.2 Home Range Distributions

The home range data found in the literature showed large variations both between the different analyzed species and within the same group of species. The fitted home range distributions made from fitting the home range data from the literature study are shown in Figures 15-20. All data collected during the literature study are shown in Appendix D.

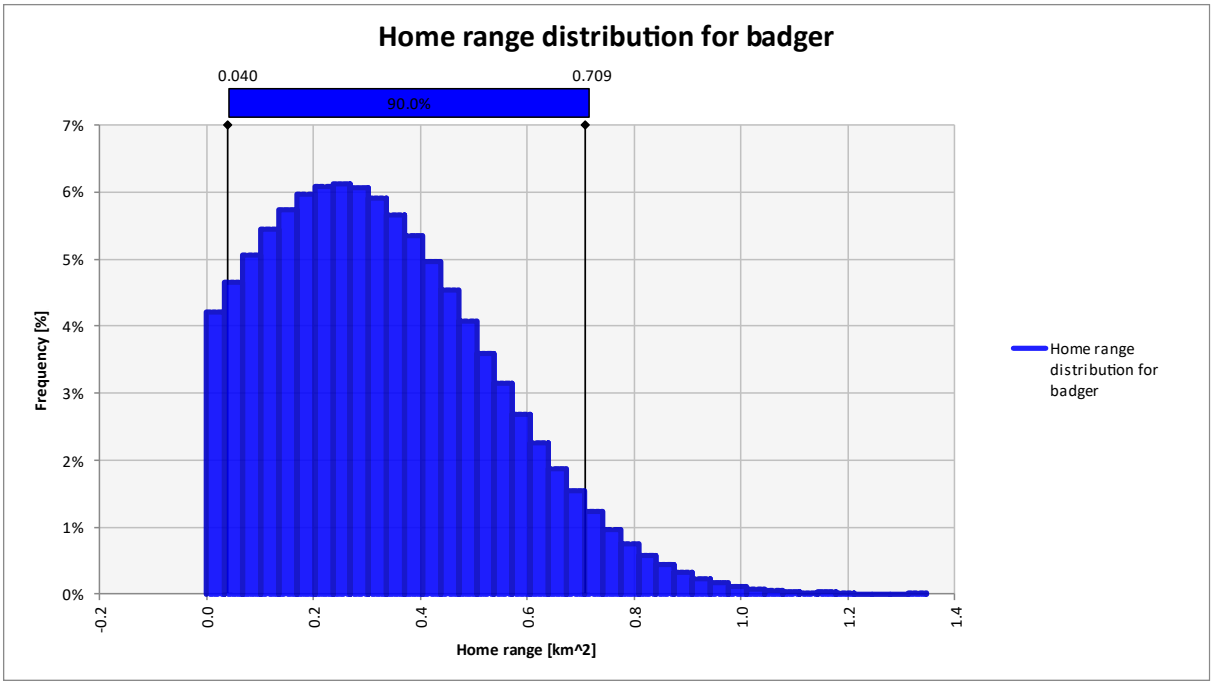


Figure 15: Home range distribution for Badger (Meles meles) [km2] represented as a relative frequency distribution [%]. Fitted from the values from the literature study found in Appendix D5. The ingoing distribution parameters are shown in Appendix B3.

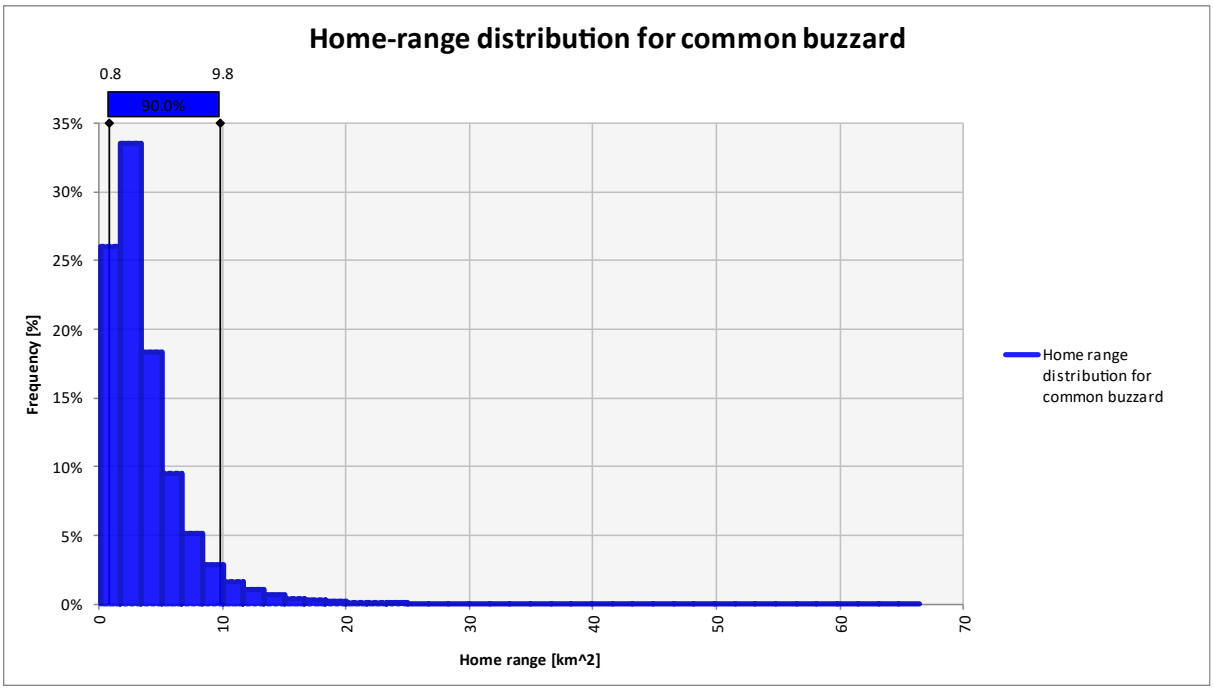


Figure 16: Home range distribution for Common Buzzard (Buteo buteo) [km2] represented as a relative frequency distribution [%]. Fitted from the values from the literature study found in Appendix D2. The ingoing distribution parameters are shown in Appendix B3.

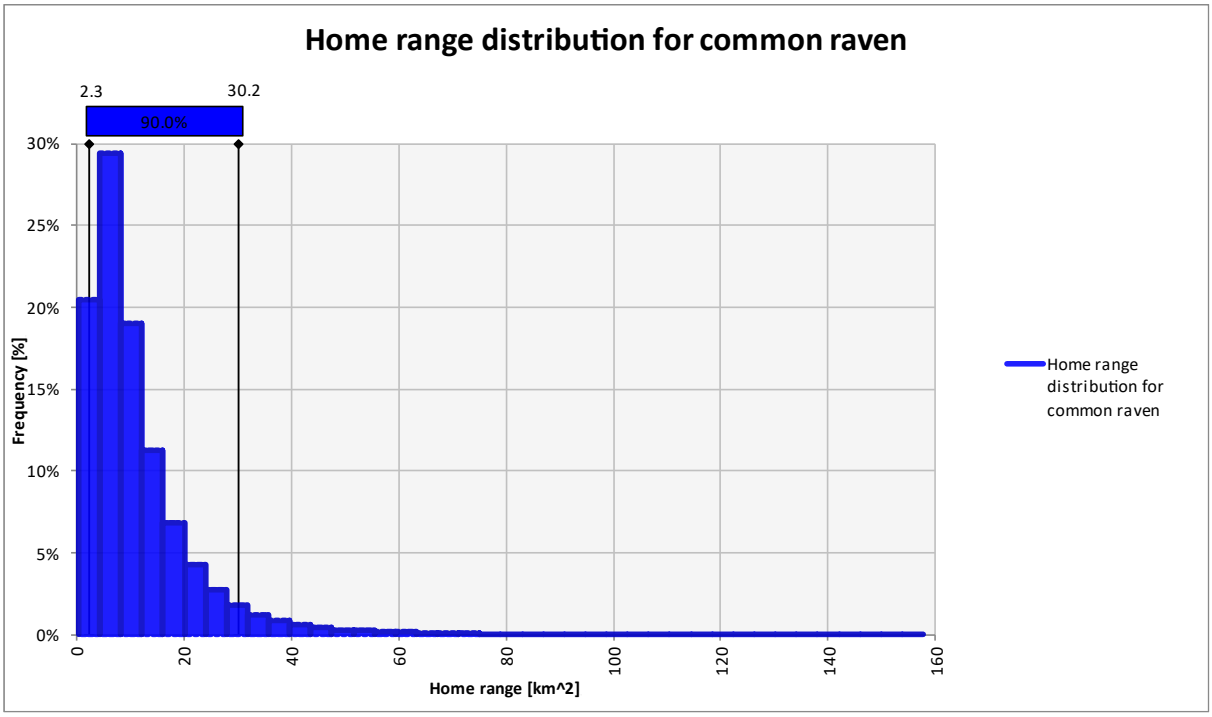


Figure 17: Home range distribution for Common Raven (Corvus Corax) [km2] represented as a relative frequency distribution [%]. Fitted from the values from the literature study found in Appendix D4. The ingoing distribution parameters are shown in Appendix B3.

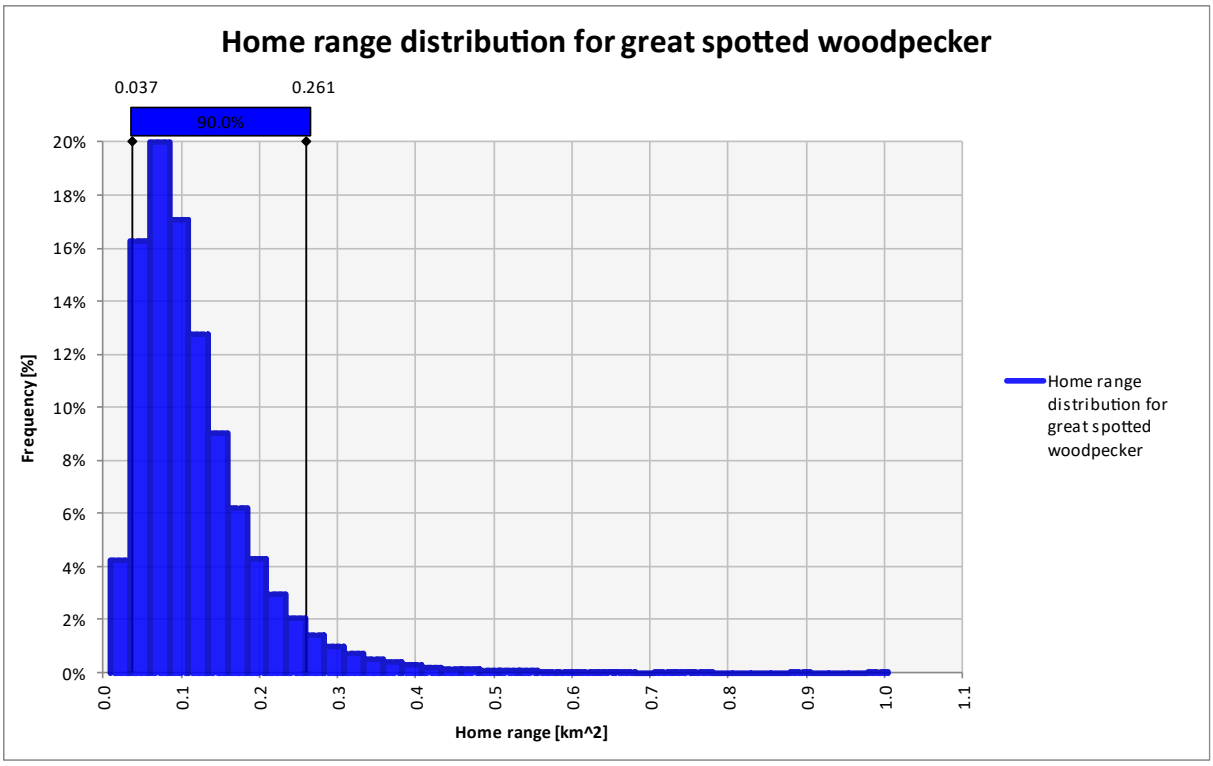


Figure 18: Home range distribution for Great Spotted Woodpecker (Dendrocopos major) [km2] represented as a relative frequency distribution [%]. Fitted from the values from the literature study found in Appendix D3. The ingoing distribution parameters are shown in Appendix B3.

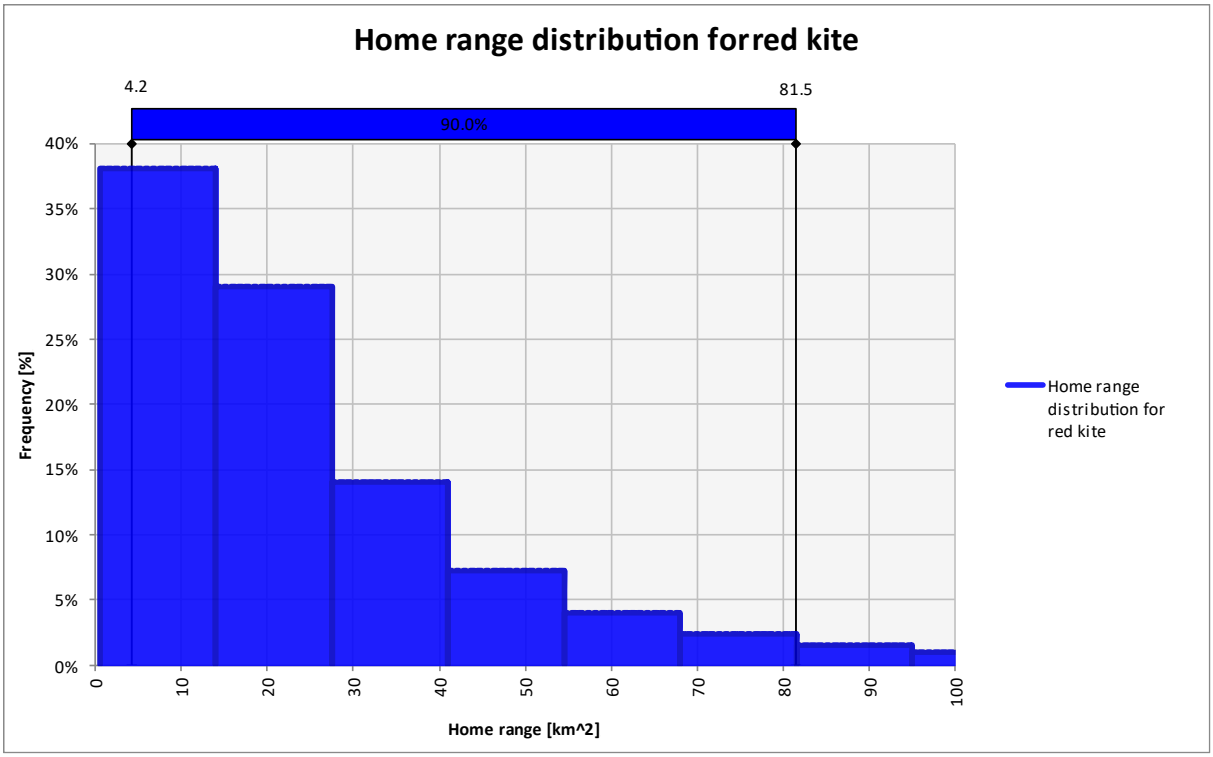


Figure 19: Home range distribution for Red Kite (Milvus milvus) [km2] represented as a relative frequency distribution [%]. Fitted from the values from the literature study found in Appendix D1. The ingoing distribution parameters are shown in Appendix B3.

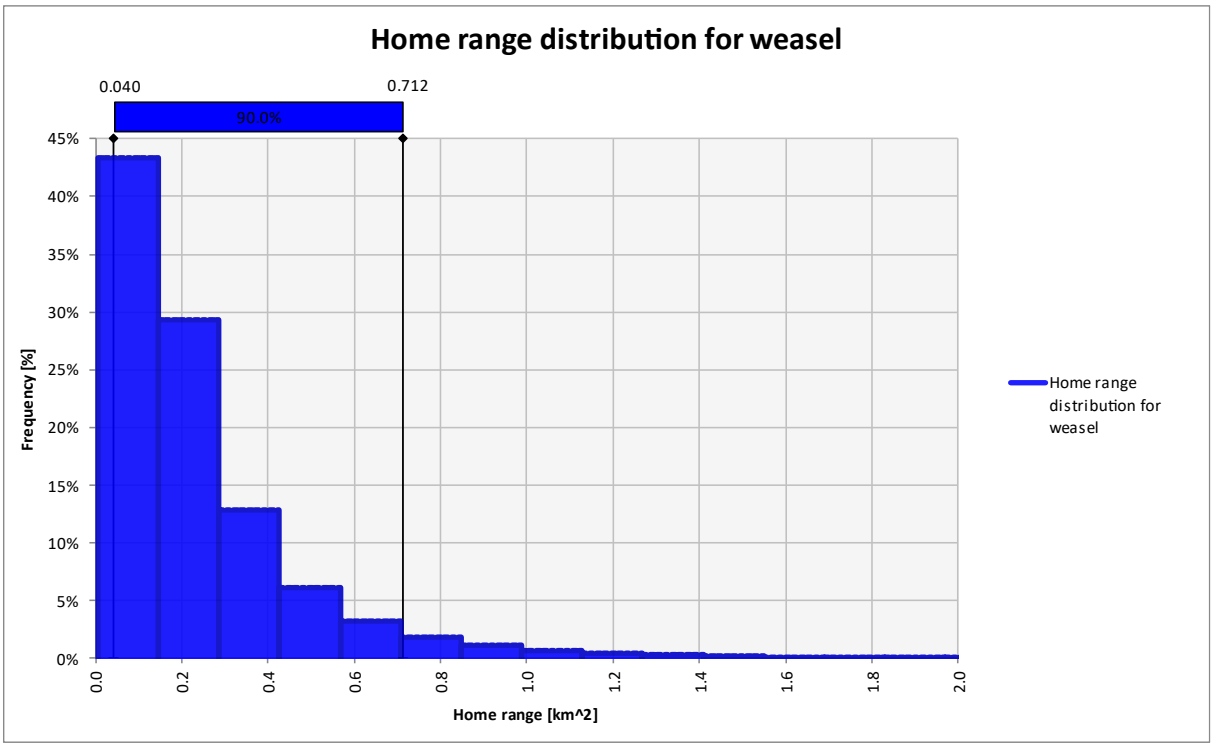


Figure 20: Home range distribution for Weasel (Mustela nivalis) [km2] represented as a relative frequency distribution [%]. Fitted from the values from the literature study found in Appendix D6. The ingoing distribution parameters are shown in Appendix B3.

5.4.3 BAF For Different Food Groups

The BAF distributions for the different food groups are shown in Figure 21. The ingoing defining parameters for the distributions are shown in Appendix B1. The calculated BAFs from Kolleberga are shown in Appendix C1.

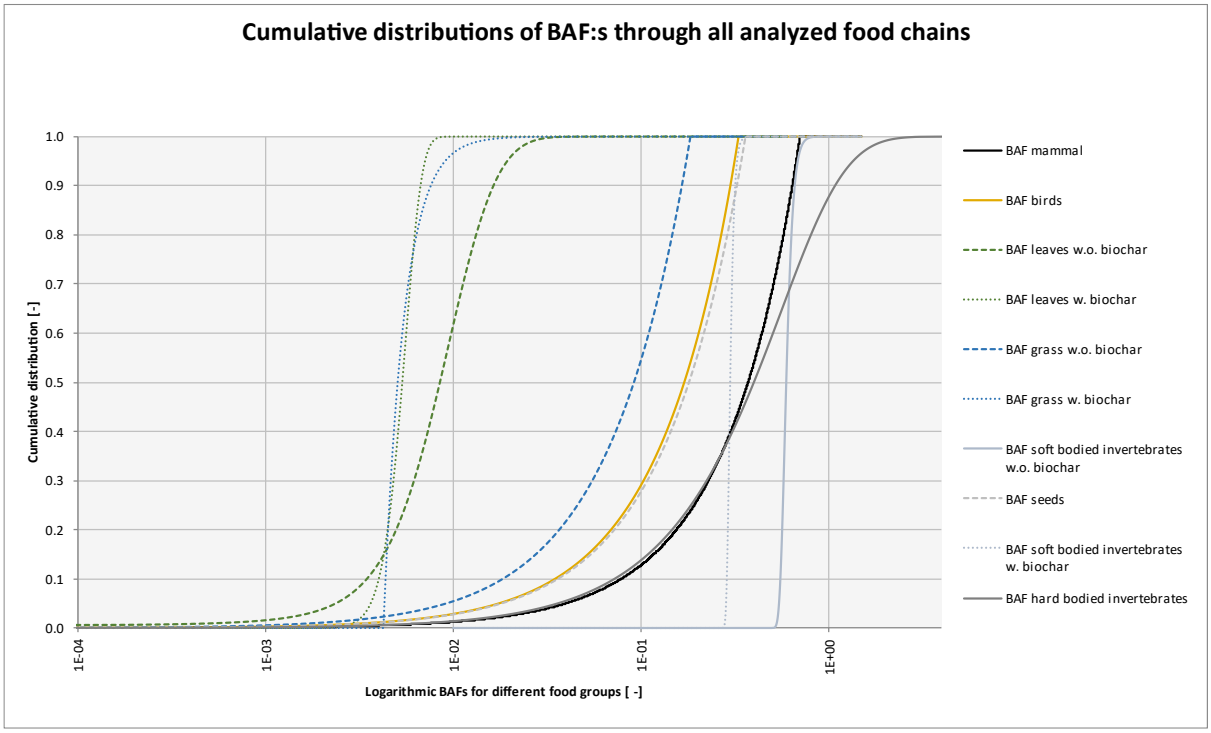


Figure 21: Cumulative distribution of the BAFs for all different food categories analyzed. The parameters which have distributions both with and without the implementation of biochar were from the Kolleberga site, the others were sourced from Rundegren (2019). The parameters defining the BAF distributions are shown in Appendix B1.

As can be seen in Figure 21, the BAF are generally much lower for the cases where biochar was used, indicating that biochar has a lowering effect on the bioaccumulation through diet in the area.

5.4.4 NOEC Distributions

Figures 22-23 show the generic cumulative distribution curves for NOEC for birds and mammals respectively.

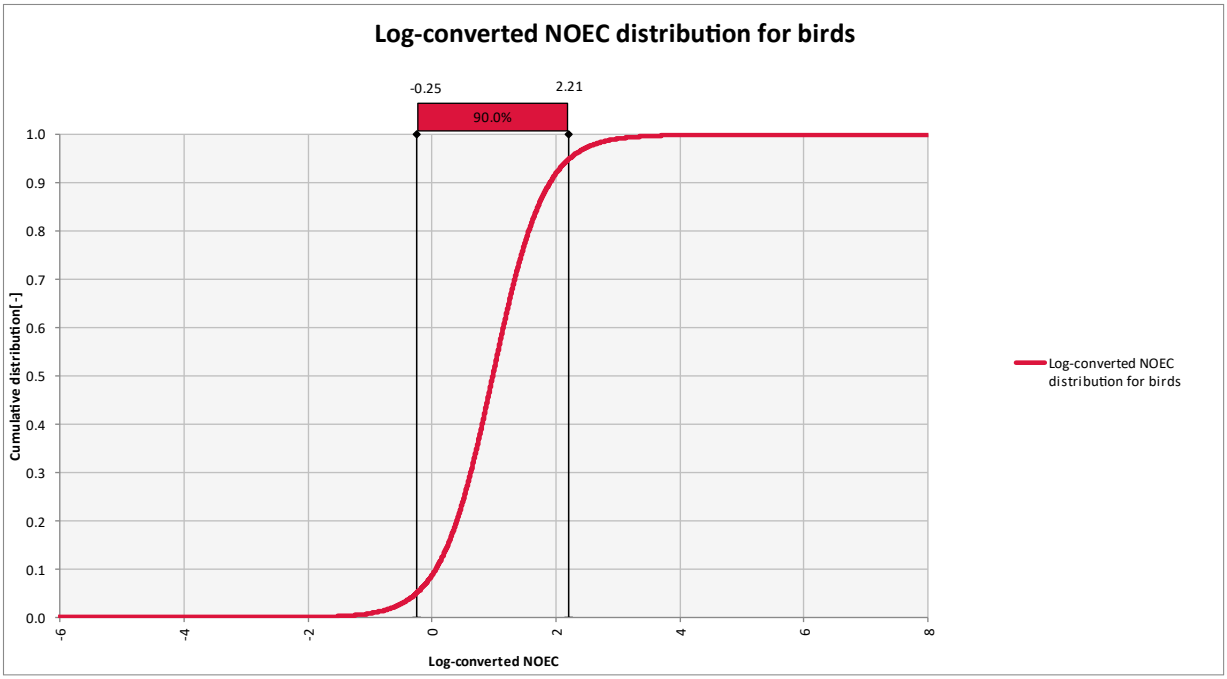


Figure 22: Cumulative distribution of log-converted NOECs for birds, used to calculate the DDT-concentrations for HC5, HC50 and HC95. Log-converted and fitted using the data shown in Appendix I1.

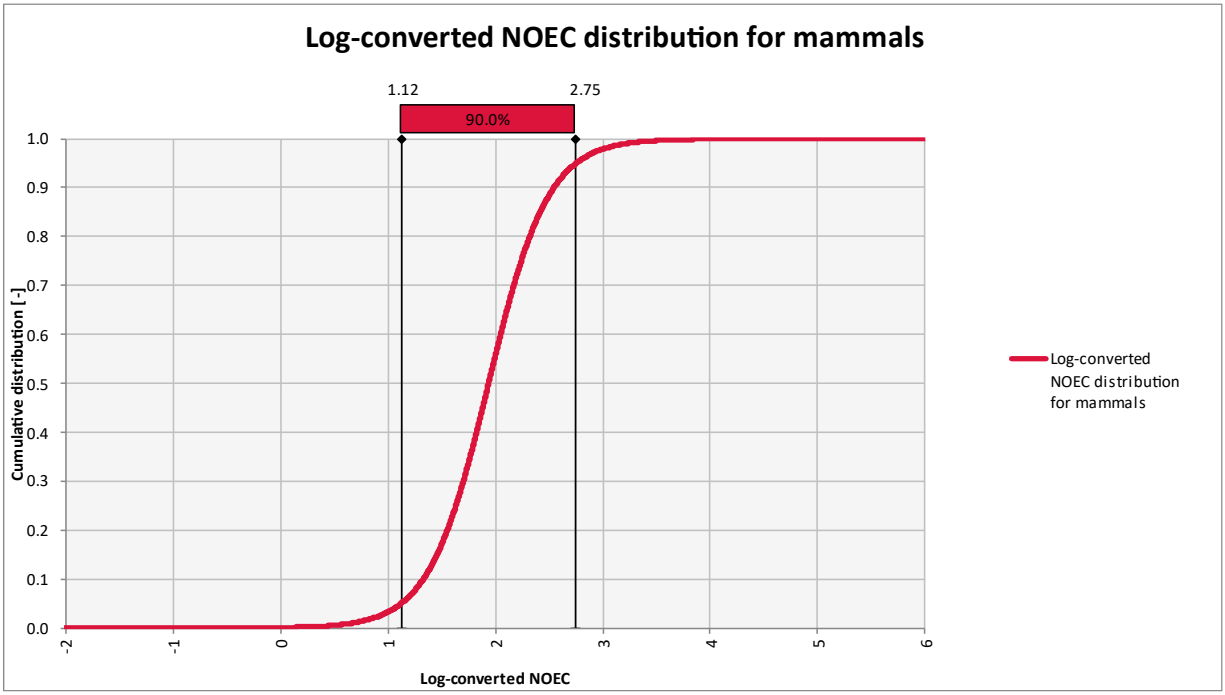


Figure 23: Cumulative distribution of log-converted NOECs for mammals, used to calculate the DDT-concentrations for HC5, HC50 and HC95. Log-converted and fitted using the data shown in Appendix I2.

5.4.4.1 NOEC Correction Factors

The calculated correction factors for each species using Equation 5 are shown in Table 4. The data used to calculate the correction factors is shown in Appendix E.

Table 4: Calculated NOEC correction factors for all selected species using the data provided in Jongbloed et al. (1996).

Species	**Correction factor**
Red Kite	0.22
Common Raven	0.23
Common Buzzard	0.22
Great Spotted Woodpecker	0.16
Badger	0.13
Weasel	0.16

5.4.5 Final Bioaccumulation for the Species of Concenrn

The final bioaccumulation through diet for the different scenarios are shown in sub-chapters 5.4.5.1-5.4.5.4.

5.4.5.1 Scenario 1

Tables 5-6 shows the probability (i.e., the ecological risk) of exceeding the 5:th percentile Hazardous Concentration (HC5) and the 50:th percentile Hazardous Concentration (HC50) for the first scenario with and without biochar. As can be seen from the tables, there was a relatively high probability of exceeding HC5 for badger, great spotted woodpecker, and common raven without biochar, and a very high probability of exceeding HC50 for great spotted woodpeckers. The probability of exceeding HC50 was low for all species except for great spotted woodpecker. When comparing the values from Table 5 with the values in Table 6, it can be seen that the ecological risks decreased for the scenarios where biochar was used for all selected species.

Table 5: The probability of exceeding different hazardous thresholds for the species of concern for scenario 1 without the implementation of biochar, evaluated from calculating the total bioaccumulation through diet. As the evaluation of ecological risk was based on the probability of exceeding HC5, this column is marked in red.

Species	**Correction factor**	**HC5 (mg/kg diet)**	**Probability of exceeding HC5 (w.o. biochar)**	**HC50 (mg/kg diet)**	**Probability of exceeding HC50 (w.o. biochar)**	**HC95 (mg/kg diet)**
Red Kite	0.22	0.123	7.6 %	2.09	<1 %	35.6
Common Raven	0.23	0.128	77.6 %	2.20	<1 %	37.2
Common Buzzard	0.22	0.123	12.2 %	2.09	<1 %	35.6
Great Spotted Woodpecker	0.16	0.0894	100 %	1.52	91.5 %	25.9
Badger	0.13	1.72	62.7 %	11.23	<1 %	73.2
Weasel	0.16	2.12	<1 %	13.82	<1 %	90.1

Table 6: The probability of exceeding different hazardous thresholds for the species of concern for scenario 1 with the implementation of biochar, evaluated from calculating the total bioaccumulation through diet. As the evaluation of ecological risk was based on the probability of exceeding HC5, this column is marked in red.

Species	Correction factor	HC5 (mg/kg diet)	Probability of exceeding HC5 (w. biochar)	HC50 (mg/kg diet)	Probability of exceeding HC50 (w. biochar)	HC95 (mg/kg diet)
Red Kite	0.22	0.123	1.9 %	2.09	<1 %	35.6
Common Raven	0.23	0.128	71.5 %	2.20	<1 %	37.2
Common Buzzard	0.22	0.123	4.8 %	2.09	<1 %	35.6
Great Spotted Woodpecker	0.16	0.0894	100 %	1.52	76.4 %	25.9
Badger	0.13	1.72	32.6 %	11.23	<1 %	73.2
Weasel	0.16	2.12	<1 %	13.82	<1 %	90.1

5.4.5.2 Scenario 2

Tables 7-8 show the ecological risks for scenario 2 without and with biochar respectively. The risk of exceeding HC5 is relatively high for badgers, common ravens, and great spotted woodpecker. The probability of exceeding HC for red kites, weasels and common buzzards were relatively low. The probability of exceeding HC50 is only high for great spotted woodpeckers, which showed similar results as in Scenario 1. Similar to Scenario 1, the implementation of biochar lead to a decrease in the ecological risks for all analyzed species.

Table 7: The probability of exceeding different hazardous thresholds for the species of concern for scenario 2 without the implementation of biochar, evaluated from calculating the total bioaccumulation through diet. As the evaluation of ecological risk was based on the probability of exceeding HC5, this column is marked in red.

Species	Correction factor	HC5 (mg/kg diet)	Probability of exceeding HC5 (w.o. biochar)	HC50 (mg/kg diet)	Probability of exceeding HC50 (w.o biochar)	HC95 (mg/kg diet)
Red Kite	0.22	0.123	<1 %	2.09	<1 %	35.6
Common Raven	0.23	0.128	21.3 %	2.20	<1 %	37.2
Common Buzzard	0.22	0.123	6.4 %	2.09	<1 %	35.6
Great Spotted Woodpecker	0.16	0.0894	100 %	1.52	91.5 %	25.9
Badger	0.13	1.72	60.4 %	11.23	<1 %	73.2
Weasel	0.16	2.12	<1 %	13.82	<1 %	90.1

Table 8: The probability of exceeding different hazardous thresholds for the species of concern for scenario 2 with the implementation of biochar, evaluated from calculating the total bioaccumulation through diet. As the evaluation of ecological risk was based on the probability of exceeding HC5, this column is marked in red.

Species	Correction factor	HC5 (mg/kg diet)	Probability of exceeding HC5 (w. biochar)	HC50 (mg/kg diet)	Probability of exceeding HC50 (w. biochar)	HC95 (mg/kg diet)
Red Kite	0.22	0.123	<1 %	2.09	<1 %	35.6
Common Raven	0.23	0.128	19.4 %	2.20	<1 %	37.2
Common Buzzard	0.22	0.123	2.8 %	2.09	<1 %	35.6
Great Spotted Woodpecker	0.16	0.0894	100 %	1.52	76.1 %	25.9
Badger	0.13	1.72	31.7 %	11.23	<1 %	73.2
Weasel	0.16	2.12	<1 %	13.82	<1 %	90.1

5.4.5.3 Scenario 3

For the third scenario (see Tables 9 and 10), the ecological risks decreased further compared to Scenario 2. For both the case without biochar, there was a relatively low probability of exceeding HC5 for all species except for great spotted woodpecker, badger, and common raven. The implementation of biochar indicated a decrease in the ecological risks for this scenario similarly to Scenarios 1 and 2.

Table 9: The probability of exceeding different hazardous thresholds for the species of concern for scenario 3 without the implementation of biochar, evaluated from calculating the total bioaccumulation through diet. As the evaluation of ecological risk was based on the probability of exceeding HC5, this column is marked in red.

Species	Correction factor	HC5 (mg/kg diet)	Probability of exceeding HC5 (w.o. biochar)	HC50 (mg/kg diet)	Probability of exceeding HC50 (w.o. biochar)	HC95 (mg/kg diet)
Red Kite	0.22	0.123	<1 %	2.09	<1 %	35.6
Common Raven	0.23	0.128	16.6 %	2.20	<1 %	37.2
Common Buzzard	0.22	0.123	6.1 %	2.09	<1 %	35.6
Great Spotted Woodpecker	0.16	0.0894	100 %	1.52	91.4 %	25.9
Badger	0.13	1.72	60.2 %	11.23	<1 %	73.2
Weasel	0.16	2.12	<1 %	13.82	<1 %	90.1

Table 10: The probability of exceeding different hazardous thresholds for the species of concern for scenario 3 with the implementation of biochar, evaluated from calculating the total bioaccumulation through diet. As the evaluation of ecological risk was based on the probability of exceeding HC5, this column is marked in red.

Species	Correction factor	HC5 (mg/kg diet)	Probability of exceeding HC5 (w. biochar)	HC50 (mg/kg diet)	Probability of exceeding HC50 (w. biochar)	HC95 (mg/kg diet)
Red Kite	0.22	0.123	<1 %	2.09	<1 %	35.6
Common Raven	0.23	0.128	15.1 %	2.20	<1 %	37.2
Common Buzzard	0.22	0.123	2.7 %	2.09	<1 %	35.6
Great Spotted Woodpecker	0.16	0.0894	100 %	1.52	76.1 %	25.9
Badger	0.13	1.72	31.6 %	11.23	<1 %	73.2
Weasel	0.16	2.12	<1 %	13.82	<1 %	90.1

5.4.5.4 Scenario 4

For the fourth scenario (see Tables 11 and 12), there was a high probability of exceeding HC5 for all species except for weasel for both the cases without and with biochar. There was still a low risk of exceeding HC50 for all species except for great spotted woodpecker and common raven. When comparing the values from Tables 11 and 12, it can be concluded that the implementation of biochar decreases the overall ecological risks.

Table 11: The probability of exceeding different hazardous thresholds for the species of concern for scenario 4 without the implementation of biochar, evaluated from calculating the total bioaccumulation through diet. As the evaluation of ecological risk was based on the probability of exceeding HC5, this column is marked in red.

Species	Correction factor	HC5 (mg/kg diet)	Probability of exceeding HC5(w.o. biochar)	HC50 (mg/kg diet)	Probability of exceeding HC50 (w.o. biochar)	HC95 (mg/kg diet)
Red Kite	0.22	0.123	90.6 %	2.09	<1 %	35.6
Common Raven	0.23	0.128	>99 %	2.20	24.0 %	37.2
Common Buzzard	0.22	0.123	78.1 %	2.09	<1 %	35.6
Great Spotted Woodpecker	0.16	0.0894	100 %	1.52	91.8 %	25.9
Badger	0.13	1.72	77.0 %	11.23	<1 %	73.2
Weasel	0.16	2.12	<1 %	13.82	<1 %	90.1

Table 12: The probability of exceeding different hazardous thresholds for the species of concern for scenario 4 with the implementation of biochar, evaluated from calculating the total bioaccumulation through diet. As the evaluation of ecological risk was based on the probability of exceeding HC5, this column is marked in red.

Species	Correction factor	HC5 (mg/kg diet)	Probability of exceeding HC5 (w. biochar)	HC50 (mg/kg diet)	Probability of exceeding HC50 (w. biochar)	HC95 (mg/kg diet)
Red Kite	0.22	0.123	82.5 %	2.09	<1 %	35.6
Common Raven	0.23	0.128	>99 %	2.20	21.6 %	37.2
Common Buzzard	0.22	0.123	60.9 %	2.09	<1 %	35.6
Great Spotted Woodpecker	0.16	0.0894	100 %	1.52	76.5 %	25.9
Badger	0.13	1.72	45 %	11.23	<1 %	73.2
Weasel	0.16	2.12	<1 %	13.82	<1 %	90.1

5.4.5.5 Remediation Suggestions

The new probabilities of exceeding HC5 and HC50 after implementing the remediations described in chapter 4.5 is shown in Tables 13-14. As can be seen when comparing the results from the scenario where biochar had no decreasing effect on the BAF for hard bodied invertebrates (Table 13) to the results in scenario 2 after implementing biochar (Table 8), there was a small decrease for all analyzed species. However, after assuming a decrease in BAF of 50 % for hard bodied invertebrates (Table 14) and comparing it to the results in Table 8, the probability of exceeding an HC5 was significantly lowered for many of the species. The most notable decrease was seen for common ravens (from 19.4 % to 7.5 %) and badgers (from 31.7 % to 16.6 %). However, the ecological risks were still high for many of the species, especially great spotted woodpeckers.

Table 13: New assumed ecological risks after excavating the dipping area and plant landfill. Conservative assumption that the effectiveness of biochar has no effect for the parameters where no site-specific data was available. As the evaluation of ecological risk was based on the probability of exceeding HC5, this column is marked in red.

	HC5 (mg/kg diet)	Probability of exceeding HC5	HC50 (mg/kg diet)	Probability of exceeding HC50	HC95 (mg/kg diet)
Badger	1.72	29.3 %	11.23	<1%	35.6
Common Buzzard	0.123	2.2 %	2.09	<1%	35.6
Common Raven	0.128	16.4 %	2.20	<1 %	37.2
Great Spotted Woodpecker	0.0894	100 %	1.52	75.7 %	25.9
Red Kite	0.123	<1 %	2.09	<1 %	35.6
Weasel	2.12	<1 %	13.82	<1 %	90.1

Table 14: New assumed ecological risks when assuming an effectiveness of 50% decrease in BAF for hard bodied invertebrates when implementing biochar and excavating the dipping area and landfill. As the evaluation of ecological risk was based on the probability of exceeding HC5, this column is marked in red.

	HC5 [mg/kg diet]	**Probability of exceeding HC5**	**HC50 [mg/kg diet]**	**Probability of exceeding HC50**	**HC95 [mg/kg diet]**
Badger	1.72	16.6 %	11.23	<1%	35.6
Common Buzzard	0.123	2.2%	2.09	<1%	35.6
Common Raven	0.128	7.5 %	2.20	<1 %	37.2
Great Spotted Woodpecker	0.0894	100 %	1.52	60.9 %	25.9
Red Kite	0.123	<1 %	2.09	<1 %	35.6
Weasel	2.12	<1 %	13.82	<1 %	90.1

5.5 Sensitivity Analysis

The sensitivity analysis showed large variations in the most sensitive parameters depending on which species and scenario that was analyzed. For the Scenarios 1, 2 and 3, the home range and the BAF for the largest food group (BAF_{Bird} for red kite and common buzzard, and $BAF_{Hard\ bodied\ invertebrates}$ for common raven) had the highest influence on the final bioaccumulation distribution when analyzing the Spearman Rank Correlation Coefficients for the species with larger home ranges (common ravens, common buzzards and red kites). For badgers and weasels, the DDT-concentrations in the field and built area had the highest influence the final bioaccumulation distribution. Finally, for the great spotted woodpecker, $BAF_{Hard\ bodied\ invertebrates}$ had the highest influence on the final bioaccumulation distribution. The most sensitive parameters were similar for the analysis made both with and without biochar. For the Scenario 4, the DDT-concentration in the field had the highest influence on the final bioaccumulation distribution for all species except for common ravens and great spotted woodpeckers where the $BAF_{hard\ bodied\ invertebrates}$ was the most sensitive parameter. Correlation coefficients for all species and scenarios are shown in Appendix J.

6
Discussion

This chapter provides a brief summary about key results in Section 6.1 and a comparison with the model structure and results from Rundegren's thesis is discussed in Section 6.2. More thorough discussions about certain parameters are found in Section 6.3 and an outline about future site management in relation to the model and the results presented in thesis is described in Sections 6.4 and 6.5.

6.1 Results Discussion

As seen in Tables 5-10, the probability of exceeding HC50 is very low for all selected species except for great spotted woodpeckers for all scenarios incorporating the home ranges of species, both with and without the inclusion of biochar. However, the probability of exceeding HC5 was still high for many of the species for all these analyzed scenarios. As this can be seen as too high of a risk to neglect, remediation could still be argued to be necessary.

When comparing scenarios 1-3 (see Tables 5, 7, and 9 for the scenarios without implementing biochar and Tables 6, 8, and 10 for the scenarios with the implementation of biochar), the ecological risks decreased with a low outside concentration for the species with home ranges significantly larger than the area of the forest nursery (i.e., red kite, common raven, and common buzzards). This indicates that the home range have a decreasing effect with the assumption that the concentrations outside of the forest nursery are significantly lower than at the site. This is likely due to the fact that the area of the forest nursery becomes a smaller part of the species feeding grounds with an increasing home range, making the impact of the contamination smaller. For the species with smaller home ranges (i.e., badgers, weasels, and great spotted woodpeckers), the ecological risks were similar, making the impact of the home ranges smaller.

In Scenario 4 (see Tables 11-12), the probability of exceeding HC5 was considered to be high for all analyzed species except for weasels, while the risk of exceeding HC50 was considered low for all species except for common raven and great spotted woodpecker. However, this scenario was not part of the original model as it did not include the home range of species and was only added to be able to compare the results from using this type of modelling to the results from Rundegren (2019). This scenario is discussed in Section 6.2.

As seen in Figures 11-13, there was a large variation in DDT-concentration between the different subareas analyzed. Further, the distributions of DDT had large variations within the subareas as well. This was likely due to local extreme values being within some subareas, such as the measurement points with the highest and lowest concentrations both being within the dipping area (see Appendix A). This made the concentrations difficult to fit into representative distributions, possibly leading to the low or high values having a large effect on the final distribution.

When looking at the total bioaccumulation through diet for great spotted woodpeckers and weasels, the ecological risk was very high and very low respectively and stood out from the rest of the results. Possible reasons for this are discussed in subsections 6.1.1-6.1.2. The effectiveness of biochar is covered in Subsection 6.1.3.

6.1.1 High Ecological Risk for Great Spotted Woodpecker

For the great spotted woodpecker, the high probability of exceeding HC5/50 is likely due to a combination of small home range and specific diet. As the literature data of the home ranges for great spotted woodpeckers was smaller than the area of the forest nursery, the average DDT-concentration on their hunting ground was assumed to be the average concentration throughout the forest nursery site for all scenarios. However, it can be assumed that a great spotted woodpecker would not reside solely at the forest nursery site when looking at the preferred habitat conditions as most of the site consists of grass fields. This might have led to an overestimation of the total bioaccumulation. An alternative way to examine the ecological risks could be to instead place the home range center at different parts of the forest nursery site and calculate an average DDT-concentration in the assumed home range. It is however important to note that the most forested area at the site is located around the highly contaminated dipping area, increasing the likelihood of great spotted woodpeckers residing in the most critical parts of the area. Since these hotspot areas are geographically small, the outside area can also be assumed to be a larger part of the home ranges, with unknown, but probably positive, consequences regarding DDT-concentrations.

Further, the diet composition for great spotted woodpecker was found to largely (56 %) consist of hard bodied invertebrates, which was found to be the most critical food chain for DDT-accumulation in Rundegren's thesis (2019). Due to the lack of data, BAF data for hard bodied invertebrates was collected with the same methodology as used by Rundegren, where the BAF data was not separated between species residing in the soil and species residing in the surrounding vegetation. As great spotted woodpeckers can be assumed to consume most of its caloric intake in the form of organisms residing in the vegetation (in trees), including soil living organisms might lead to an overestimation of the bioaccumulation through diet as these organisms are exposed to the contaminant directly at its source.

6.1.2 Low Ecological Risk for Weasel

In contrast to woodpeckers, the ecological risks for weasels were low for all the scenarios analyzed (see Tables 5-12). This is primarily due to dietary differences. Firstly, the total BAF for weasels was very low. This was likely due to a combination the dietary compositions of the lower tier prey species (great tit and bank vole), which had large variations in comparison to Jongbloed et al. (1996) and Rundegren (2019), and the lower tier BAFs which were generally lower than those calculated by Rundegren (2019). This might have led to a systematic underestimation of the total ecological risks, and more precise dietary compositions from the area might be beneficial to make a more accurate estimate.

6.1.3 Effectiveness of Biochar

The effectiveness of GRO was evaluated by studying the effectiveness of implementing biochar at the site, and it can be concluded that biochar generally lowers the bioaccumulation through diet, as it lowers the BAF from the soil to the lower tier food groups analyzed in this thesis. However, the percentual decrease of BAF varied depending on the food group analyzed (between around 50 % for earthworms, and around 135 % for grass). However, more site-specific data from other food groups would make the results more accurate for the Kolleberga site specifically. This is further discussed in sub-section 6.3.4.

6.2 Comparison to the Results from Rundegren's Thesis

When comparing the results from this thesis to the study made by Rundegren (2019), the ecological risks calculated for all scenarios in this thesis are generally much lower than the ones calculated by Rundegren for badgers, weasels and red kites. This was especially apparent for the final bioaccumulation through diet for weasels, which showed almost no risk of exceeding neither HC5 or HC50. This can be due to multiple different factors, which will be discussed in the following sections.

A large difference between the model used in this thesis compared to the one developed by Rundegren (2019) is the handling of the values of the DDT-concentration at the site. This thesis had an early focus on identifying the hotspot areas for DDT-concentration (i.e., the old dipping point and the plant landfill) and dividing the area into subareas. The distributions of DDT-concentration were then assigned to each subarea individually. Rundegren did instead assign a distribution for the DDT-concentration throughout the entire area of the forest nursery, which might have caused the DDT-concentrations measured in the DDT hotspots to have a large influence on the final results. This becomes especially apparent as Rundegren connected the total bioaccumulation through diet to the DDT-concentration through the food chain to the soil concentrations by calculating Maximum Permissible soil Concentrations (MPCs) to estimate the final ecological risks. This might have caused an overestimation of the ecological risks in the study made by Rundegren in comparison to this thesis.

Another parameter with large variation between the studies are the dietary fractions of the species' diets. As the dietary studies were made independently between this thesis and Rundegren's thesis (2019), the dietary distributions varied a lot between the studies. As there are large differences between the bioaccumulation factors depending on the diet consumed, this could cause large variations in the calculations of species-specific BAFs. Other parameters affecting the calculated lower tier BAFs for the species are the BAFs for the different food groups. The site-specific BAF data used in this thesis showed large variations comparing to the lower tier BAF data which was used in Rundegren, causing large variations when calculating the BAF for the top predators.

6.3 Model Uncertainties

As the model includes a lot of uncertainties, these need to be addressed. A discussion about the parametric uncertainties is shown in this sub-chapter.

6.3.1 Uncertainties in DDT-Concentration

The DDT-concentration values measured on the site were assumed to be reliable and division into subareas was assumed to make the distribution more representative. However, there was a large variation in measured concentrations in the dipping area and plant landfill since both extreme high and extreme low values existed on the area. It is known that the dipping area and plant landfill are hotspot areas, which makes it reasonable to assume high values. There was no clear explanation as of why some values were extremely low. The answer can perhaps be connected to the disposition of the dipping area but could be subject of further analysis.

The DDT-concentration outside the nursery was also a major uncertainty as there were no available measurements covering the area. The outside concentrations were thus put in three different scenarios (with 0; 0.1; 1 mg/kg DS respectively) which were assumed to be reasonable assumptions as DDT has been used in different quantities in and around Sweden historically, such as in privately owned gardens to combat fungal and insectile attacks (Öberg, 2023), Thus the concentrations could be expected to vary greatly both within an area and between different areas depending on the historical usage. The model would probably estimate the total contamination risk more accurately if samples were taken throughout the surrounding areas of the Kolleberga forest nursery site to enable assigning of distributions for the possible DDT-concentrations like on the other subareas. This would also enable possibilities to potentially find other hotspot areas. However, as the area around the nursery is practically infinite, there is a risk that obtaining representative sample data is an impossibility. Therefore, it can be more beneficial to investigate historical archives to trace possible DDT-use in the surrounding area and thereafter perform targeted measurements to obtain a fuller picture of possible representative DDT-concentrations. This can also be motivated with that the economic costs would not justify the benefits if the concentrations were believed to not pose a large ecological risk.

6.3.2 Dietary Uncertainties

Due to the lack of local dietary studies, the diets were estimated by performing a literature review. Even though a lot of the dietary studies were very detailed, the selection of quantitative dietary data for the selected species was small. This was especially apparent for the diet of the great spotted woodpecker, where the diets of other species of woodpeckers had to be used due to the small sample of data (See Appendix H3). Several studies also only mentioned the Frequency of Occurrence (FO) but did not mention the percentage of biomass consumed making these reports irrelevant for this thesis. There were also large variations in the local conditions of the studies analyzed, making it impossible to fit the data into representative distributions which lead the decision to use estimated average dietary fractions as point values instead. As the diet of species is largely dependent on the local food supply, it was difficult to

find any correlations between the dietary compositions in the analyzed studies. Initially, an attempt to analyze possible diets was made by analyzing the taxon lists from Artportalen (2024c) it was quickly dismissed as it can be assumed that there is no particular correlation between observations and actual diets. Further, the Ecological Tool in the software SADA developed by USEPA was also tried as a method for accurately estimating the dietary compositions of species. However, this tool only contained a limited number of species and only species living in North America. The method was thus also quickly dismissed, as the species in the database were at best closely related to the species analyzed in this thesis, but most often not that either. Doing an inventory of the local food supply would be beneficial to get more accurate estimations.

Further, the decision for using representative prey animals (i.e., bank vole and great tit), was built upon the lack of site-specific dietary data and the limited timeframe. The choice of species was purely built on the fact that these are relatively commonly found species in the area, but the top predators are likely to have a more versatile diet in the field. Local dietary studies for the top predators, and diet estimations for a wider group of potential prey species, would possibly give a more accurate estimation of the local bioaccumulation through diet.

6.3.3 Uncertainties in Home Ranges

When incorporating home range, there are a lot of uncertainties. As the home range is affected by multiple site-specific factors (Rolando, 2002), intraspecies variations might be large. Due to the lack of site-specific home range data, the home ranges in this study were sourced from the literature. As there was a lack of studies examining the home ranges of species, a wide variety of studies from different areas had to be used, causing large variance within the same species group when fitting into representative distributions. Even though extreme values were excluded (See yellow marks in Appendix D), the variance was still high. This is likely to be due to multiple reasons, elaborated in sub-sections 6.3.3.1-6.3.3.3.

6.3.3.1 Not the Main Area of Research

Many of the studies did not have the estimation of regular home ranges as their main area of research, but instead focusing on other parameters such as the change in movements between the sexes and during the breeding season. This was seen in both the duration of the studies conducted and the sample sizes used, both parameters showing large variations between the different studies used. Jędrzejewski et al. (1995) conducted a study on weasels which showed that the home range had large variations depending on the local abundance of rodents, making the local food abundance interesting for further investigations. This study followed a pattern of several reports that investigated extreme conditions regarding any of the parameters that affect the home range that might not be representative when trying to depict normal conditions.

6.3.3.2 Home Range Measuring Methods

Due to the lack of available literature, the data used were sampled using different methods. To make the study as homogenous as possible, studies conducted using MCP as a method was used due to this method being one of the most used methods to estimate home range. However, the MCP method has been criticized within the research field for being inaccurate for performing home range estimations (Kenward, Walls, & Hodder, 2001). This is due to the inability to accurately distinguish between core ranges and outer boundaries, being able to statistically describe home range structure, and the inability to accurately describe the shape and size of home ranges with few samples. Huck et al. (2008), suggest that the usage of Kernel methods built on the concept of probability distributions to mention home ranges are more accurate than MCP. However, these methods are disputed within the scientific field whether the smoothing parameter affecting the area of influence is to be fixed or adaptable, causing variance within the published research. Huck et al. (2008) also suggest using the method Local Convex Hull (LCH) which can be seen as a development of MCP, but the polygons used are based on the nearest neighbors. However, the scientific field is divided regarding the most suitable method, making it difficult to choose the most suitable method to use.

Many reports also failed to mention which percentile was used in the evaluation of the home ranges. As the MCP method is performed by drawing polygons around a certain percentile of observation points, there can potentially be a large difference between e.g., an MCP90 and an MCP100. One of the few studies estimating the difference between different percentiles of MCP was made by Naef-Daenzer & Grüebler (2008), where the MCP100 was almost 10 times larger than that of an MCP90 for great tit. This was likely to be due to occasional large detours from its core range. It can be assumed that this could be the case for other species as well, causing possible overestimations of the home range in some reports used. As far as possible, this report tried to use an MCP90 or MCP95 when mentioned in the original source, but due to data scarcity, exceptions from this rule had to be applied in some cases, possibly leading to an overestimation of some of the home range data used.

Further, the choice of using MCP90 and MCP95 might have led to an overestimation of the feeding grounds. As many species have a core range where they reside most of their time (Wal & Rodgers, 2012), it can be assumed that a large part of the food intake takes place within the core range. The core range is commonly defined as the 50:th percentile home range (MCP50) (Peris, et al., 2020), and is often much smaller than the entire home range. Using MCP90 and MCP95 might therefore lead to an underestimation of the ecological risks at the site if the core range is located inside the forest nursery. However, using the core range might on the other hand lead to an overestimation of the ecological risks, as it can be assumed that some of the food is consumed outside of the core range as food availability often is a key parameter to extend the home range.

6.3.3.3 Shape of the Home Range

Further, this thesis assumed a circular shape on the home range, which might be a misrepresentation compared to the real conditions. The reason for doing this simplification was partly based on the initial gathering of data, where circular polygons were drawn in Artportalen (2024c) to extract observation data from the area, and partly due to the limited timeframe of this thesis. The reason for placing the home range in the center of the forest nursery site was to

estimate a worst-case scenario for bioaccumulation and thereby lowering the probability of underestimating the ecological risks at the site. However, if site-specific measurements were to be performed, the center of the home range might be more accurately placed. This assumption also led to the assumption that the subareas were evenly distributed throughout the home ranges for the species with home ranges larger than the forest nursery site. However, for the species with home ranges smaller than the forest nursery site, the average soil concentration was estimated by weighting the subareas equally throughout the species home range. This was a simplification which was made in this thesis but is unlikely to be representative in reality as the ground conditions are very versatile at the site and that the site is irregularly shaped. An alternative method to investigate this could be to place the center of the home range at different parts of the forest nursery site and calculate an average concentration in the assumed home range based on the most likely habitat.

6.3.4 Uncertainties in BAFs

When looking at the BAF data used, there are some uncertainties which needs to be addressed. Firstly, when analyzing the BAF data calculated from the ongoing pilot experiment at the site, this data can be seen as very accurate as it was collected directly at the site. However, as local BAF data from multiple food groups were missing, these had to be sourced in the same way as described in Rundegren (2019). As the BAF of different food groups can have large variations depending on the site, these might not be representative for the Kolleberga site. An example of this is that Jongbloed et al. (1996) calculated a mean BAF of 0.17 for earthworms from the literature, while a study made at a DDT-contaminated forest nursery in Kårehogen on Orust (Golder Assiciates AB, 2020), had a mean BAF of 1.5. In this study, the average BAF was calculated to be 0.61 in the area where no biochar was added, furthering the uncertainties of using generic values from literature when trying to accurately estimate the local ecological risks at the site. Site-specific sampling of DDT-accumulation for the missing food groups instead of using generic BAF values could therefore be a reasonable next step in making the study more accurate.

Another uncertainty is regarding the BAF data for soft invertebrates used in this study. As the data provided for soft invertebrates was only for earthworms, it might be an overestimation of the BAF for many species. As earthworms reside solely in the soil, the bioaccumulation can be expected to be significantly higher than e.g., different types of larvae residing in the surrounding vegetation. The same reasoning can be relevant for hard bodied invertebrates, where most of the raw BAF data used in Jongbloed et al. (1996) was for hard bodied invertebrates residing in the soil, hence also being directly exposed to the contamination at its source. Taking local samples of the DDT-concentration of non-soil living organisms could be useful to better estimate the BAFs of residing outside of the soil. This can also be further motivated by the BAF for hard bodied invertebrates being the most sensitive parameter for great spotted woodpecker and common raven for scenarios 1-3. It was also found to be the most critical food group for bioaccumulation of DDT according to Rundegren (2019), making the percentile reduction of biochar especially interesting to evaluate for this food group specifically. The same reasoning could be used for sampling the DDT-concentration in prey birds in the area, as this was the most sensitive parameter for common buzzards and red kites.

Another uncertainty in the model is the assumption of the bioavailability is 100 %. Even though using a bioavailability of 100 % is standardized in this type of investigation, using this assumption might lead to an overestimation of the ecological risk. However, assuming a lower

bioavailability might lead to an underestimation of the ecological risks, which is why this was not done in this study as the bioavailability was unknown. However, it can be assumed that the bioavailability is lower than 100 % for top predators in the field as there are multiple levels in the food chain before reaching the top predatory species.

When analyzing the effects on the BAFs when implementing biochar, the data that depicted use of biochar made an important assumption that biochar would be implemented on the whole site. At this stage, implementation of biochar is in its early phases, and it remains to be seen whether it will be possible to implement it on the whole site or at designated areas.

6.3.5 Uncertainties in the Effectiveness of Biochar

When looking at the results from the effectiveness of implementing biochar, there are some uncertainties which needs to be addressed. Firstly, the pilot experiment which provided the BAF data for this study has only been tested on a small surface with a limited amount of plant species. This can provide an estimation of how these types of plants can potentially affect the DDT-accumulation, but as different plant species have different characteristics, it is not possible to obtain accurate data on the general effectiveness when looking at the diets of a prey animal. The plants used during the pilot study were also not representative for the general diets of the species analyzed, as they did not include neither seeds, fruits or berries which can be assumed to be some of the most commonly consumed food groups for preys. This made it difficult to estimate the actual effects of the studies on the top predators analyzed. However, if plants containing these food groups were to be used in the area, such as sea buckthorn (Hippophae rhamnoides in Latin), which have been used in previous phytoremediation studies on petroleum contaminated soils (Duan et al., 2023), and heavy metals contaminated soils (Fang, et al., 2023; Bingöl et al., 2023), the relevance of the collected data would suit this investigation better.

It was also impossible to evaluate the effectiveness of implementing biochar for animal food groups which were not connected to the ongoing pilot study at the site, mainly hard bodied invertebrates, prey birds, and prey mammals. As there was no site-specific data available about their DDT-uptake, generic data without the implementation of biochar was collected by using the same methodology as used in Rundegren (2019). One alternative to perform this analysis could be to assume that the ratio between the BAFs with and without the implementation of biochar for these species would be similar to that of soft bodied invertebrates. This was an assumption which was not made in this thesis, as the ratio between the mean BAF showed large variations (between around 50 % for earthworms and 135 % for grass), causing large uncertainties in the true effectiveness for different species groups analyzed. A more conservative approach was therefore used, assuming that there was no effect on the BAF for the food groups where no site-specific data was used, which potentially could lead to an underestimation of the effectiveness of implementing biochar at the site.

Secondly, as the data used was from an ongoing pilot experiment, it is hard to determine the long-term effectiveness. As this thesis has only been going on for a few years, the percentual effectiveness calculated in this thesis is only based on the current effectiveness and to determine the long-term effectiveness, regular monitoring will be necessary in the future. This means that even though the effectiveness of GRO estimated in this thesis could be seen as representative, it cannot be seen as a reliable source to estimate the future impact which GRO could have to reduce the ecological risks. It is also not certain how well all GROs work based on this study

since it only examines the effects of biochar. If any other GROs are used as remediation method, it is better to use method-specific data before applying a model like this one.

6.4 Recommendations for Remediation

As the ecological risks from the site were too high for all scenarios analyzed, remediation is necessary. Further, as measurements from the dipping area and landfill showed concentrations up to 227 mg/kg DS (see Appendix A3), excavating these parts of the forest nursery can be seen as necessary. As mentioned in the limitation chapter, this thesis only investigated the ecological risks for top predators, but it is important to note that there are smaller organisms residing in these areas which could be severely negatively affected by these high DDT-concentrations. Rundegren (2019) fitted single-species toxicity data into a species-sensitivity distribution (SSD) connected to DDT-concentrations in the soil. Rundegren's results showed a PAF of 5 % of the local ecosystem at soil concentrations of around 2 mg/kg DS (see Figure 8 in Rundegren (2019)), while soil concentrations around 40 mg/kg DS would lead to a PAF of 50 %. Comparing these values to the soil concentrations found in the dipping point and landfill, these soil concentrations were exceeded for 87.5 % and 14.9 % respectively.

The same reasoning could also be argued for the built environment, where the measurements of DDT-concentrations showed large variation but the DDT-concentration but had measurements reaching up to 53 mg/kg DS (See Appendix A5). However, the sample size from this subarea was very low compared to the field, dipping area, and landfill. It also showed large variance in DDT-concentration between the measurements, making it tough to draw conclusions about further remediation at the site. More measurements from this site would make the decision support for the future remediation options for this site more reliable.

As discussed in Chapter 5.10, the implementation of biochar showed a decrease of varying effect depending on the dietary composition of the species analyzed. As this thesis used a more conservative estimate, i.e., assuming no reduction in BAF from biochar where no site-specific data was available, the true effectiveness of the implementation of biochar might have been underestimated. However, two different types of scenarios were tested to obtain an estimation of the effects of biochar. These were:

- Excavating the dipping area and plant landfill and implementing biochar at the entire forest nursery site. The effects from biochar were assumed to be none for the food groups where no site-specific data was available.
- Excavating the dipping area and plant landfill and implementing biochar at the entire forest nursery site. The effects from biochar for hard bodied invertebrates were assumed to be 50 % similarly to the effects on soft bodied invertebrates.

In both these scenarios, an average DDT-concentration outside of the forest nursery was 0.1 mg/kg DS similarly to scenario 2. The reasoning for this was that there are residential buildings located close to the nursery, making the assumption of a concentration below that of KM most realistic. When comparing the resulting ecological risks from the implementation of these measures between the scenarios (see Tables 13 and 14), the ecological risks from these were significantly decreased for common ravens (from a probability of exceeding an HC5 of 16.4 % to 7.5 %) and for badgers (from 29.3 % to 16.6 %). The probability of exceeding an HC50 was also decreased for great spotted woodpeckers from 75.7 % to 60.9 %. However, more studies

in the area would be beneficial before a final decision can be made regarding a wide-scale implementation of biochar at the site can be reached.

6.5 Further Research

When looking at future research which can be made to further develop the model, there are multiple different studies which would be beneficial in different ways. These can be divided into different categories and are presented in this sub-chapter.

6.5.1 Home Range Data

As mentioned earlier, the home range data used in this thesis had a large spread of values due to the large spread of both geographical and demographical locations. This provided a large variation in data, causing large uncertainties in this parameter. Local home range studies on the selected species would help to limit the home range span and obtain a better understanding on the actual home range in the Kolleberga area. This could be done by for example using radio or GPS tracking (such as the methods used in Loretto et al. (2015) and Marchand et al. (2018)) to estimate the displacement in movements from their nesting site. This could in turn be used to accurately calculate the home ranges of the selected species, making it possible to estimate the most probable hunting grounds. It is also important to choose a suitable home range estimation method based on an analysis of the local conditions.

6.5.2 Weighting System for Home Range

If it is deemed to be too expensive to conduct home range estimations at the site, a thorough analysis should be made which evaluate the parameters that affect the home range by going through the compiled literature. A way to accomplish this could possibly be to establish a larger degree of cooperation between researchers in the area (it is evident from the literature that several authors are recurring in different works and that cooperation exists in the area) to obtain a greater homogeneity in the presentation of results. However, even without this large-scale international cooperation, smaller groups of local ecology experts could interpret the varying presentations of results and background conditions to draw conclusions about how the home ranges would look like locally. Coming studies will most likely investigate different aspects with different approaches but if some parameter data is noted and reported in a consistent way, it will be possible to draw some conclusions about what can be expected home range-wise in the Kolleberga area. Some of the examined parameters based on previous discussion could for instance be:

- Local food availability in qualitative and quantitative terms which require an investigation about what food exists in the area and how available it is.
- The local geography such as topography and type of landscape, to account for habitats, boundaries and other geographical aspects that can affect the movement of species. This home range can then, for instance, decrease or expand in other directions.
- Population density, how common the investigated species, and other possible rivals for food, is in the area.

- How the climate in the area potentially could affect the abovementioned parameters.

The parameters could for example be assigned a scoring system where a high score indicate a large home range whereas the opposite would apply for low home ranges. By examining and comparing different conditions, it should be possible to use other studies to draw better conclusions by using existing studies, rather than only use the values as they are. It could also potentially analyze how the species behave in relation to changing habitat, such as whether excavation and removal of the tree-rich area would make woodpeckers turn to other areas that are less likely to be contaminated. A similar weighting system can perhaps also be used to interpret diet data when the needed information is unavailable. A clear advantage with a weighting system and use of ecological expertise to predict these results is that it most likely would be cheaper than performing more extensive home range and dietary distribution investigations.

6.5.3 Development of Model

The original intention with the thesis was to not only measure the total bioaccumulation for the top predators but also for species in lower trophic levels. As the model was developed, this gave excessively high values for the prey species which was because their home ranges were too small. A development of the model to make it applicable to species with smaller home ranges could be interesting if the purpose is to examine the effects on the species in question. Such a development could also include a larger degree of spatial analysis. In this model, the subareas are equally distributed based on their respective sizes, a spatial analysis could include different center points with different distances to the different parts of the nursery area. However, the data for the top predators can be stated to give a more representative indication of the state of the nursery site as a cohesive ecosystem.

Originally, this thesis attempted to see if there was any correlation between prevalence of different DDT-metabolites (both between DDT, DDD and DDE and between para-para (p,p'-) and orto-para (o,p'-)) and the DDT-concentration at the site. A simple statistical overview was done which did not provide any correlation and the original intentions were subsequently abandoned within the framework of this thesis. However, investigating this topic more thoroughly and incorporating it in the model can potentially give indications about the state of the degradation process of DDT at the site.

6.5.4 Developing the Food Web Modelling

The food web model could obtain more dynamism in several ways. This thesis has followed Rundegren's development by Jongbloed's original method and added inter-trophic relationships between non-adjacent levels which have increased the model's reliability. However, there are several potential developments regarding the food web model.

A clearer division into different compartments is another option to clearly visualize divisions between different compartments of the total food chain which can be useful and depict real conditions if the food web is larger and more complex (McKenney, 2023). This would also enable indirect relationships between top predators which can be further developed by

accounting for various indirect relationships between species where the extent of one trophic relationship might affect another. It can be exemplified by a species which is predatory towards another species from a lower trophic level and thus share a direct relationship, while the weaker species from the same trophic level which can only benefit from hunting the lower-level species if the stronger species do not, share an indirect trophic relationship.

However, it is very evident that food web modelling has proven to be a very useful way to provide an overview over the secondary poisoning and bioaccumulation processes. It has partly succeeded in addressing the two disadvantages of ecological risk assessment that Swartjes (2011) pointed out as it has helped account for a larger number of species and that these are not equally sensitive to contaminants. Despite this, it has highlighted the need for uptake values and bioaccumulation factors for a much larger number of species is needed to obtain a desired basis for analysis.

6.5.5 Dietary Data

Another parameter which was hard to estimate was the diet composition. As the literature search provided a wide range of dietary compositions for the same species, it was impossible to fit the dietary data to the local conditions found in Kolleberga. Dietary studies on top predators in the area, such as either analyzing pellet content or looking at the stomach content of predatory species in the area could provide a more exact dietary composition from the local surroundings and therefore make it possible to more accurately estimate the dietary compositions. However, it is important to actively evaluate the proportions of the diet composition and not frequency of occurrence because quantitative data is the big scarcity regarding most of the mentioned diet measuring methods. It is also important to further analyze the dietary composition of more prey species than the chosen representative species (great tit and bank vole) to account for more bioaccumulation pathways and obtain a more comprehensive overview of the total bioaccumulation.

The need for a thorough analysis for the precise local conditions is noticeable when it is evident that the bisam rat is the second most common specified mammal in the diet of the red kite in neighbouring Poland (Zawadzka, 1999) but is totally absent in Southern Sweden (SLU Artdatabanken, 2024a). If a more detailed food web is constructed with inclusion of more prey species, it is important to control if these species actually are present in the local surroundings.

Apart from conducting field measurements of dietary distributions, there are alternative ways to obtain more reliable dietary estimations. This can possibly be done by attempting to quantify already existing qualitative data, either by finding it through investigating the original source, or by use of biological expertise who could also possibly interpret frequency of occurrence data. The ecological tool in SADA could also be further developed by including more species. Species-specific and contaminant-specific data about NOEC would also provide a sharper analysis of which contamination levels that are harmful towards which species, within the context of the site.

6.5.6 Extension of Species in the Model

This thesis only investigated a limited number of species and for further research, similar analysis could be conducted for a larger number of species, including other top predators and a larger number of prey species. This will enable bioaccumulation estimation in more species and thus provide a larger overview of the ecological risk of DDT-contamination. More advanced tools than taxon lists in which the public contribute, could also be applied to better estimate the proportions of species existing in the area. This could also work as guidance of which species have the highest priority to investigate.

6.5.7 Cost-benefit Analysis

Combining the bioaccumulation results and the sensitivity analysis provides an overview of the most suitable options regarding performance and environmental effect. However, before being applied, the results of the options should be combined with a cost-benefit analysis which examines economic, environmental, and social costs compared to their benefits. One example of when this is particularly important is within the decision-making about the possibilities of excavating different parts of the area. The ecological benefits are obvious in excavating the geographically small and highly DDT-contaminated hotspot areas. However, these benefits are present but not as obvious for the built area in the site and much more certain due to the lack of measurements, combined with another cost structure due to the large area and the costs of demolishing or moving the present buildings. This could also be applied when deciding the scale of implementation of biochar on the field. Similar cost-benefit analyses will, if handled right, act as good decision support for future decisions about remediation action or further investigations and measurements about parameters affecting the ecological risk in and around the area.

7
Summary and Conclusions

This thesis aimed to evaluate the ecological risks for top predators at the Kolleberga forest nursery in southern Sweden, and to evaluate the effectiveness which biochar could have to reduce the ecological risks. This was done by developing a new probabilistic scenario-based ERA model to evaluate the bioaccumulation through diet. The new model incorporates the concentration in the different subareas, the home range, dietary compositions, and BAF of the analyzed top predatory species. The ecological risks from the newly developed model were also compared to an old thesis made in the same area by Rundegren (2019). The main conclusions from the study in this thesis are:

- The DDT-concentrations at the site showed a large variation between the different subareas, but also a large variation within the different subareas analyzed.
- The home range and dietary data from literature showed large variation, making it hard to fit into representative distributions.
- The ecological risks of DDT-accumulation through diet at the site were lower using this model than using the model used in Rundegren (2019). They are however too high to be neglected.
- For scenario 1, the probability of exceeding an HC5 was above 5 % for all species except for weasel without implementing biochar. For scenarios 2-3, the probability of exceeding an HC5 was lowered to <1 % for red kite, while still being above 5 % for all other species except for weasel.
- A clear decrease was seen between scenarios 1-3 for the species with large home ranges (i.e., red kite, common raven, and common buzzard), where a lowered outside concentration led to a large decrease in the overall ecological risk. This was most notable for common ravens, where a decrease in outside concentration from 1 mg/kg DS to 0 mg/kg DS led to a decrease in the probability of exceeding an HC5 from 77.6 % to 16.6 %, indicating that the home range of species can have a large impact on the overall ecological risks.
- For the fourth scenario, the probability of exceeding an HC5 was high (>77 %) for all species except for weasel without the implementation of biochar.
- There was a high ecological risk for great spotted woodpecker for all scenarios, which is likely due to a combination of its home range being smaller than the forest nursery and its diet consisting to a large part of hard bodied invertebrates. An average concentration throughout the forest nursery was assumed, but this can be seen as a simplification as the preferred habitat of great spotted woodpeckers only consists of a small part of the forest nursery site. An alternative way could be to assume a home range where the great spotted woodpeckers are assumed to reside and calculate an average concentration in the assumed home range.
- Biochar was found to lower the BAFs for all lower tier food groups analyzed in this study, but the percentual effects varied between the different food groups analyzed.
- Site-specific data on the BAFs for food groups missing in this study would help evaluate the true effectiveness which biochar have on the final bioaccumulation.
- The home range data, non-site specific BAF data, and dietary data were very uncertain, as these parameters can vary greatly depending on the local conditions. Collecting site-specific data for these parameters would help make the evaluation more robust.

- Preliminary recommendations for remediation are to excavate the dipping area and plant landfill, but further investigations are needed to get a more accurate evaluation of future remediation.
- Excavation of the dipping are and plant landfill and implementing biochar led to a decrease in ecological risks for all species, but the probability of exceeding an HC5 was still <5 % for badger, common raven, and great spotted woodpecker.
- Excavating the dipping area and plant landfill and assuming that the BAF for hard bodied invertebrates lowered the probability of exceeding HC5 compared to assuming no effects from biochar lowered the probability of exceeding HC5 significantly for badger (from 29.3 % to 16.6 %), and common raven (from 16.4 % to 7.5 %), but more data is needed to estimate the effectiveness which biochar can have on the BAF of hard bodied invertebrates in the field.
- Potential further research includes:
    - Collecting local home range and dietary data to depict the movements of the analyzed species more accurately at the site.
    - Implement a weighting system for home range to be able to estimate the home ranges depending on the local site-conditions.
    - Developing the model to calculate the bioaccumulation more accurately for species with smaller home ranges by calculating the average soil concentrations when placing the home range at different parts of the forest nursery.
    - Extend the model to include more species.
    - Perform a cost-benefit analysis to evaluate the economical aspect of doing the investigations and remediation suggestions mentioned in this study.

References

Asker, I. (2011). *DDT används fortfarande. Varför?* . Uppsala.

Aven, T. (2010). *On how to define, understand and describe risk.* Stavanger: University of Stavanger.

Bachmann, S., & Pasinelli, G. (2002). Space use of Great Spotted Woodpeckers Dendrocopos major and Middle Spotted Woodpeckers D. medius in syntopy and remarks ⊤ interspecfic competition. *Ornithologische Beobachter, 99*(1), pp. 33-48.

Balestrieri, A., Cardarelli, E., Pandini, M., Remonti, L., Saino, N., & Prigioni, C. (2016, 02 10). Spatial organisation of European badger (Meles meles) in northern Italy as assessed by camera-trapping. *European Journal of Wildlife Research, 62*, pp. 219-226.

Bandara, P., Randika, J., Soysa, H., Ruwandeepika, H., & Gunatilake, S. (2022). Bioremediation of Pesticide-contaminated Soil: A Review on Indispensable Role of Soil Bacteria. *Journal of Agricultural Sciences - Sri Lanka, 17*(1), . 19-43.

Bernes, C. (1998). *Organiska miljögifter - Ett svenskt perspektiv på ett internationellt problem.* Stockholm: Naturvårdsverket.

Bingöl, S. M., Comakli, E., Özgül, M., Altun, M., & Comakli, T. (2023, 12). The heavy metals content in leaves and branch of Hippophae rhamnoides L. and Pyrus elaeagnifolia Pall. in the highway side (European route E80) in Türkiye. *Environmental Earth Sciences, 82*(23).

Blanco, J. C., Hiraldo, F., & Heredia, B. (1990). Vatiations in the diet and foraging behavior of a wintering red kite (Milvus milvus) population in response to changes in food availability. *Ardeola, 37*(2), 267-278.

Blus, L. J. (2011). DDT, DDD, and DDE in birds. i L. J. Blus, *DDT, DDD, and DDE in birds* (ss. 425-440). CRC Press.

Bodin, C., Benhamou, S., & Poulle, M.-L. (03 2006). What do European badgers (Meles meles) know about the spatial organisation of neighbouring groups? *Behavioural Processes, 72*(1), pp. 84-90.

Botisov, S., Frantzen, S., Bruvold, A., & Grosvik, B. E. (2024). Varying temporal trends in the levels of six groups of legacy persistent organic pollutants (POPs) in liver of three gadoid species from the North Sea. *Chemosphere, 349*.

Britannica, weasel. (2024, April 29). Retrieved from https://kids.britannica.com/students/article/weasel/277680

Burt, W. H. (1943, August). Territoriality and home range concepts as applied to mammals. *Journal of mammalogy*, pp. 346-352.

Börjesson, H., Ek, L., Eriksson Segerström, K., & Nyman, H. (2022). *Undersökning av markanvändning på DDT-förorenade tidigare skogsplantskolor*. Gothenburg: Chalmers University of Technology.

Chen, Z., Maartens, F., Vega, H., Kunene, S., Gumede, J., & Krieger, R. I. (2009, December). 2,2-bis(4-Chlorophenyl)Acetic Acid (DDA), a Water-Soluble Urine Biomarker of DDT Metabolism in Humans. *Internationa Journal of Toxicology*.

Cleary, G. P., Corner, L. A., O'Keeffe, J., & Marples, N. M. (2009, 11 01). The diet of the badger Meles meles in the Republic of Ireland. *Mammalian Biology, 74*, pp. 438-447.

Collins, C. D., Craggs, M., Garcia-Alcega, S., Kademoglou, K., & Lowe, S. (05 2015). Towards a unified approach for the determination of the bioaccessibility of organic pollutants. *Environment International, 78*, pp. 24-31.

Cundy, A. B., Bardos, P., Puschenreiter, M., & Mench, M. J. (04 2016). Brownfields to green fields: Realising wider benefits from practical contaminant phytomanagement strategies. *Journal of Environmental Management*.

Denyes, M. J., Rutter, A., & Zeeb, B. A. (02 2016). Bioavailability assessments following biochar and activated carbon amendment in DDT-contaminated soil. *Chemosphere, 144*, pp. 1428-1434.

Dinkins, J. B., Conover, M. R., Kirol, C. P., Beck, J. L., & Frey, S. N. (2016). Effects if common raven and coyote removal and temporal variation in climate on greater sage-grouse nesting success. *Biological Conservation, 202*, pp. 50-58.

Drenning, P. (2021). *Gentle Remediation Options (GRO) for Managing Risks and Providing Ecosystem Services at Contaminated Sites.* Gothenburg: Chalmers University of Technology.

Drenning, P. (2024). *Opportunity Windows and Added Value of Gentle Remediation Options for Contaminated Land Management.* Department of Architecture and Civil Engineering. Gothenburg: Chalmers University of Technology.

Drenning, P., Chowdhury, S., Volchko, Y., Rosen, L., Andersson-Sköld, Y., & Norrman, J. (2022). A risk management framework for Gentle Remediation Options (GRO). *Science of the Total Environment*.

Duan, Q., Han, G., & Rennenberg, H. (2023, 01 21). The effects of petroleum contaminated soils on the growth, gas exchange and antioxidative level of sea-buckthorn. *Plant and Soil, 486*, pp. 535-550.

Elmeros, M. (06 2006). Food habits of stoats Mustela erminea and weasels Mustela nivalis in Denmark. *Acta Teriologica, 51*, pp. 179-186.

Elmeros, M., Madsen, A. B., & Prang, A. (2005). Home range of badger (Meles meles) in a heterogeneous landscape in Denmark. *Lutra, 48*(1), pp. 35-44.

Enell, A., & Holmström, S. (2020). *Undersökning av biotillgänglighet av DDT i jord genom jämviktsprovtagning. En förstudie.* Linköping: SGI.

Engel, K. A., & Young, L. S. (1989). Spatial and temporal patterns in the diet of common ravens in Southwestern Idaho. *The Condor, 91*, pp. 372-378.

Erlinge, S. (1975). Feeding Habits of the Weasel Mustela nivalis in Relation to Prey Abundance. *Oikos, 26*(3), pp. 378-384.

European Chemicals Agency. (n.d). *Understanding POPs*. Retrieved from echa.europa.eu: https://echa.europa.eu/understanding-pops

European Comission. (den 06 11 2003). *Presence of persistent chemicals in the human body results of Commissioner Wallstrom's blood test*. Retrieved from ec.europa.eu: https://ec.europa.eu/commission/presscorner/detail/en/MEMO_03_219

Fang, L., Zeng, Z., Jia, Q., Lin, Y., Chen, H., He, Y., & Chen, J. (2023). Physiological response and phytoremediation potential of dioecious Hippophae rhamnoides inoculated with arbuscular mycorrhizal fungi to Pb and Zn pollution. *Frontiers in Plant Science, 14*.

Forsberg, K., & Wåhlén, H. (2020, March). *SGU.* Retrieved from SGUs satsning på DDT-förorenade områden: https://www.sgu.se/globalassets/samhallsplanering/fororenade-omraden/plantskolor-och-bekampningsmedel/plantskolor_poster_mars_2020.pdf

Frantz, A. C., Schley, L., Schaul, M., Balestrieri, A., & Roper, T. J. (2010). SPATIAL ORGANISATION OF BADGERS (MELES MELES) IN A MEDIUM-DENSITY POPULATION IN LUXEMBOURG. *Hystrix, the Italian Journal of Mammalogy, 21*(1), pp. 3-18.

Gal, J., Hursthouse, A., & Tatner, P. (08 2008). Cobalt and secondary poisoning in the terrestrial food chain: Data review and research gaps to support risk assessment. *Environment International, 34*(6), pp. 821-838.

García, J. T., Viñuela, J., & Sunyer, C. (1996). Geographic variation of the winter diet of the Red Kite Milvus milvus in the Iberian Peninsula. *IBIS, 140*, pp. 302-309.

Génsbøl, B. (2006). *Rovfåglar i Europa.* Stockholm: Prisma.

Geotechnical Institute of Sweden (SGI). (2017). *Föroreningsproblematik vid gamla handelsträdgårdar. Råd vid miljötekniska undersökningar.* Linköping: SGI.

Golder Associates AB. (2020). *Miljö- och hälsoriskbedömning.* Gothenburg: SGU.

Gomes, D. J., Wierzbowska, I. A., Bevanger, K., O'Mahony, D., & Rola, K. (18 12 2019). Diet of the European badgers (Meles meles) in urban and rural areas of Norway. *European Journal of Wildlife Research, 66*.

Google. (2024a). *Google Earth*. Retrieved from earth.google.com

Google. (2024b). *Google Maps*. Retrieved from google.com/maps

Goszczynski, J., Jędrzejweska, B., & Jędrzejwski, W. (2000). Diet composition of badgers (Meles meles) in a pristine forestand rural habitats of Poland compared to other European populations. *Journal of Zoology London, 250*, pp. 495-505.

Greipsson, S. (2011). *Phytoremediation*. Retrieved from nature.com: https://www.nature.com/scitable/knowledge/library/phytoremediation-17359669/

Guerzou, A., Guerzou, M., Derdoukh, W., Souttou, K., & Doumandji, S. (2019). Corvus Corax Diet Composition in Different Agricultural Lands in Algeris. *Acta Universitatis Agriculturae et Silviculturae Mendelianae Brunensis, 67*(1), pp. 41-57.

Guerzou, A., Medina, F. M., Derdoukh, W., Guerzou, M., Souttou, K., Sekour, M., & Doumandji, S. (2013). Diet of Common Raven Corvus Corax (Aves, Corvidae) in Algeria. *Advances in Environmental Biology, 7*(7), pp. 1288-1291.

Hogstad, O., & Stenberg, I. (den 01 01 1997). Breeding success, nestling diet and parental care in the White-backed WoodpeckerDendrocopos leucotos. *Journal für Orthithologie, 138*, pp. 25-38.

Huck, M., Davison, J., & Roper, T. J. (2008, 12 01). Comparison of two sampling protocols and four home-range estimators using radio-tracking data from urban badgers Meles meles. *Wildlife Biology, 14*(4), pp. 467-477.

Iwaniuk, A. N., Koperski, D. T., Cheng, K. M., Elliott, J. E., Smith, L. K., Wilson, L. K., & Wylie, D. R. (2006, 10 02). The effects of environmental exposure to DDT on the brain of a songbird: Changes in structures associated with mating and song. *Behavioural Brain Research, 173*(1), pp. 1-10. doi:https://doi.org/10.1016/j.bbr.2006.05.026

Jędrzejewski, W., Jędrzejewska, B., & Szymura, L. (01 1995). Weasel Population Response, Home Range, and Predation on Rodents in a Deciduous Forest in Poland. *Ecology, 76*(1), pp. 179-195.

Jiao, Z.-b., Wan, T., Wen, J.-b., Hu, J.-f., Luo, Y.-q., Fu, L.-j., & Zhang, L.-s. (2008, 05 28). Seasonal diet of the Great Spotted Woodpecker (Picoides major) in shelterwood plantations of Wulate Qianqi County, Inner Mongolia. *Forestry Studies in China, 10*, pp. 119-124.

Jongbloed, R. H., Traas, T. P., & Luttik, R. (1996). A Probablistic Model for Deriving Soil Quality Criteria Based on Secondary Poisoning of Top Predators. *Ecotoxicology and Environmental Safety, 34*, pp. 279-306.

Kenward, R. E., Walls, S. S., & Hodder, K. H. (2001). Life path analysis: scaling indicates priming effects of social and habitat factors on dispersal distances. *Journal of Animal Ecology, 70*, pp. 1-13.

King, C. M. (1975, 06). THE HOME RANGE OF THE WEASEL (MUSTELA NIVALIS) IN AN ENGLISH WOODLAND. *Journal of Animal Ecology, 44*(2), pp. 639-668.

Klepper, O., Bakker, J., Traas, T. P., & van de Meent, D. (08 1998). Mapping the potentially affected fraction (PAF) of species as a basis for comparison of ecotoxicological risks between substances and regions. *Journal of Hazardous Materials, 61*(1-3), pp. 337-344. doi:https://doi.org/10.1016/S0304-3894(98)00141-1

Krams, I., Krama, T., & Igaume, K. (2006). Alarm calls of wintering great tits Parus major: warning of mate, reciprocal altruism or a message to the predator? *Journal of Avian Biology*, pp. 131-136.

Kumplene, J., & Lagerkvist, A. (2019). *Efterbehandlingstekniker för DDT-förorenade material.* Luleå: Luleå University of Technology.

Lanszki, J., & Heltai, M. (2007). Diet of the weasel in Hungary. *Folia Zoology, 56*(1), pp. 109-112.

Linz, G. M., & Knittle, E. &. (June 1992). Home Range of Breeding Common Ravens in Coastal Southern California. *The Southwestern Naturalist*.

Loretto, M.-C., Reimann, S., Schuster, R., Graulich, D. M., & Bugnyar, T. (21 09 2015). Shared space, individually used: spatial behaviour of non-breeding ravens (Corvus corax) close to a permanent anthropogenic food source. *Journal of Ornithology*.

Lu, P., Li, L.-F., & Huang, X.-Y. (07 2023). Modified Biochar for Remediation of Soil Contaminated with Arsenic and Cadmium: A Review. *Huanjing Kexue/Environmental Science, 44*(7), pp. 4077-4090.

MacDonald, D. W., Tew, T. E., & Todd, I. A. (2004). The ecology of weasels (Mustela nivalis) on mixed farmland in southern England. *Biologia, 59*(2), pp. 235-241.

Magrini, C., Manzo, E., Zapponi, L., Angelici, F. M., Boitani, L., & Cento, M. (2009). WeaselMustela nivalis spatial ranging behaviour and habitat selection in agricultural landscape. *Acta Theriol, 54*, pp. 137-146.

Marchand, P., Loretto, M.-C., Henry, P.-Y., Duriez, O., Jiguet, F., & Bugnyar, T. &. 2018 Relocations and one-time disturbance fail to sustainably disperse non-breeding common ravens Corvus corax due to homing behaviour and extensive home ranges. *European Journal of Wildlife Research*.

Masahiko, N., & Shindo, N. (2001). Effects of snow cover on the social and foraging behavior of the great tit Parus major. *Ecological Research*, pp. 301-308.

McKenney, E. (2023). *Applied Ecology.* Raleigh: North Carolina State University.

Molina-Vacas, G., Bonet-Arbolí, V., Rt-Plaza, E. R., & Rodríguez-Teijeiro, J. D. (2009). SPATIAL ECOLOGY of EurOPEAN badgers (MELES MELES) in Mediterranean habitats of the North -Eastern Iberian Peninsula. I: Home range size, spatial distribution AND SOCIAL ORGANIZATION. *Life & Environment*, pp. 223-232.

Mougeot, F., Garcia, J. T., & Viñuela, J. (2011). *Ecology and Conservation of European Forest-dwelling Raptors.* Bilbao: Diputación Foral de Bizkaia.

Nachtigall, W., Stubbe, M., & Herrmann, S. (01 07 2003). Home range and habitat use of red kite (Milvus milvus) in winter — a telemetry study in the northern Harz foreland (Germany). *Journal of Ornithology, 144*, pp. 284-294.

Naef-Daenzer, B., & Grüebler, M. (01 10 2008). Post-Fledging Range use of Great Tit Parus major Families in Relation to Chick Body Condition. *Ardea*, pp. 181-190.

Nationalencyklopedin. (1995). skogsplantskola. *Nationalencyklopedin (Vol XVI)* (pp. 552). Höganäs: Bra böcker.

Nationalencyklopedin, grävling. (29 04 2024). Retrieved from http://www.ne.se/uppslagsverk/encyklopedi/lång/grävling

Naturvårdsverket. (2016). *Datablad för DDT, DDD och DDE.* Stockholm: Naturvårdsverket.

Naturvårdsverket. (10 11 2023). *Grävling under huset*. Retrieved from naturvardsverket.se: https://www.naturvardsverket.se/amnesomraden/arter-och-artskydd/rad-om-vilda-djur/gravling-under-huset/

Naturvårdsverket. (03 05 2024). *Riktvärden för förorenad mark.* Retrieved from naturvardsverket.se: https://www.naturvardsverket.se/vagledning-och-stod/fororenade-omraden/riktvarden-for-fororenad-mark/

Nemček, V. (26 03 2014). Movements of a juvenile red kite Milvus milvus in the border zone of Aaustria, Slovakia and the Czech Republic. *Raptor Journal*, pp. 43-48.

Nilsen, E. B., Pedersen, S., & Linnell, J. D. (2007). Can minimum convex polygon home ranges be used to draw biologically meaningful conclusions? *Special Feature on Stoichiometry in Ecology*.

Onwurah, I. N. (10 1999). Role of diazotrophic bacteria in the bioremediation of crude oil-polluted soil. *Journal of Chemical Technology and Biotechnology, 74*(10), pp. 957-964.

Pagani-Núñez, E., Ruiz, I., J., Q., Negro, J., & Senar, J. C. (2011). The diet of Great Tit Parus major nestlings in a Mediterranean Iberian forest: the important role of spiders. *Animal Biodiversity and Conservation, 34*(2), pp. 355-361. doi:https://doi.org/10.32800/abc.2011.34.0355

Palisade. (2024, May 20). *Palisade Help Resources*. Retrieved from https://help.palisade.com/v8_4/en/@RISK/About/About/About-RISK.htm

Peris, A., Closa, F., Ignasi, M., Acevedo, P., Barasona, J. A., & Casas-Díaz, E. (03 12 2020). Towards the comparison of home range estimators obtained from contrasting tracking regimes: the wild boar as a case study. *European Journal of Wildlife Research, 66*.

Pfeiffer, T., & Meyburg, B.-U. (15 05 2015). GPS tracking of Red Kites (Milvus milvus) reveals fledgling number is negatively correlated with home range size. *Journal of Ornithology, 156*, pp. 963-975.

Piacentini, E., & Chiatante, G. (2022). Habitat selection, density and breeding of Great Spotted Woodpecker Dendrocopos major in a protected natural area in northern Italy. *Avocetta, 46*, pp. 97-114.

Powell, A. N., Backensto, S., Smith, L., Rea, C., Pavelka, M., & Suydam, R. &. (10 2007). Foraging Ecology of Common Ravens (Corvus corax) on Alaska's Coastal Plain. *Coastal Marine Institute - University of Alaska*, pp. 99-110.

Preziose, D. V., & Pastorok, R. A. (den 01 12 2008). Ecological food web analysis for chemical risk assessment. *Science of the Total Environment, 406*(3), pp. 491-502.

Rodriguez, A., Lemos, D., Trujillo, Y. T., Amaya, J. G., & Ramos, L. D. (01 09 2019). Effectiveness of biochar obtained from corncob for immobilization of lead in contaminated soil. *Journal of Health and Pollution, 9*(23).

Rolando, A. (2002). On the ecology of home range in birds. *Revue d'Écologie (La Terre et La Vie, 57*(1), pp. 53-73.

Rolstad, J., Rolstad, E., & Stokke, P. K. (1995). Feeding habitat and nest-size selection of breeding Great Spotted Woodpeckers Dendrocopos Major. *Ornis Fennica*(72), pp. 62-71.

Rossi, B. A. (2019). *Space Use and Nesting Ecology of Common Ravens (Corvus Corax) in Central Washington State.* Ellensburg: Central Washington University.

Rossmanith, E., Höntsch, K., Blaum, N., & Jeltsch, F. (17 04 2007). Reproductive success and nestling diet in the Lesser Spotted Woodpecker (Picoides minor): the early bird gets the caterpillar. *Journal of Ornithology, 148*, pp. 323-332.

Rundegren, A. (2019). *Probabilistic ecological risk assessment of secondary poisoning from DDT - A case study of the terrestrial ecosystem at Kolleberga plant nursery.* Lund: Lund University.

Saitou, T. (1979). Ecological study of social organization in the Great Tit, Parus major L. III. Home range of the basic flocks and dominance relationship of the members in a basic flock. *Yamashina Institute for Ornithology Research Report*.

Scarpignato, A. L. (2011). *Home range and habitat use of breeding common ravens in Redwood National and State Parks.* Arcata, California: Humboldt State University.

Selås, V., Tveiten, R., & Aanonsen, O. M. (2007). Diet of Common Buzzards (Buteobuteo) in southern Norwaydetermined from prey remains and video recordings. *Ornis Fennica*, pp. 97-104.

Skrabal, J., Literak, I., Dostal, M., Raab, R., Horal, D., Matusik, H., & Spakovszky, P. (25 11 2021). Red Kites Milvus milvus wintering in their natal area: demographic, environmental, and temporary factors affecting spatiotemporal behaviour patterns. *Bird Study, 68*(3), pp. 381-395.

SLU Artdatabanken. (2024a, 15 05). *Artfakta Bisam*. Retrieved from https://artfakta.se/taxa/232133/information

SLU Artdatabanken. (2024b, 24 05). *Artfakta Skogssork.*

SLU Artdatabanken. (2024c, 08 03). *Artportalen*. Retrieved from Sökformulär: https://artportalen.se/ViewSighting/SearchSighting

Song, W.-K. (2020). Home Range Analysis of Great Tit (Parus major) before and after Fledging in an Urban Park. *Journal of the Korean Society of Environmental*.

Staav, R., & Fransson, T. (2007). *Nordens Fåglar.* Stockholm: Prisma.

Sun, T., Wang, F., Xie, Y., Liu, X., Yu, H., Lv, M., . . . Xu, Y. (02 2023). Biochar remediation of PFOA contaminated soil decreased the microbial network complexity. *Journal of Environmental Chemical Engineering, 11*(1).

Swan, G. (2011). *Spatial Variation in the Breeding Success of the Common Buzzard Buteo buteo in relation to Habitat Type and Diet.* London: Imperial College London.

Swartjes, F. A. (2011). *Dealing with Contaminated Sites - From Theory Towards Practical Application.* Bilthoven: Springer Science+Business Media B.V.

Sweco. (2022). *Sammanställning och utvärdering av jord- och grundvattendata från förstudier.* Retrieved from SGU: https://www.sgu.se/globalassets/samhallsplanering/fororenade-omraden/plantskolor-och-bekampningsmedel/sammanstallning-och-utvardering-av-jord--och-grundvattendata-fran-forstudier.pdf?_t_tags=siteid%3Ad78b016e-2a51-437d-a75a-657400cdd11c%2Clanguage%3Aen&_t

Swedish Environmental Protection Agency. (2012). *National Implementation Plan for the Stockholm Convention on Persistent Organic Pollutants for Sweden 2012.* Stockholm: Swedish Environmental Protection Agency.

Tome, D., Kroffel, M., & Mihelic, T. (2009). The diet of the raven Corvus corax in south-west Slovenia. *Annales, 19*(2).

Traas, T. P., & Luttik, R. &. (1996). A Probabilistic Model for Deriving Soil Quality Criteria Based on Secondary Poisoning of Top Predators. *Ecotoxicology and Environmental Safety*, pp. 264-278.

Turusov, V., Rikitsky, V., & Tomatis, L. (02 2002). Dichlorodiphenyltrichloroethane (DDT): Ubiquity, Persistence, and Risks. *Environmental Health Perspectives, 110*(2).

Tyréns. (2020). *Utvärderingsrapport - Miljöteknisk Markundersökning Kompletterande Utredning, Kolleberga Plantskola.* Örnsköldsvik: Tyréns.

Törneman, N., Cox, E. E., Durant, N. D., Azziz, C., & Bouwer, E. (2009). *Biotillgänglighet som företeelse och vid riskbedömningar av förorenade områden.* Bromma: Naturvårdsverket.

University of Michigan. (1999). *Corvus corax - common raven*. Retrieved from animaldiversity.org: https://animaldiversity.org/accounts/Corvus_corax/ 04 2024

US EPA. (03 04 2023). *DDT - A Brief History and Status*. Retrieved from epa.gov: https://www.epa.gov/ingredients-used-pesticide-products/ddt-brief-history-and-status

USEPA. (2024). *ECOTOX Knowledgebase*. Hämtat från cfpub.epa.gov: https://cfpub.epa.gov/ecotox/search.cfm

van den Berg, H., Manuweera, G., & Konradsen, F. (2017). Global trends in the production and use of DDT for control of malaria and other vector-borne diseases. *Malaria Journal*.

van Gasteren, H., Both, I., Shamoun-Barnes, J., & Laloë, J.-O. (12 2014). GPS-logger onderzoek aan Buizerds helpt vongelaanvaringen op militaire vliegvelden te voorkomen [A pilot study on GPS tracking of Common Buzzards Buteo buteo at military airfields to advance bird strike prevention]. *Limosa, 87*(2), pp. 107-116.

Vermeulen, F., Covaci, A., D'Havé, H., Van den Brink, N. W., Blust, R., De Coen, W., & Bervoets, L. (2010). Accumulation of background levels of persistent organochlorine and organobromine pollutants through the soil–earthworm–hedgehog food chain. *Environment International, 36*(7), pp. 721-727.

Viro, P., & Sulkava, S. (1985). Food of the Bank Vole in Northern Finnish Spruce Forests. *Acta Theriologica, 30*(15), pp. 259-266.

Väli, Ü. (2017). Home range size and breeding dispersal of a common buzzard (Buteo buteo). *Slovak Raptor Journal, 11*, pp. 111-116.

Wal, E. V., & Rodgers, A. R. (10 01 2012). An individual-based quantitative approach for delineating core areas of animal space use. *Ecological Modelling*, *224*(1), 48-53. doi:https://doi.org/10.1016/j.ecolmodel.2011.10.006¨

Wang, J., Wang, J., Zhang, Z., Li, Y., Zhang, B., Zhang, Z., & Zhang, G. (01 08 2016). Cold-adapted bacteria for bioremediation of crude oil-contaminated soil. *Journal of Chemical Technology and Biotechnology, 91*(8), pp. 2286-2297.

WHO. (2020, 11 02). *Food safety: Persistent Organic Pollutants (POPs)*. Retrieved from who.int: https://www.who.int/news-room/questions-and-answers/item/food-safety-persistent-organic-pollutants-(pops)

WSP. (den 23 April 2024). *Projekt*. Retrieved from Prioritera saneringsåtgärder genom platsspecifik miljö- och hälsoriskbedömning: https://www.wsp.com/sv-se/projekt/prioritera-saneringsatgarder-genom-platsspecifik-miljo-och-halsoriskbedomning

Wåhlén, H., & Eliaeson, K. (2020). *Efterbehandling av DDT-förorenad jord.* Örebro: Structor.

Yan, A., Wang, Y., Tan, S. N., Yusof, M. L., Ghosh, S., & Chen, Z. (30 04 2020). Phytoremediation: A Promising Approach for Revegetation of Heavy Metal-Polluted Land. *Sec. Plant Biotechnology, 11*.

Yergeau, E., Arbour, M., Brousseau, R., Juck, D., Lawrence, J. R., Masson, L., . . . Greer, C. W. (10 2009). Microarray and real-time PCR analyses of the responses of high-arctic soil bacteria to hydrocarbon pollution and bioremediation treatments. *Applied and Environmental Microbiology, 75*(19), pp. 6258-6267.

Zabala, J., Garin, I., Zuberogoitia, I., & Aihartza, J. (2002). Habitat selection and diet ofbadgers (Meles meles) in Biscay (northern Iberian Peninsula). *Italian Journal of Zoology, 69*, pp. 233-238.

Zawadzka, D. (1999). Feeding habits of the Black Kite Milvus migrans, Red Kite Milvus milvus, White-tailed Eagle Haliaeetus albicilla and Lesser Spotted Eagle Aquila pomarina in Wigry National Park (NE Poland). *Acta Ornithologica*, pp. 65-75.

Öberg, J. K. (2023). *Trädgårdstrendernas påverkan på inskters levnadsmiljö i privatträdgården - En studie om trädgårdshistoriska och blombesökande insekters krav på levnadsmiljö.* Alnarp: SLU.

Appendix A
Measured DDT-Concentration in Kolleberga

Appendix A 1: DDT measurements from the field at the Kolleberga forest nursery with the assumption that ND=DL The values marked in red are values that exceed the limit values for MKM in accordance with (Naturvårdsverket, 2016). Sourced from: (Tyréns, 2020). Beneath the DDT-data the corresponding correlation coefficients (R^2) are shown for each form of DDD, DDE and DDT, estimated through Goodness-Of-Fit (G.O.F.) tests using the © ProUCL 5.2 software.

Measurement point	**DDD, p,p'**	**DDD-o,p**	**DDE, p,p'**	**DDE-o,p**	**DDT-o,p**	**DDT, p,p'**	**Sum DDT**
	mg/kg TS	mg/kg TS	mg/kg TS	mg/kg TS	mg/kg TS	mg/kg TS	mg/kg TS
T38B	0,25	0,09	0,41	*0,023*	0,19	0,73	1,69
T33	0,35	0,11	0,35	0,019	0,4	1,1	2,33
T37	0,32	0,08	0,35	0,014	0,33	1	2,09
T34	0,69	0,19	0,76	0,035	1,1	2,8	5,58
T35	0,69	0,18	0,61	0,033	0,72	2,5	4,73
T31	0,65	0,2	0,52	0,027	0,68	2,5	4,58
T30	0,72	0,19	0,85	0,035	1	3,4	6,2
T32	0,72	0,19	0,66	0,029	0,83	3,1	5,53
T123	0,061	0,26	0,024	1	0,64	3,2	5,19
T36	0,14	0,03	0,13	*0,012*	0,088	0,65	1,05
T121	0,085	0,42	0,047	1,6	1	5,2	8,35
T122	0,059	0,33	0,025	1	0,71	3,9	6,02
T117	0,07	0,34	0,025	0,75	0,78	3,7	5,67
T118	0,075	0,45	0,026	1,1	0,85	4,7	7,2
T120	0,1	0,55	0,049	1,6	1,3	6,8	10,4
T119	0,13	0,68	0,055	1,7	1,6	8,3	12,47
T114	0,15	0,8	0,044	1,4	1,7	8,3	12,39
T116	0,18	0,91	0,06	1,9	2,1	11	16,15
T112	0,18	0,78	0,039	1,1	1,6	8,1	11,8
T113	1,5	0,22	1,2	0,044	3,3	17	23,26
T115	0,083	0,49	0,018	0,48	1,4	7,3	9,77
T111	0,3	0,031	0,25	0,0084	0,31	2,9	3,8

Correlation coefficient	**DDD, p,p'**	**DDD-o,p**	**DDE, p,p'**	**DDE-o,p**	**DDT-o,p**	**DDT, p,p'**	**Sum DDT**
Normal	0.865	0.955	0.901	0.908	0.937	0.922	0.939
Gamma	0.969	0.979	0.978	0.864	0.988	0.988	0.991
Log-normal	0.971	0.971	0.952	0.915	0.969	0.979	0.983

*Appendix A 2: DDT measurements from the field at the Kolleberga forest nursery with the assumption that ND=0.5*DL The values marked in red are values that exceed the limit values for MKM in accordance with (Naturvårdsverket, 2016). Sourced from: (Tyréns, 2020). Beneath the DDT-data the corresponding correlation coefficients (R^2) are shown for each form of DDD, DDE and DDT, estimated through Goodness-Of-Fit (G.O.F.) tests using the © ProUCL 5.2 software.*

Measurement point	DDD, p,p'	DDD-o,p	DDE, p,p'	DDE-o,p	DDT-o,p	DDT, p,p'	Sum DDT
	mg/kg TS	mg/kg TS	mg/kg TS	mg/kg TS	mg/kg TS	mg/kg TS	mg/kg TS
T112	0,18	0,78	0,039	1,1	1,6	8,1	11,8
T30	0,72	0,19	0,85	0,035	1	3,4	6,2
T113	1,5	0,22	1,2	0,044	3,3	17	23,26
T114	0,15	0,8	0,044	1,4	1,7	8,3	12,39
T31	0,65	0,2	0,52	0,027	0,68	2,5	4,58
T115	0,083	0,49	0,018	0,48	1,4	7,3	9,77
T32	0,72	0,19	0,66	0,029	0,83	3,1	5,53
T116	0,18	0,91	0,06	1,9	2,1	11	16,15
T117	0,07	0,34	0,025	0,75	0,78	3,7	5,67
T33	0,35	0,11	0,35	0,019	0,4	1,1	2,33
T118	0,075	0,45	0,026	1,1	0,85	4,7	7,2
T34	0,69	0,19	0,76	0,035	1,1	2,8	5,58
T119	0,13	0,68	0,055	1,7	1,6	8,3	12,47
T120	0,1	0,55	0,049	1,6	1,3	6,8	10,4
T35	0,69	0,18	0,61	0,033	0,72	2,5	4,73
T121	0,085	0,42	0,047	1,6	1	5,2	8,35
T122	0,059	0,33	0,025	1	0,71	3,9	6,02
T123	0,061	0,26	0,024	1	0,64	3,2	5,19
T37	0,32	0,08	0,35	0,014	0,33	1	2,09
T38B	0,25	0,09	0,41	***0,0115***	0,19	0,73	1,68
T36	0,14	0,03	0,13	***0,006***	0,088	0,65	1,04
T111	0,3	0,031	0,25	0,0084	0,31	2,9	3,8

Correlation coefficient	DDD, p,p’	DDD-o,p	DDE, p,p’	DDE-o,p	DDT-o,p	DDT, p,p’	Sum DDT
Normal	0.865	0.955	0.901	0.908	0.937	0.922	0.939
Gamma	0.969	0.979	0.978	0.864	0.988	0.988	0.991
Log-normal	0.971	0.971	0.952	0.915	0.969	0.979	0.983

Appendix A 3: DDT measurements from dipping area and the plant landfill at the Kolleberga forest nursery with the assumption that ND=DL The values marked in red are values that exceed the limit values for MKM, the values marked in yellow are below the limit values for MKM but above the limit values for KM, and the values marked in green are below the limit values for KM in accordance with (Naturvårdsverket, 2016). Sourced from: (Tyréns, 2020). Beneath the DDT-data the corresponding correlation coefficients (R^2) are shown for each form of DDD, DDE and DDT, estimated through Goodness-Of-Fit (G.O.F.) tests using the © ProUCL 5.2 software.

Measurement point	**DDD, p,p'**	**DDD-o,p**	**DDE, p,p'**	**DDE-o,p**	**DDT-o,p**	**DDT, p,p'**	**Sum DDT**
	mg/kg TS	mg/kg TS	mg/kg TS	mg/kg TS	mg/kg TS	mg/kg TS	mg/kg TS
T39A	0,31	0,098	0,26	*0,023*	0,22	1,1	2,01
T109	0,11	0,012	0,23	0,0024	0,18	1,5	2,03
T106	1,4	0,34	2,1	0,035	2,9	19	25,78
T41A	15	0,55	3,8	0,091	7,3	34	60,74
T40A	9,5	0,38	3,1	0,051	3	15	31,03
T105	15	2,6	15	*0,03*	24	120	176,63
T108	19	6,7	3,3	*0,03*	38	160	227,03
T101	0,055	0,0049	0,12	*0,001*	0,055	0,58	0,82
T102	*0,03*	*0,03*	*0,03*	*0,03*	*0,03*	0,074	0,22
T103	*0,03*	*0,03*	*0,03*	*0,03*	*0,03*	*0,03*	0,18
T43	*0,012*	*0,024*	*0,012*	*0,024*	*0,012*	*0,012*	0,1
T104	*0,001*	*0,001*	0,0036	*0,001*	*0,001*	0,0055	0,01
T107	*0,001*	0,0048	0,025	*0,001*	0,0077	0,045	0,08
T110	*0,03*	*0,03*	*0,03*	*0,03*	*0,03*	*0,03*	0,18
T42	0,017	*0,023*	0,021	*0,023*	*0,012*	0,017	0,11
T44	1,2	0,41	0,24	*0,027*	0,021	0,086	1,97
T45	0,87	0,3	0,28	*0,026*	0,058	0,28	1,8

Correlation coefficient	**DDD, p,p'**	**DDD-o,p**	**DDE, p,p'**	**DDE-o,p**	**DDT-o,p**	**DDT, p,p'**	**Sum DDT**
Normal	0.788	0.655	0.695	0.889	0.695	0.71	0.726
Gamma	0.916	0.952	0.96	0.928	0.981	0.97	0.97
Log-normal	0.975	0.985	0.974	0.859	0.962	0.968	0.974

*Appendix A 4: DDT measurements from dipping area and the plant landfill at the Kolleberga forest nursery with the assumption that ND=0.5*DL The values marked in red are values that exceed the limit values for MKM, the values marked in yellow are below the limit values for MKM but above the limit values for KM, and the values marked in green are below the limit values for KM in accordance with (Naturvårdsverket, 2016). Sourced from: (Tyréns, 2020). Beneath the DDT-data the corresponding correlation coefficients (R^2) are shown for each form of DDD, DDE and DDT, estimated through Goodness-Of-Fit (G.O.F.) tests using the © ProUCL 5.2 software.*

Measurement point	**DDD, p,p'**	**DDD-o,p**	**DDE, p,p'**	**DDE-o,p**	**DDT-o,p**	**DDT, p,p'**	**Sum DDT**
	mg/kg TS	mg/kg TS	mg/kg TS	mg/kg TS	mg/kg TS	mg/kg TS	mg/kg TS
T39A	0,31	0,098	0,26	***0,0115***	0,22	1,1	2
T109	0,11	0,012	0,23	0,0024	0,18	1,5	2,03
T106	1,4	0,34	2,1	0,035	2,9	19	25,78
T41A	15	0,55	3,8	0,091	7,3	34	60,74
T40A	9,5	0,38	3,1	0,051	3	15	31,03
T105	15	2,6	15	***0,015***	24	120	176,62
T108	19	6,7	3,3	***0,015***	38	160	227,02
T101	0,055	0,0049	0,12	***0,0005***	0,055	0,58	0,82
T102	***0,015***	***0,015***	***0,015***	***0,015***	***0,015***	0,074	0,15
T103	***0,015***	***0,015***	***0,015***	***0,015***	***0,015***	***0,015***	0,09
T43	***0,006***	***0,012***	***0,006***	***0,012***	***0,006***	***0,006***	0,05
T104	***0,0005***	***0,0005***	0,0036	***0,0005***	***0,0005***	0,0055	0,01
T107	***0,0005***	0,0048	0,025	***0,0005***	0,0077	0,045	0,08
T110	***0,015***	***0,015***	***0,015***	***0,015***	***0,015***	***0,015***	0,09
T42	0,017	***0,0115***	0,021	***0,0115***	***0,006***	0,017	0,08
T44	1,2	0,41	0,24	***0,0135***	0,021	0,086	1,97
T45	0,87	0,3	0,28	***0,013***	0,058	0,28	1,8

Correlation coefficient	**DDD, p,p'**	**DDD-o,p**	**DDE, p,p'**	**DDE-o,p**	**DDT-o,p**	**DDT, p,p'**	**Sum DDT**
Normal	0.788	0.655	0.696	0.811	0.695	0.71	0.726
Gamma	0.912	0.958	0.962	0.956	0.981	0.97	0.97
Log-normal	0.974	0.971	0.972	0.906	0.966	0.968	0.97

Appendix A 5: DDT measurements from the built areas connected to the Kolleberga forest nurser assuming that ND:s (written in italic) are equal to the detection limit. The values marked in red are values that exceed the limit values for MKM, the values marked in yellow are below the limit values for MKM but above the limit values for KM, and the values marked in green are below the limit values for KM in accordance with (Naturvårdsverket, 2016). Sourced from: (Tyréns, 2020). Beneath the DDT-data the corresponding correlation coefficients (R^2) are shown for each form of DDD, DDE and DDT, estimated through Goodness-Of-Fit (G.O.F.) tests using the © ProUCL 5.2 software.

Measurement point	**DDD, p,p'**	**DDD-o,p**	**DDE, p,p'**	**DDE-o,p**	**DDT-o,p**	**DDT, p,p'**	**Sum DDT**
	mg/kg TS	mg/kg TS	mg/kg TS	mg/kg TS	mg/kg TS	mg/kg TS	mg/kg TS
T1	0,2	1	0,035	1,4	2,2	10	15
T2	0,087	0,32	0,017	0,69	0,63	3,3	5
T3	1,1	3,2	0,074	4,8	6,5	37	53
T4	0,11	0,43	0,018	0,64	0,94	5,4	7,5
T5	0,1	0,45	0,02	0,8	0,89	4,3	6,6
T6	0,12	0,7	0,018	0,94	1,2	7,7	11
T7	0,097	0,37	0,012	0,59	0,68	3,3	5
T8	0,024	0,2	0,005	0,22	0,21	1,3	2
T9	0,024	0,15	0,0056	0,21	0,21	1,8	2,4
T10	*0,001*	0,0026	*0,001*	0,0083	0,0058	0,02	0,038

Correlation coefficient	**DDD, p,p'**	**DDD-o,p**	**DDE, p,p'**	**DDE-o,p**	**DDT-o,p**	**DDT, p,p'**	**Sum DDT**
Normal	0.706	0.786	0.866	0.782	0.791	0.772	0.776
Gamma	0.917	0.956	0.969	0.944	0.964	0.953	0.954
Log-normal	0.916	0.879	0.956	0.905	0.914	0.887	0.894

Appendix B
Parameters Defining Distribution

Appendix B 1: Table showing the parameters defining distribution of Bioaccumulation Factors (BAFs) for the different food groups used in this thesis. The BAF distribution which have data both with and without the implementation of biochar were calculated from the Kolleberga site, the other distribution parameters were sourced from Rundegren (2019). A full list of the raw data used to fit the distributions from Kolleberga is found in Appendix D.

Parameter	**Description of parameter**	**Type of distribution**	**Parameters defining distribution**	**Additional information**	**Statistical parameters used to analyse the best fit**
BAF_{Mammal}	Bioaccumulation factor for mammals.	Triangular	Minimum: -2.733 Most likely: 0.704 Maximum: 0.704	Value truncation at 0 to discard negative values in the distribution. Distribution parameters sourced from Rundegren (2019).	A-D: N/A. p-value: N/A.
BAF_{Bird}	Bioaccumulation factor for birds.	Triangular	Minimum: -2.824 Most likely: 0.331 Maximum: 0.331	Value truncation at 0 to discard negative values in the distribution. Distribution parameters sourced from Rundegren (2019).	A-D: N/A. p-value: N/A.
$BAF_{Leaves\_w.o,\_biochar}$	Bioaccumulation factor for leaves without implementing biochar.	ExtValue	a: 0.006952 b: 0.004184	Site-specific data for the uptake in salix leaves from the ongoing pilot experiment was used to calculate the BAFs which were fitted into distributions. Value truncation at 0 to discard negative values in the distribution.	A-D: 0.1736 p-value: 0.975
$BAF_{Leaves\_w.\_biochar}$	Bioaccumulation factor for leaves with the implementation of biochar.	Normal	μ: 0.00535 σ: 0.00105	Site-specific data for the uptake in salix leaves from the ongoing pilot experiment was used to calculate the BAFs which were fitted into distributions. Value truncation at 0 to discard negative values in the distribution.	A-D: 0.4766 p-value: 0.138

$BAF_{Grass\_w.o.\_biochar}$	Bioaccumulation factor for grass without the implementation of biochar.	Normal	μ: 0.0181 σ: 0.00678	Site-specific data for a grass blend from the ongoing pilot experiment was used to calculate the BAFs which were fitted into distributions. Value truncation at 0 to discard negative values in the distribution.	A-D: N/A p-value: N/A
$BAF_{Grass\_w.\_biochar}$	Bioaccumulation factor for grass with the implementation of biochar.	Normal	μ: 0.00776 σ: 0.00105	Site-specific data for a grass blend from the ongoing pilot experiment was used to calculate the BAFs which were fitted into distributions. Value truncation at 0 to discard negative values in the distribution.	A-D: N/A p-value: N/A
$BAF_{Soft\ invertebrates\_w.o.\_biochar}$	Bioaccumulation factor for soft bodied invertebrates without the implementation of biochar.	Normal	μ: 0.613 σ: 0.0545	Site-specific data for earthworms from the ongoing pilot experiment was used to calculate the BAFs which were fitted into distributions. Value truncation at 0 to discard negative values in the distribution.	A-D: N/A p-value: N/A
$BAF_{Soft\ invertebrates\_w.\_biochar}$	Bioaccumulation factor for soft bodied invertebrates without the implementation of biochar.	Normal	μ: 0.292 σ: 0.0165	Site-specific data for earthworms from the ongoing pilot experiment was used to calculate the BAFs which were fitted into distributions. Value truncation at 0 to discard negative values in the distribution.	A-D: N/A p-value: N/A
BAF_{Seeds}	Bioaccumulation factor for seeds.	Uniform	Minimum: -2.261 Maximum: 0.361	Value truncation at 0 to discard negative values in the distribution. Distribution parameters sourced from Rundegren (2019).	A-D: 0.250 p-value: 0.924
$BAF_{Hard\_invertebrates}$	Bioaccumulation factor for hard bodied invertebrates.	Logistic	α: -0.0222 β: 0.372	Value truncation at 0 to discard negative values in the distribution. Distribution parameters sourced from Rundegren (2019).	A-D: 0.486 p-value: 0.173

Appendix B 2: Table showing the parameters defining distribution of DDT-concentration for the different subareas at the site. A full list of the raw data used to fit the distributions is found in Appendix C.

Parameter	**Description of parameter**	**Type of distribution**	**Parameters defining distribution**	**Additional information**
c_{field}	DDT-concentration in the field	Lognormal	μ: 7.556 σ: 5.284	Value truncation at 0 to discard negative values. Data fitted from the provided measurements of DDT from Tyréns (2020).
c_{DA+LF}	DDT-concentration in the dipping area and landfill	Lognormal	μ: 31.2 σ: 66.9	Value truncation at 0 to discard negative values. Data fitted from the provided measurements of DDT from Tyréns (2020).
c_{BA}	DDT-concentration in the built area	Lognormal	μ: 10.75 σ: 15.49	Value truncation at 0 to discard negative values. Data fitted from the provided measurements of DDT from Tyréns (2020).

Appendix B 3: Table showing the parameters defining distribution of home range for the different species analyzed.

Parameter	Description of parameter	Type of distribution	Parameters defining distribution	Additional information
HR_{Badger}	Home range distribution for badgers.	Normal	μ: 0.2477 σ: 0.2655	Value truncation at 0 to discard negative values. Data fitted from the literature study. The fitted data can be seen in Appendix B5.
$HR_{Common\ Buzzard}$	Home range distribution for common buzzards	Lognormal	μ: 3.791 σ: 3.270	Value truncation at 0 to discard negative values. Data fitted from the literature study. The fitted data can be seen in Appendix B2.
$HR_{Common\ Raven}$	Home range distribution for common ravens	Lognormal	μ: 11.27 σ: 10.48	Value truncation at 0 to discard negative values. Data fitted from the literature study. The fitted data can be seen in Appendix B4.
$HR_{Great\ Spotted\ Woodpecker}$	Home range distribution for great spotted woodpeckers	Lognormal	μ: 0.1167 σ: 0.07638	Value truncation at 0 to discard negative values. Data fitted from the literature study. The fitted data can be seen in Appendix B3.
$HR_{Red\ Kite}$	Home range distribution for red kites	Lognormal	μ: 27.73 σ: 31.18	Value truncation at 0 to discard negative values. Data fitted from the literature study. The fitted data can be seen in Appendix B1.
HR_{Weasel}	Home range distribution for weasels	Lognormal	μ: 0.2477 σ: 0.2655	Value truncation at 0 to discard negative values. Data fitted from the literature study. The fitted data can be seen in Appendix B6.

Appendix B 4: Distribution parameters for the generic NOEC values sourced from Rundegren (2019).

Parameter	Description of parameter	Type of distribution	Parameters defining distribution	Additional information
$NOEC_{Birds}$	Generic No-Observed Effect Concentration for birds.	Logistic	α: 0.978 β: 0.418	Values log-converted from the generic NOEC-values found in Appendix L2.
$NOEC_{Mammals}$	Generic No-Observed Effect Concentration for mammals.	Logistic	α: 1.94 β: 0.277	Values log-converted from the generic NOEC-values found in Appendix L2.

Appendix C
Raw Data Used to Obtain Distributions for Site-Specific BAFS

Appendix C 1: Raw data used from the Kolleberga site provided from the ongoing pilot experiment lead by Paul Drenning (2024).

Type of species	**Food group**	**Soil concentration (mg/kg DS)**	**Species concentration**	**BAF [-]**	**Source**	**Additional information**
Grass blend (without biochar)	Grass	6.77	0.166 mg/kg DW	0.0245	Measurements from the site provided by Drenning (2024).	No information about water content which is why the dry weight was used. Measurements from box 1, treatment type 3 in 2021 from the ongoing pilot experiment by Paul Drenning (2024).
Grass blend (without biochar)	Grass	6.77	0.128 mg/kg DW	0.0189	Measurements from the site provided by Drenning (2024).	No information about water content which is why the dry weight was used. Measurements from box 2, treatment type 3 in 2021 from the ongoing pilot experiment by Paul Drenning (2024).
Grass blend (without biochar)	Grass	6.77	0.0744 mg/kg DW	0.0110	Measurements from the site provided by Drenning (2024).	No information about water content which is why the dry weight was used. Measurements from box 3, treatment type 3 in 2021 from the ongoing pilot experiment by Paul Drenning (2024).
Grass blend (with biochar)	Grass	7.18	0.0627 mg/kg DW	0.00874	Measurements from the site provided by Drenning (2024).	No information about water content which is why the dry weight was used. Measurements from box 1, treatment type 4 in 2021 from the

						ongoing pilot experiment by Paul Drenning (2024).
Grass blend (with biochar)	Grass	7.18	0.0567 mg/kg DW	0.00790	Measurements from the site provided by Drenning (2024).	No information about water content which is why the dry weight was used. Measurements from box 2, treatment type 4 in 2021 from the ongoing pilot experiment by Paul Drenning (2024).
Grass blend (with biochar)	Grass	7.18	0.0477 mg/kg DW	0.00665	Measurements from the site provided by Drenning (2024).	No information about water content which is why the dry weight was used. Measurements from box 2, treatment type 4 in 2021 from the ongoing pilot experiment by Paul Drenning (2024).
Salix leaves (without biochar)	Leaves	6.77	0.0303 mg/kg DW	0.00447	Measurements from the site provided by Drenning (2024).	No information about water content which is why the dry weight was used. Measurements from box 1, treatment type 5 in 2022 from the ongoing pilot experiment by Paul Drenning (2024).
Salix leaves (without biochar)	Leaves	6.77	0.0301 mg/kg DW	0.00420	Measurements from the site provided by Drenning (2024).	No information about water content which is why the dry weight was used. Measurements from box 2, treatment type 5 in 2022 from the ongoing pilot experiment by Paul Drenning (2024).
Salix leaves (without biochar)	Leaves	6.77	0.0459 mg/kg DW	0.00417	Measurements from the site provided by Drenning (2024).	No information about water content which is why the dry weight was used. Measurements from box 3, treatment type 5 in 2022 from the ongoing pilot experiment by Paul Drenning (2024).

Salix leaves (without biochar)	Leaves	7.16	0.0425 mg/kg DW	0.00592	Measurements from the site provided by Drenning (2024).	No information about water content which is why the dry weight was used. Measurements from box 1, treatment type 7 in 2022 from the ongoing pilot experiment by Paul Drenning (2024).
Salix leaves (without biochar)	Leaves	7.16	0.0425 mg/kg DW	0.00629	Measurements from the site provided by Drenning (2024).	No information about water content which is why the dry weight was used. Measurements from box 2, treatment type 7 in 2022 from the ongoing pilot experiment by Paul Drenning (2024).
Salix leaves (without biochar)	Leaves	7.16	0.0381 mg/kg DW	0.00535	Measurements from the site provided by Drenning (2024).	No information about water content which is why the dry weight was used. Measurements from box 3, treatment type 7 in 2022 from the ongoing pilot experiment by Paul Drenning (2024).
Salix leaves (with biochar)	Leaves	7.18	0.0302 mg/kg DW	0.00447	Measurements from the site provided by Drenning (2024).	No information about water content which is why the dry weight was used. Measurements from box 1, treatment type 8 in 2022 from the ongoing pilot experiment by Paul Drenning (2024).
Salix leaves (with biochar)	Leaves	7.18	0.0341 mg/kg DW	0.00505	Measurements from the site provided by Drenning (2024).	No information about water content which is why the dry weight was used. Measurements from box 2, treatment type 8 in 2022 from the ongoing pilot experiment by Paul Drenning (2024).

Salix leaves (with biochar)	Leaves	7.18	0.0320 mg/kg DW	0.00474	Measurements from the site provided by Drenning (2024).	No information about water content which is why the dry weight was used. Measurements from box 3, treatment type 8 in 2022 from the ongoing pilot experiment by Paul Drenning (2024).
Salix leaves (with biochar)	Leaves	7.76	0.0417 mg/kg DW	0.00617	Measurements from the site provided by Drenning (2024).	No information about water content which is why the dry weight was used. Measurements from box 1, treatment type 8 in 2022 from the ongoing pilot experiment by Paul Drenning (2024).
Salix leaves (with biochar)	Leaves	7.76	0.0482 mg/kg DW	0.00713	Measurements from the site provided by Drenning (2024).	No information about water content which is why the dry weight was used. Measurements from box 2, treatment type 8 in 2022 from the ongoing pilot experiment by Paul Drenning (2024).
Salix leaves (with biochar)	Leaves	7.76	0.0520 mg/kg DW	0.00770	Measurements from the site provided by Drenning (2024).	No information about water content which is why the dry weight was used. Measurements from box 3, treatment type 8 in 2022 from the ongoing pilot experiment by Paul Drenning (2024).
Earthworms (Without biochar)	Soft bodied invertebrates	7.15	4.90 mg/kg WW	0.685	Measurements from the site provided by Drenning (2024).	Measurements of DDT-uptake in earthworms from treatment type 1 from the ongoing pilot experiment. Data provided by Paul Drenning (2024).
Earthworms (Without biochar)	Soft bodied invertebrates	6.77	4.04 mg/kg WW	0.596	Measurements from the site	Measurements of DDT-uptake in earthworms from treatment type 2 from the ongoing pilot experiment.

					provided by Drenning (2024).	Data provided by Paul Drenning (2024).
Earthworms (Without biochar)	Soft bodied invertebrates	7.16	3.97 mg/kg WW	0.554	Measurements from the site provided by Drenning (2024).	Measurements of DDT-uptake in earthworms from treatment type 3 from the ongoing pilot experiment. Data provided by Paul Drenning (2024).
Earthworms (Without biochar)	Soft bodied invertebrates	6.75	4.18 mg/kg WW	0.619	Measurements from the site provided by Drenning (2024).	Measurements of DDT-uptake in earthworms from treatment type 4 from the ongoing pilot experiment. Data provided by Paul Drenning (2024).
Earthworms (With biochar)	Soft bodied invertebrates	6.83	2.02 mg/kg WW	0.296	Measurements from the site provided by Drenning (2024).	Measurements of DDT-uptake in earthworms from treatment type 5 from the ongoing pilot experiment. Data provided by Paul Drenning (2024).
Earthworms (With biochar)	Soft bodied invertebrates	7.18	1.92 mg/kg WW	0.267	Measurements from the site provided by Drenning (2024).	Measurements of DDT-uptake in earthworms from treatment type 6 from the ongoing pilot experiment. Data provided by Paul Drenning (2024).
Earthworms (With biochar)	Soft bodied invertebrates	7.76	2.34 mg/kg WW	0.302	Measurements from the site provided by Drenning (2024).	Measurements of DDT-uptake in earthworms from treatment type 7 from the ongoing pilot experiment. Data provided by Paul Drenning (2024).
Earthworms (With biochar)	Soft bodied invertebrates	7.12	2.14 mg/kg WW	0.301	Measurements from the site provided by Drenning (2024).	Measurements of DDT-uptake in earthworms from treatment type 8 from the ongoing pilot experiment. Data provided by Paul Drenning (2024).

Appendix D
Home Range Data

Appendix D 1: Home ranges for Milvus Milvus (Red Kite) found during the literature search. The values marked in yellow were considered as extreme values and excluded from the final home range distribution.

Name	***Latin name***	**Home range**	**Additional information**	**Country**	**Source**
Red kite	*Milvus Milvus*	63.6 km^2 (4.8-507.1 km^2)	Median during nesting periods.	Germany	(Pfeiffer & Meyburg, 2015)
Red kite	*Milvus Milvus*	6.2-8.0 km^2	For the MCP 95%. (Average 7.1 km^2)	Germany	(Nachtigall, Stubbe, & Herrmann, 2003)
Red kite	*Milvus Milvus*	190 km^2	Average home range for the MCP 95%. Standard deviation of +/- 144 km^2.	Czech Republic, Austria, and Slovakia	(Skrabal, o.a., 2021)
Red kite	*Milvus Milvus*	12.5 km^2	Average home range for the MCP 95%. Estimation for a juvenile. Standard deviation of +/- 4.6 km^2.	Austria and Slovakia	(Nemček, 2014)

Appendix D 2: Home ranges for Buteo Buteo (Common Buzzard) found during the literature search.

Name	*Latin name*	Home range	Additional information	Country/region	Source
Common buzzard	*Buteo Buteo*	5.88-16.77 km^2	For the Kernel 95%.	Estonia	(Väli, 2017)
Common buzzard	*Buteo Buteo*	0.28-1.13 km^2	For the Kernel 95%.	Leeuwarden, The Netherlands	(van Gasteren et al., 2014)
Common buzzard	*Buteo Buteo*	0.48-5.17 km^2	For the Kernel 95%.	Eindhoven, The Netherlands	(van Gasteren et al., 2014)
Common buzzard	*Buteo Buteo*	0.43-2.80 km^2	Using radio tagging. The lower value indicate core area while the higher include 99%	United Kingdom	(Kenward et al., 2001)

Appendix D 3: Home ranges for Dendrocopos Major (Great Spotted Woodpecker) found during the literature search.

Name	*Latin name*	Home range	Additional information	Country/region	Source
Great Spotted Woodpecker	*Dendrocopos Major*	0.1 km^2	Average home range	Lombardy, Italy	(Piacentini & Chiatante, 2022)
Great Spotted Woodpecker	*Dendrocopos Major*	0.07-0.43 km^2	85% home range estimate average during the breeding season. Avg: 0.2 km^2	Swedish-Norwegian border	(Rolstad et al., 1995)
Great Spotted Woodpecker	*Dendrocopos Major*	0.05 km^2	100% MCP for both Great Spotted Woodpecker and Middle Spotted Woodpecker.	Northeastern Switzerland	(Bachmann & Pasinelli, 2002)

Appendix D 4: Home ranges for Corvus corax (common raven) found during the literature search. Extreme values excluded in the final home range distribution are marked yellow.

Name	***Latin name***	**Home range**	**Additional information**	**Country**	**Source**
Common raven	*Corvus Corax*	0.3-45.8 km^2	In California	United States	(Linz et al., 1992)
Common raven	*Corvus Corax*	27.3-195 km^2	In Minnesota	United States	(Dinkins et al., 2016)
Common raven	*Corvus Corax*	5.1-40.5 km^2	Territory size, not guaranteed to be the same as home range.	Not specified	(University of Michigan, 1999)
Common raven	*Corvus Corax*	0.82-3.81 km^2	+/- 0.415 km^2. In Redwood National and state parks.	United States	(Scarpignato, 2011)
Common raven	*Corvus corax*	84-1814 km^2	Capture and subsequent GPS tracking. Calculation with MCP	Saint-Flour, Auvergne-Rhône-Alpes, France	(Marchand, et al., 2018)
Common raven	*Corvus corax*	0.067-0.597 km^2	Radio tracking and 95% Utilisation Distribution, report dismissed MCP for giving misleading results.	Almtal, Upper Austria, Austria	(Loretto et al., 2015)
Common raven	*Corvus corax*	8.2 km^2 +/- 12.5 km^2	Mixed approach and thus mixed methods. MCP.	Narwhal Island, Alaska	(Powell et al., 2007)

Appendix D 5: Home ranges for Meles Meles (Badger) found during the literature search.

Name	***Latin name***	**Home range**	**Additional information**	**Country/region**	**Source**
Badger	*Meles Meles*	2.96-3.94 km^2	Estimated by using 100% MCP.	Jutland, Denmark	(Elmeros et al., 2005)
Badger	*Meles Meles*	0.728-3.076 km^2	Mean home ranges for males females (0.728 +/- 0.151 km^2) and males (3.076 +/- 0.964 km^2) respectively using 95% MCP.	Catalonia, Spain	(Molina-Vacas et al., 2009)
Badger	*Meles Meles*	0.029-0.138 km^2	100% MCP used. Both rotational (Avg. 0.0625) and continuous (Avg. 0.0705) methods used.	Brighton, United Kingdom	(Huck et al., 2008)
Badger	*Meles Meles*	2.56-4.29 km^2	Radio-tracking and displacement from its nesting site used to estimate the home ranges. Home ranges are calculated on group level (10 badgers in 3 groups)	Grand Est region, France	(Bodin et al., 2006)
Badger	*Meles Meles*	0.425-1.718 km^2	100% MCP from radio-tracking used to estimate the home ranges. (Avg. 0.765 km^2 +/- 0.49 km^2)	Luxembourg	(Frantz et al., 2010)
Badger	*Meles Meles*	1.95 km^2.	Camera trapping used to identify the movements of badgers to estimate the home ranges.	Lombardy (Around the River Po Plain), Italy	(Balesteri, et al., 2016)

			Average home range. Standard deviation of +/-0.23 km^2.		

Appendix D 6: Home ranges for Weasels (Mustela Nivalis) found during the literature search.

Name	***Latin name***	**Home range**	**Additional information**	**Country/region**	**Source**
Weasel	*Mustela Nivalis*	0.0101-0.049 km^2	Live-trapping used to estimate the home ranges. The study area used was 32 ha.	Scotland	(King, 1975)
Weasel	*Mustela Nivalis*	0.07-0.25 km^2	Live-trapping used to estimate the home ranges. The study area used was 222 ha.	Scotland	(King, 1975)
Weasel	*Mustela Nivalis*	0.01-0.15 km^2	Live-trapping used to estimate the home ranges. The study area used was 27 ha.	England	(King, 1975)
Weasel	*Mustela Nivalis*	0.008 km^2	Snow-tracking used to estimate the home ranges. The study area of 59 ha was used. Observations only performed for 13 days, which makes the possibilities for uncertainties large.	United States	(King, 1975)
Weasel	*Mustela Nivalis*	0.002-0.03 km^2	Snow-tracking used to estimate the home ranges. The study area	Finland	(King, 1975)

			not defined. Might have accuracy problems		
Weasel	*Mustela Nivalis*	0.1 km^2	Snow-tracking used to estimate the home ranges. The study area not defined.	Boreal forest, Russia	(King, 1975)
Weasel	*Mustela Nivalis*	0.11-0.37 km^2 during a rodent outbreak, 1.17-2.16 km^2 during a year with less food resources.	Radio-tracking used in the summer, snow-tracking used in the winter. MCP used to estimate the home ranges. Very dependent on number of rodents in the area (average in abundance was 0.24 km^2 and in scarcity was 1.665 km^2, assumption has given an estimated value of 0.59625 km^2)	Podlaskie Voivodeship, Poland	(Jędrzejewski et al., 1995)
Weasel	*Mustela Nivalis*	0.279-1.926 km^2	Radio-tracking used to track the movements. Home ranges estimated using MCP. (Avg. 0.7095 (Avg. value between non-breeding females (Mean: 0.286 km^2 +/- 0.009 km^2) and adult males (Mean: 1.133 km^2 +/- 0.579 km^2)))	Oxfordshire, United Kingdom	(MacDonald et al., 2004)

Weasel	*Mustela Nivalis*	0.04-1.14 km^2 (Mean 0.45 km^2)	Radio-tracking and trapping used to track the movements. 100% MCP used to estimate the home ranges. (Avg. 0.45 km^2 +/- 0.468 km^2)	Rieti, Lazio, Italy	(Magrini et al., 2009)

Appendix D 7: Home ranges for Great Tit (Parus Major) found during the literature search.

Name	***Latin name***	**Home range**	**Additional information**	**Country/Region**	**Source**
Great tit	*Parus major*	0.0176 km^2	Radio-tracking (one bird) was used to track movements.	Cheonan, Hoseo, South Korea	(Song, 2020)
Great tit	*Parus major*	0.007-0.159 km^2 (Mean 0.055 +/- 0.025 km^2)	Tracking through observations used.	Tokyo, Japan	(Saitou, 1979)
Great tit	*Parus major*	0.0093183 +/- 0.0028567 km^2 (in snowy conditions) 0.0062637 +/- 0.0008581 km^2 (pre-snowy conditions)	Polygon shaping (at least similar to MCP) was used to estimate the home range.	Jōetsu, Niigata, Japan	(Masahiko & Shindo, 2001)
Great tit	*Parus major*	Mean: 0.083 +/- 0.032 km^2 (Range = 0.032-0.137)	90% MCP (100% MCP gave a value of 0.772 km^2).	Jura, Switzerland	(Naef-Daenzer & Grüebler, 2008)
Great tit	*Parus major*	**Flock range** (Avg 5 birds) 0.0532 +/- 0.0063 km^2	Regular inspections and tracking by ringing and subsequent plotting used to track movements.	Kraslava, South-Eastern Latvia	(Krams et al., 2006)

Appendix E
NOEC Correction Factors

Appendix E 1: NOEC correction factors for energy requirement (EMR) (Jongbloed et al., 1996).

	Normal case	**Worst case**
CF (EMR/FMR)	0.4	0.25

Appendix E 2: NOEC correction factors for caloric intake of food for different food groups (Jongbloed et al., 1996).

	CF Bird	**CF Mammal**
Birds	0.58	0.47
Mammals	0.52	0.42
Soft bodied invertebrates	0.22	0.18
Hard bodied invertebrates	0.53	0.43
Leaves	0.07	0.05
Seeds	1.45	1.18

Appendix E 3: NOEC correction factors for food assimilation energy (FAE) (Jongbloed et al., 1996).

	CF Bird	**CF Mammal**
Birds	1.02	0.92
Mammals	1.02	0.92
Soft bodied invertebrates	1	1
Hard bodied invertebrates	0.92	0.99
Leaves	0.51	0.57
Seeds	0.97	1.01

Appendix F
Area Estimations of the Subareas

Appendix F 1: The area calculations of the field (1/4) © (Google, 2024b).

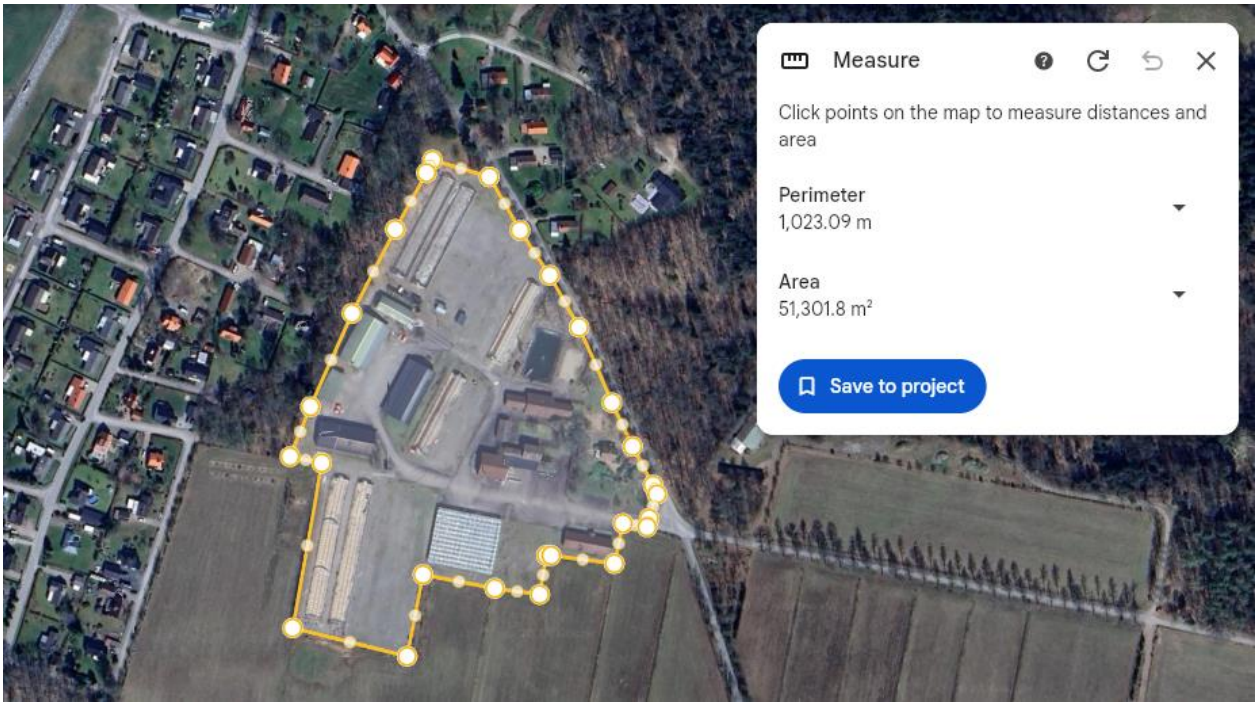
Appendix F 2: The area calculations of the field (2/4) © (Google, 2024b).

Appendix F 3: The area calculations of the field (3/4) © (Google, 2024b).

Appendix F 4: The area calculations of the field (4/4) © (Google, 2024b).

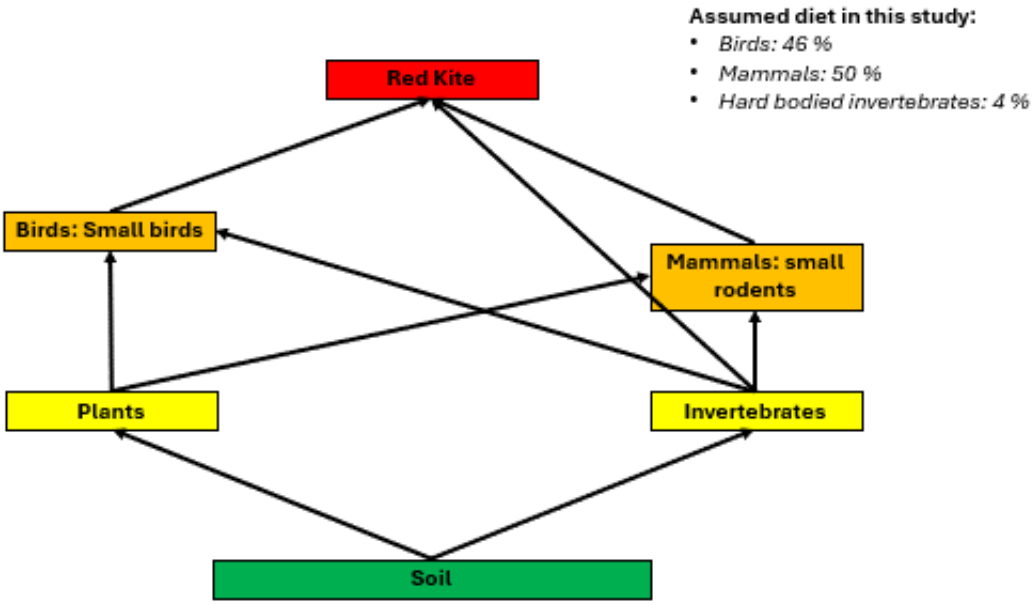
Appendix F 5The area calculation of the dipping area. © (Google, 2024b).

Appendix F 6: The area calculation of the landfill area. © (Google, 2024b).

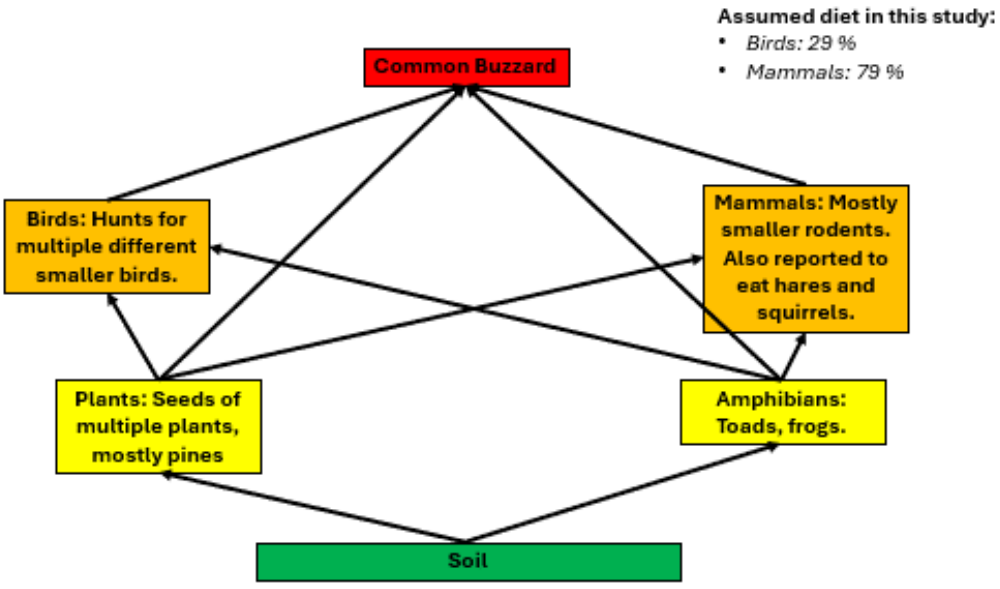


Appendix F 7: The area calculation of the building area. © (Google, 2024b).

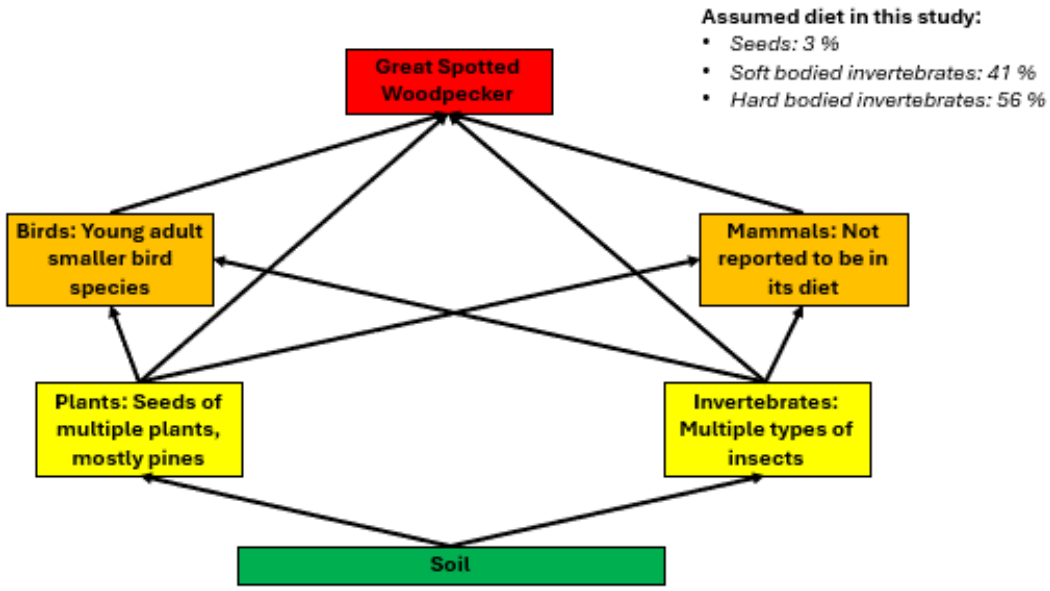
Appendix G
Constructed Food Webs



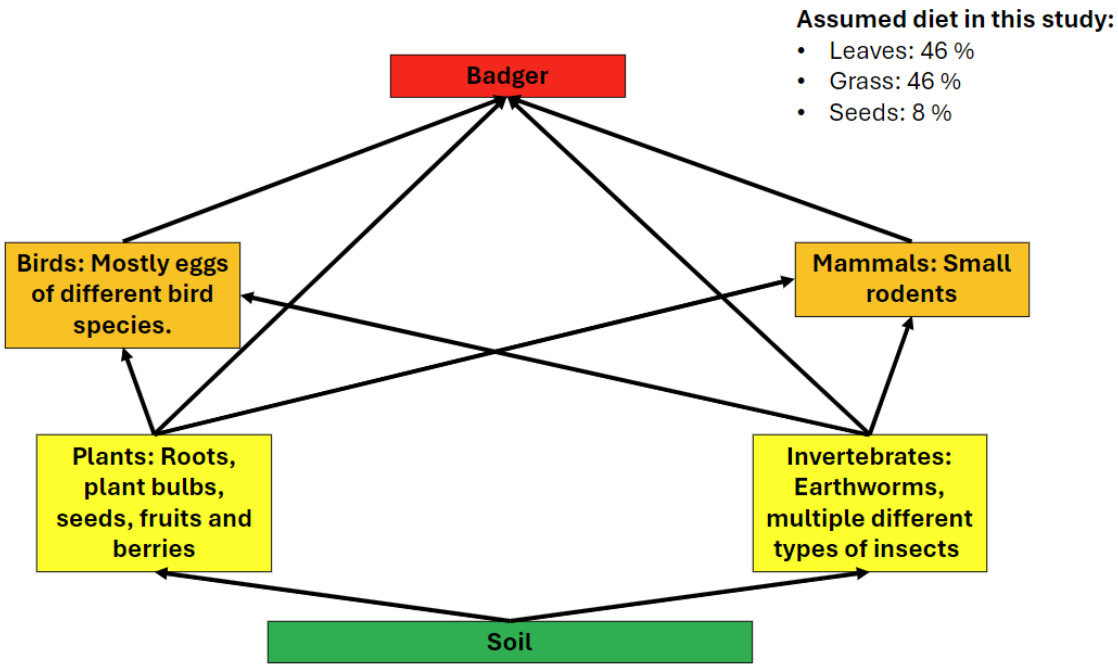
Appendix G 1: The DDT transport throughout the food chain of a Red Kite (Milvus milvus). Source: (Staav & Fransson, 2007).



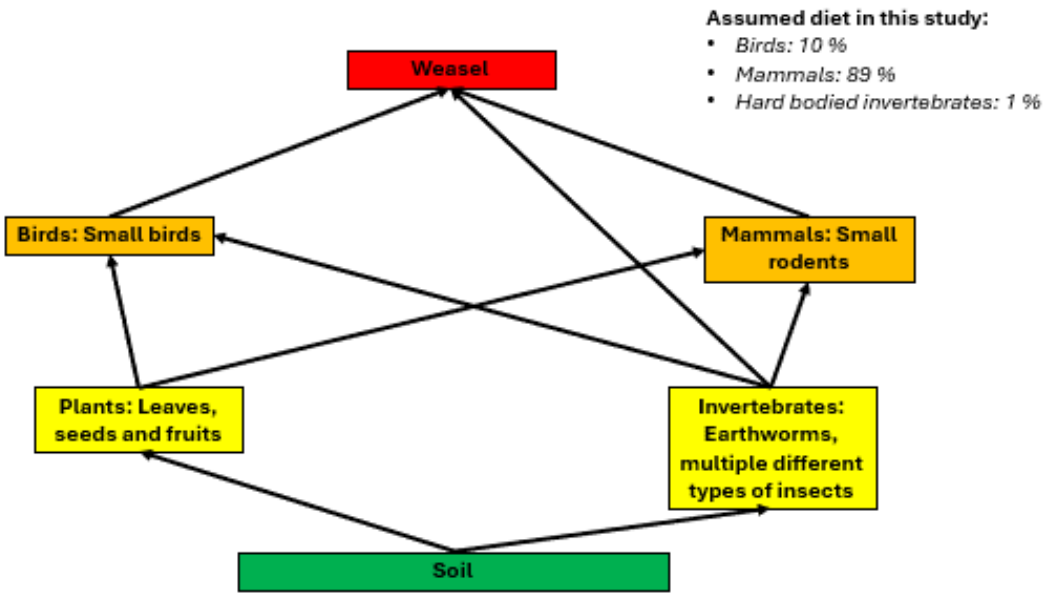
Appendix G 2: The DDT transport throughout the food chain for a Common Buzzard (Buteo buteo). Source: (Staav & Fransson, 2007).



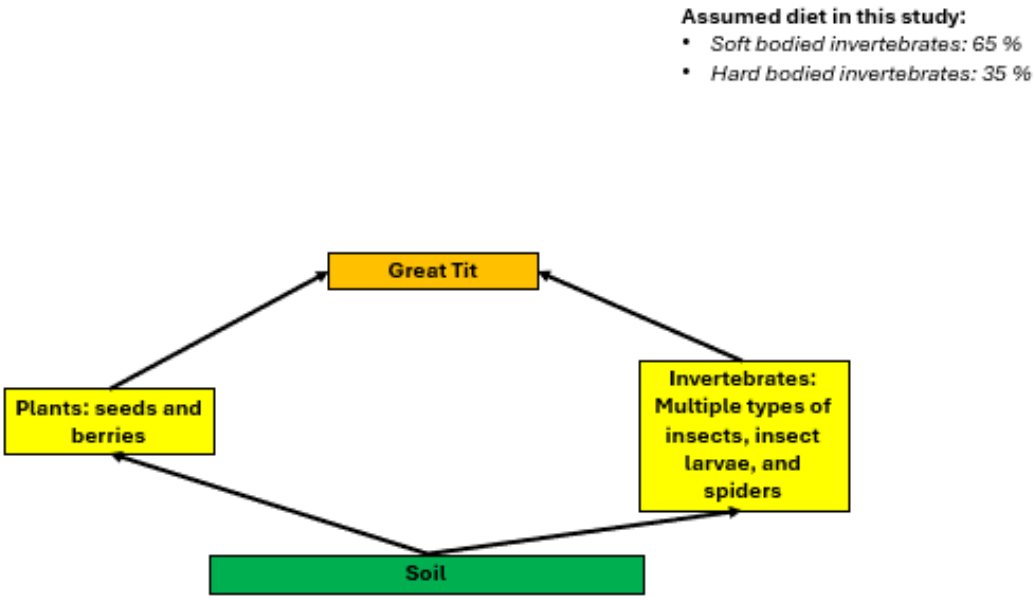
Appendix G 3: The DDT transport throughout the food chain for a Great Spotted Woodpecker (Dendrocopos major). Source: (Staav & Fransson, 2007).



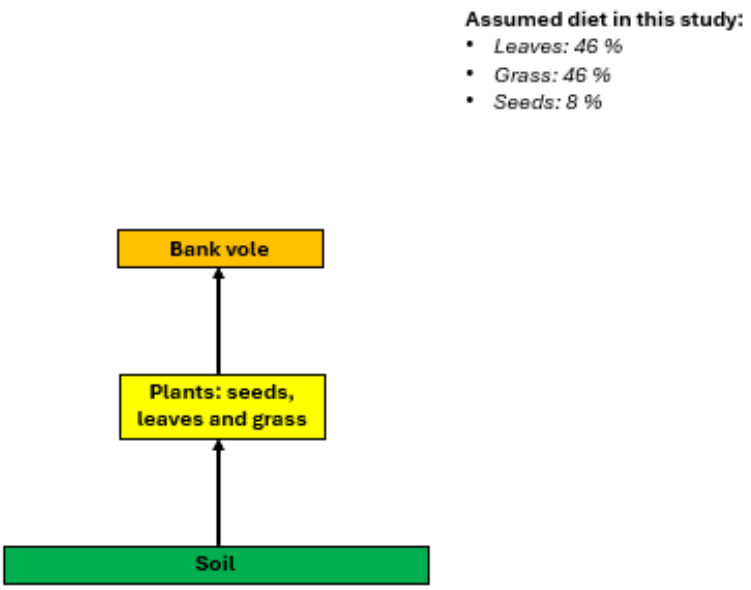
Appendix G 4: The DDT transport throughout the food chain for a Badger (Meles meles). Source: (Naturvårdsverket, 2023).



Appendix G 5: The DDT transport throughout the food chain for a weasel (Mustela nivalis).



Appendix G 6: The DDT transport throughout the food chain for a Great Tit (Parus major). Source: (Staav & Fransson, 2007).



Appendix G 7: The DDT transport throughout the food chain for a Bank vole (Clethrionomys glareolus). Source: (SLU Artdatabanken, 2024b).

Appendix H
Collected Dietary Data

Appendix H 1: Dietary distributions for red kite (Milvus milvus) found during the literature search.

Region	Mammals	Birds	Hard bodied invertebrates	Unit	Source
Northern Plateu, Spain	75	22	3	% biomass	(Mougeot et al., 2011)
Northern Plateu, Spain	59	38.6	2.4	% biomass	(García et al., 1996)
Southern Plateu, Spain	55.6	35.8	8.6	% biomass	(García et al., 1996)
Doñana, Spain (dry season)	24	75.6	0.4	% biomass	(Blanco et al., 1990)
Doñana, Spain (wet season)	35.8	64.1	0.1	% biomass	(Blanco et al., 1990)

Appendix H 2: Dietary distributions for common buzzard (Buteo buteo) found during the literature search.

Region	Mammals	Birds	Unit	Source
Central Europe (1)	98	2	% biomass	(Génsbøl, 2006)
Central Europe (2)	70	30	% biomass	(Génsbøl, 2006)
Trossachs, Scotland (1)	80	20	% biomass	(Swan, 2011)
Trossachs, Scotland (2)	60	40	% biomass	(Swan, 2011)
Southern Norway (1)	60	40	% biomass	(Selås et al., 2007)
Southern Norway (2)	65	35	% biomass	(Selås et al., 2007)

Appendix H 3: Dietary distributions for great spotted woodpecker (Dendrocopos major) found during the literature search.

Region	Hard bodied invertebrates	Soft bodied invertebrates	Seeds	Unit	Source
Inner Mongolia, China	83.96	9.64	5.68	% biomass	(Jiao, et al., 2008)
Franfurt/Main, Germany	60	40		% biomass	(Rossmanith et al., 2007)
Surndal, West Germany	25.5	74.5		% biomass	(Hogstad & Stenberg, 1997)

Appendix H 4: Dietary distributions for common raven (Corvus corax) found during the literature search.

Region	Mammals	Birds	Hard bodied invertebrates	Soft bodied invertebrates	Leaves	Fruits and seeds	Unit	Source
Djelfa, Algeria	7.85	3.95	87.93				% biomass	(Guerzou, et al., 2013)
Karst, Slovenia	45	6.8	3		34.4	12.7	% biomass	(Tome et al., 2009)
Southwestern Idaho	14.6	1	7		1.8	71.7	% biomass	(Engel & Young, 1989)
Djefa, Algeria	32.48	66.01	1.47	0.04			% biomass	(Guerzou et al., 2019)
Laghouat, Algeria	50.02	43.59	6.11	0.28			% biomass	(Guerzou et al., 2019)

Appendix H 5: Dietary distributions for badger (Meles meles) found during the literature search.

Region	Mammals	Birds	Soft bodied invertebrates	Hard bodied invertebrates	Seeds	Grass	Unit	Source
Ireland	1.32	6	12.36	20	12.68	47.64	% biomass	(Cleary et al., 2009)
Norway	12.9	2	33.5	8.1	15.1	28.4	% biomass	(Gomes et al., 2019)
Eastern Poland	07.4	0.8	56.2	3.3	6.6	2.8	% biomass	(Goszczynski et al., 2000)
Basque county, Spain	2	2	53.01	0.12	39.46	3.41	% biomass	(Zabala et al., 2002)

Appendix H 6: Dietary distributions for weasel (Mustela nivalis) found during the literature search.

Region	Mammals	Birds	Hard bodied invertebrates	Unit	Source
Around the Danube River, central Hungary	100	0	0	% biomass	(Lanszki & Heltai, 2007)
Between the Danube and the Tisza rivers, Hungary	87	13	0	% biomass	(Lanszki & Heltai, 2007)
Around the Tisza River, Hungary	86.2	13.8	0	% biomass	(Lanszki & Heltai, 2007)
Denmark	79.51	14.52	5.95	% biomass	(Elmeros M. , 2006)
Southern Sweden	98	2	0	% biomass	(Erlinge, 1975)

Appendix H 7: *Dietary distributions for bank vole (Clethrinomys glareolus) found during the literature search. The different dietary fractions are from the same study but during different seasons throughout the year. Unfortunately, there was a lack of data for this species, and more dietary studies would benefit further research within the field.*

Region	Soft bodied invertebrates	Hard bodied invertebrates	Unit	Source
Barcelona, Spain	65	35	% biomass	(Pagani-Núñez et al., 2011)

Appendix H 8: Dietary distributions for bank vole (Clethrinomys glareolus) found during the literature search. The different dietary fractions are from the same study but during different seasons throughout the year. Unfortunately, there was a lack of data for this species, and more dietary studies would benefit further research within the field.

Region	Seeds	Leaves	Grass	Unit	Source
Northern and central Finland (Spring)	5.2	49.5	38.4	% biomass	(Viro & Sulkava, 1985)
Northern and central Finland (Summer)	10.1	41.9	46	% biomass	(Viro & Sulkava, 1985)
Northern and central Finland (Autumn)	1.3	33	63.3	% biomass	(Viro & Sulkava, 1985)
Northern and central Finland (early Winter)	5.5	56.1	38.5	% biomass	(Viro & Sulkava, 1985)
Northern and central Finland (L	2.3	53.2	43.9	% biomass	(Viro & Sulkava, 1985)

Appendix I
NOEC data

Appendix I 1: NOEC data collected from Rundegren (2019) for bird species.

Species	Effect parameter	Exposure period	Reported value	Converted value (NOEC, mg/kg)	Reference (as written in Rundegren, (2019))	Source (as specified in Rundegren, 2019)
Streptopelia risoria	Reproduction	8 days	10 (LOEC)	0.5	Peakall (1970)	Jongbloed et al. (1996)
Molothrus ater	Mortality	13 days	<100 (LOEC)	3.3	Van Velzen et al. (1972)	Jongbloed et al. (1996)
Anas platyrynchos	Reproduction	2 years	3.3	3.3	Heath et al. (1969)	Jongbloed et al. (1996)
Anas platyrynchos	Mortality	106 days	10 (LOEC)	5	Vanglider & Peterle (1980)	ECOTOX
Anas platyrynchos	Growth	106 days	10 (LOEC)	5	Vanglider & Peterle (1980)	ECOTOX
Coturnix c. japonica	Reproduction	12 weeks	10	10	Davison et al. (1976)	Jongbloed et al. (1996)
Coturnix c. japonica	Morphology	21 days	100	10	Bernstein & Johnson (1973)	ECOTOX
Colinus virginianus	Mortality	63 days	50	17	Coburn & Treichler (1946)	Jongbloed et al. (1996)
Colinus virginianus	Morphology		50	100	Geometric mean for the two studies below	ECOTOX

Colinus virginianus	Morphology	121 days	50		Hurst et al. (1974)	ECOTOX
Colinus virginianus	Morphology	242 days	150		Lehman et al. (1974)	ECOTOX
Phasianus colchicus	Reproduction	8 weeks	<100	50	Genelly & Rudd (1956)	Jongbloed et al. (1996)
Falco sparverius	Reproduction			5.6	Geometric mean for the three studies below	Jongbloed et al. (1996)
Falco sparverius	Reproduction	5.5 months	0.3	3	Lincer (1975)	Jongbloed et al. (1996)
Falco sparverius	Reproduction	Not reported	<3	6	Peakall et al. (1973)	Jongbloed et al. (1996)
Falco sparverius	Reproduction	>2 years	<2.6	10	Wiemeyer & Porter (1970)	Jongbloed et al. (1996)
Otus asio	Reproduction	>1 year	2.8	2.8	McLane & Hall (1972)	Jongbloed et al. (1996)
Gallus domesticus	Feeding behaviour	196 days	50	50	Lillie et al. (1972)	ECOTOX
Gallus domesticus	Mortality			5.8	Geometric mean for the three studies below	ECOTOX
Gallus domesticus	Mortality	196 days	78.3	78.3	Lillie et al. (1972)	ECOTOX
Gallus domesticus	Mortality	196 days	50	50	Lillie et al. (1972)	ECOTOX
Gallus domesticus	Mortality	70 days	0.1	0.05	Sauter & Steele (1972)	ECOTOX

Gallus domesticus	Reproduction	70 days	0.46 (LOEC)	0.23	Sauter & Steele (1972)	ECOTOX
Anas rubripes	Mortality	152 days	10 (LOEC)	5	Longcore & Samson (1973)	ECOTOX
Anas rubripes	Reproduction	1095 days	10 (LOEC)	5	Longcore & R.C. Stendell (1977)	ECOTOX
Anas sparsa	Morphology	45 days	40 (LOEC)	20	Lundholm (1990)	ECOTOX
Columba livia	Morphology	56 days	18 (LOEC)	9	Jefferies & French (1972)	ECOTOX
Galliformes	Mortality	154 days	200	200	DeWitt (1955)	ECOTOX
Passer domesticus	Growth			34.6	Geometric mean for the two studies below	ECOTOX
Passer domesticus	Growth	5 days	1500	75	Hill (1972)	ECOTOX
Passer domesticus	Growth	5 days	320	16	Hill et al. (1971)	ECOTOX

Appendix I 2: NOEC data collected from Rundegren (2019) for mammal species.

Species	**Effect parameter**	**Exposure period**	**Reported value**	**Converted value (NOEC, mg/kg)**	**Reference (as written in Rundegren (2019))**	**Source (as specified in Rundegren, 2019)**
Rattus norvegicus	Reproduction	7 months	20	20	Clement & Okey (1974)	Jongbloed et al. (1996)
Mus musculus	Reproduction	6 generations	25	25	Keplinger et al. (1970)	Jongbloed et al. (1996)
Saimura sciureus	Mortality	6 months	5 (3)	28.4	Cranmer et al. (1972)	Jongbloed et al. (1996)

Microtus pennsyl-vanicus	Mortality	31 days	1000	100	Coburn & Treichler (1946)	Jongbloed et al. (1996)
Macaca mulatta	Mortality, Growth	7.5 years	200	200	Durham et al. (1963)	Jongbloed et al. (1996)
Canis domesticus	Mortality	4 years	400	400	Lehman (1965)	Jongbloed et al. (1996)
Myolis lucifugus	Mortality	40	150 (LOEC)	75	Clark & Stafford (1981)	ECOTOX
Tadaria brasiliensis	Mortality	40	107 (LOEC)	53.5	Clark & Kroll (1977)	ECOTOX
Tadaria brasiliensis	Growth	40	107 (LOEC)	53.5	Clark & Kroll (1977)	ECOTOX
Ovis aries	Growth	94	62	62	Wilson et al. (1946)	ECOTOX
Oryctolagus cuniculus	Morphology	57	2.67 (mg/kg bdwt/d) (LOEC)	44.055	Street & Sharma (1975)	ECOTOX
Oryctolagus cuniculus	Growth	57	6.54 (mg/kg bdwt/d)	215.82	Street & Sharma (1975)	ECOTOX
Canis familiaris	Morphology	32	50 (mg/kg bdwt/d) (LOEC)	325	Cropeland & Cranmer (1974)	ECOTOX
Canis familiaris	Growth	32	50 (mg/kg bdwt/d)	650	Cropeland & Cranmer (1974)	ECOTOX

Appendix J
Sensitivity Analysis Outputs

Appendix J 1: Results from the sensitivity analysis for scenario 1 without implementing biochar.

Badger		**Common Buzzard**		**Common Raven**		**Great Spotted Woodpecker**		**Red Kite**		**Weasel**	
Input parameter	*Spearman Rank Correlation Coefficient*	*Input parameter*	*Spearman Rank Correlation Coefficient*	*Input parameter*	*Spearman Rank Correlation Coefficient*	*Input parameter*	*Spearman Rank Correlation Coefficient*	*Input parameter*	*Spearman Rank Correlation Coefficient*	*Input parameter*	*Spearman Rank Correlation Coefficient*
DDT concentration in the field	0.66	BAF bird	0.73	BAF hard bodied invertebrates	0.90	DDT concentration in the field	0.61	BAF birds	0.86	DDT concentration in the field	0.53
Home range	-0.40	Home range	-0.39	Home range	-0.24	BAF hard bodied invertebrates	0.58	BAF hard bodied invertebrates	0.29	BAF hard bodied invertebrates	0.35
DDT concentration in the built area	0.33	DDT concentration in the field	0.25	BAF seeds	0.18	DDT concentration in the built area	0.31	BAF seeds	0.19	BAF birds	0.33
BAF hard bodied invertebrates	0.23	BAF hard bodied invertebrates	0.24	DDT concentration in the field	0.15	DDT concentration in the dipping point and plant landfill	0.20	Home range	-0.18	BAF mammals	0.31

DDT concentration in the dipping point and landfill	0.22	BAF mammal	0.18	BAF birds	0.13	BAF soft bodied invertebrates	0.07	DDT concentration in the field	0.09	DDT concentration in the built area	0.27
BAF soft bodied invertebrates	0.11	DDT concentration in the built area	0.13	DDT concentration in the built area	0.07	Home range	-0.01	BAF mammals	0.09	Home range	-0.23
BAF seeds	0.08	BAF seeds	0.1	DDT concentration in the dipping point and landfill	0.05	BAF seeds	0.00	BAF soft bodied invertebrates	0.08	DDT concentration in the dipping point and plant landfill	0.18
BAF grass	0.01	DDT concentration in the dipping point and landfill	0.09	BAF soft bodied invertebrates	0.02			DDT concentration in the built area	0.05	BAF seeds	0.15
BAF birds	0.00	BAF soft bodied invertebrates	0.07	BAF mammals	0.01			DDT concentration in the dipping point and plant landfill	0.03	BAF grass	0.06
		BAF grass	0.04	BAF grass	0.00			BAF grass	0.02	BAF leaves	0.04
		BAF leaves	0.02	BAF leaves	0.00			BAF leaves	0.01	BAF soft bodied invertebrates	0.04

Appendix J 2: Results from the sensitivity analysis for scenario 1 after implementing biochar.

Badger		**Common Buzzard**		**Common Raven**		**Great Spotted Woodpecker**		**Red Kite**		**Weasel**	
Input parameter	*Spearman Rank Correlation Coefficient*	*Input parameter*	*Spearman Rank Correlation Coefficient*	*Input parameter*	*Spearman Rank Correlation Coefficient*	*Input parameter*	*Spearman Rank Correlation Coefficient*	*Input parameter*	*Spearman Rank Correlation Coefficient*	*Input parameter*	*Spearman Rank Correlation Coefficient*
DDT concentration in the field	0.63	BAF bird	0.67	BAF hard bodied invertebrates	0.91	BAF hard bodied invertebrates	0.71	BAF birds	0.77	DDT concentration in the field	0.51
Home range	-0.38	Home range	-0.38	Home range	-0.23	DDT concentration in the field	0.53	BAF hard bodied invertebrates	0.41	BAF hard bodied invertebrates	0.45
BAF hard bodied invertebrates	0.36	BAF hard bodied invertebrates	0.35	BAF seeds	0.18	DDT concentration in the built area	0.27	BAF seeds	0.29	BAF mammals	0.30
DDT concentration in the built area	0.32	DDT concentration in the field	0.24	DDT concentration in the field	0.14	DDT concentration in the dipping point and plant landfill	0.18	Home range	-0.18	BAF birds	0.26
DDT concentration in the dipping point and landfill	0.21	BAF mammals	0.20	BAF birds	0.08	BAF soft bodied invertebrates	0.03	BAF mammals	0.10	DDT concentration in the built area	0.26

BAF seeds	0.14	BAF seeds	0.15	DDT concentration in the built area	0.07	Home range	-0.01	DDT concentration in the field	0.09	Home range	-0.22
BAF soft bodied invertebrates	0.05	DDT concentration in the built area	0.12	DDT concentration in the dipping point and landfill	0.04	BAF seeds	0.01	DDT concentration in the built area	0.05	BAF seeds	0.20
BAF grass	0.00	DDT concentration in the dipping point and plant landfill	0.08	BAF mammals	0.01			BAF soft bodied invertebrates	0.04	DDT concentration in the dipping point and plant landfill	0.17
BAF birds	0.00	BAF soft bodied invertebrates	0.03	BAF soft bodied invertebrates	0.01			DDT concentration in the dipping point and plant landfill	0.03	BAF soft bodied invertebrates	0.02
BAF mammals	0.00	BAF grass	0.01	BAF leaves	0.00			BAF grass	0.00	BAF leaves	0.01
		BAF leaves	0.01	BAF grass	0.00			BAF leaves	0.00	BAF grass	0.01

Appendix J 3: Results from the sensitivity analysis for scenario 2 without implementing biochar.

Badger		**Common Buzzard**		**Common Raven**		**Great Spotted Woodpecker**		**Red Kite**		**Weasel**	
Input parameter	*Spearman Rank Correlation Coefficient*	*Input parameter*	*Spearman Rank Correlation Coefficient*	*Input parameter*	*Spearman Rank Correlation Coefficient*	*Input parameter*	*Spearman Rank Correlation Coefficient*	*Input parameter*	*Spearman Rank Correlation Coefficient*	*Input parameter*	*Spearman Rank Correlation Coefficient*
DDT concentration in the field	0.64	Home range	-0.61	BAF hard bodied invertebrates	0.64	DDT concentration in the field	0.61	BAF birds	0.64	DDT concentration in the field	0.52
Home range	-0.44	BAF bird	0.53	Home range	-0.58	BAF hard bodied invertebrates	0.58	Home range	-0.56	BAF hard bodied invertebrates	0.34
DDT concentration in the built area	0.32	DDT concentration in the field	0.35	DDT concentration in the field	0.31	DDT concentration in the built area	0.31	DDT concentration in the field	0.26	BAF birds	0.32
BAF hard bodied invertebrates	0.22	DDT concentration in the built area	0.18	DDT concentration in the built area	0.16	DDT concentration in the dipping point and plant landfill	0.20	BAF hard bodied invertebrates	0.2	BAF mammals	0.30
DDT concentration in the dipping point and landfill	0.21	BAF hard bodied invertebrates	0.17	BAF seeds	0.12	BAF soft bodied invertebrates	0.07	BAF seeds	0.15	DDT concentration in the built area	0.27

BAF soft bodied invertebrates	0.10	BAF mammals	0.14	DDT concentration in the dipping point and landfill	0.10	Home range	-0.02	DDT concentration in the built area	0.13	Home range	-0.26
BAF seeds	0.08	DDT concentration in the dipping point and landfill	0.12	BAF birds	0.10	BAF seeds	0.00	DDT concentration in the dipping point and plant landfill	0.09	DDT concentration in the dipping point and plant landfill	0.18
BAF grass	0.01	BAF seeds	0.07	BAF soft bodied invertebrates	0.02			BAF mammals	0.07	BAF seeds	0.15
BAF birds	0.00	BAF soft bodied invertebrates	0.05	BAF mammals	0.01			BAF soft bodied invertebrates	0.06	BAF grass	0.06
		BAF grass	0.03	BAF grass	0.00			BAF grass	0.01	BAF leaves	0.04
		BAF leaves	0.02					BAF leaves	0.01	BAF soft bodied invertebrates	0.03

Appendix J 4: Results from the sensitivity analysis for scenario 2 after implementing biochar.

Badger		**Common Buzzard**		**Common Raven**		**Great Spotted Woodpecker**		**Red Kite**		**Weasel**	
Input parameter	*Spearman Rank Correlation Coefficient*	*Input parameter*	*Spearman Rank Correlation Coefficient*	*Input parameter*	*Spearman Rank Correlation Coefficient*	*Input parameter*	*Spearman Rank Correlation Coefficient*	*Input parameter*	*Spearman Rank Correlation Coefficient*	*Input parameter*	*Spearman Rank Correlation Coefficient*
DDT concentration in the field	0.61	Home range	-0.60	BAF hard bodied invertebrates	0.67	BAF hard bodied invertebrates	0.71	BAF birds	0.57	DDT concentration in the field	0.50
Home range	-0.43	BAF birds	0.50	Home range	-0.56	DDT concentration in the field	0.53	Home range	-0.56	BAF hard bodied invertebrates	0.44
BAF hard bodied invertebrates	0.34	DDT concentration in the field	0.34	DDT concentration in the field	0.30	DDT concentration in the built area	0.27	BAF hard bodied invertebrates	0.30	BAF mammals	0.29
DDT concentration in the built area	0.31	BAF hard bodied invertebrates	0.25	DDT concentration in the built area	0.15	DDT concentration in the dipping point and plant landfill	0.18	DDT concentration in the field	0.26	BAF birds	0.26
DDT concentration in the dipping point and landfill	0.20	DDT concentration in the built area	0.17	BAF seeds	0.14	BAF soft bodied invertebrates	0.03	BAF seeds	0.22	DDT concentration in the built area	0.25

BAF seeds	0.15	BAF mammals	0.16	DDT concentration in the dipping point and landfill	0.10	Home range	-0.01	DDT concentration in the built area	0.13	Home range	-0.25
BAF soft bodied invertebrates	0.05	DDT concentration in the dipping point and plant landfill	0.12	BAF birds	0.06	BAF seeds	0.01	DDT concentration in the dipping point and plant landfill	0.09	BAF seeds	0.20
BAF birds	0.00	BAF seeds	0.11	BAF mammals	0.01			BAF mammals	0.08	DDT concentration in the dipping point and plant landfill	0.17
BAF grass	0.00	BAF soft bodied invertebrates	0.02	BAF soft bodied invertebrates	0.01			BAF soft bodied invertebrates	0.03	BAF soft bodied invertebrates	0.02
BAF mammal	0.00	BAF grass	0.01	BAF grass	0.00			BAF leaves	0.00	BAF leaves	0.01
		BAF leaves	0.00	BAF leaves	0.00			BAF grass	0.00	BAF grass	0.01

Appendix J 5: Results from the sensitivity analysis for scenario 3 without implementing biochar.

Badger		**Common Buzzard**		**Common Raven**		**Great Spotted Woodpecker**		**Red Kite**		**Weasel**	
Input parameter	*Spearman Rank Correlation Coefficient*	*Input parameter*	*Spearman Rank Correlation Coefficient*	*Input parameter*	*Spearman Rank Correlation Coefficient*	*Input parameter*	*Spearman Rank Correlation Coefficient*	*Input parameter*	*Spearman Rank Correlation Coefficient*	*Input parameter*	*Spearman Rank Correlation Coefficient*
DDT concentration in the field	0.64	Home range	-0.65	Home range	-0.68	DDT concentration in the field	0.61	Home range	-0.73	DDT concentration in the field	0.52
Home range	-0.45	BAF bird	0.48	BAF hard bodied invertebrates	0.50	BAF hard bodied invertebrates	0.58	BAF birds	0.43	BAF hard bodied invertebrates	0.34
DDT concentration in the built area	0.32	DDT concentration in the field	0.36	DDT concentration in the field	0.36	DDT concentration in the built area	0.31	DDT concentration in the field	0.33	BAF birds	0.32
BAF hard bodied invertebrates	0.22	DDT concentration in the built area	0.18	DDT concentration in the built area	0.18	DDT concentration in the dipping point and plant landfill	0.20	DDT concentration in the built area	0.17	BAF mammals	0.30
DDT concentration in the dipping point and landfill	0.21	BAF hard bodied invertebrates	0.15	DDT concentration in the dipping point and landfill	0.12	BAF soft bodied invertebrates	0.07	BAF hard bodied invertebrates	0.13	DDT concentration in the built area	0.26

BAF soft bodied invertebrates	0.10	BAF mammals	0.13	BAF seeds	0.11	Home range	-0.02	DDT concentration in the dipping point and plant landfill	0.12	Home range	-0.26
BAF seeds	0.08	DDT concentration in the dipping point and landfill	0.12	BAF birds	0.08	BAF seeds	0.00	BAF seeds	0.11	DDT concentration in the dipping point and plant landfill	0.18
BAF grass	0.01	BAF seeds	0.07	BAF soft bodied invertebrates	0.02			BAF mammals	0.05	BAF seeds	0.15
BAF birds	0.00	BAF soft bodied invertebrates	0.04	BAF mammals	0.01			BAF soft bodied invertebrates	0.04	BAF grass	0.06
		BAF grass	0.03	BAF leaves	0.00			BAF grass	0.01	BAF leaves	0.04
		BAF leaves	0.02					BAF leaves	0.01	BAF soft bodied invertebrates	0.03

Appendix J 6: Results from the sensitivity analysis for scenario 3 after implementing biochar.

Badger		**Common Buzzard**		**Common Raven**		**Great Spotted Woodpecker**		**Red Kite**		**Weasel**	
Input parameter	*Spearman Rank Correlation Coefficient*	*Input parameter*	*Spearman Rank Correlation Coefficient*	*Input parameter*	*Spearman Rank Correlation Coefficient*	*Input parameter*	*Spearman Rank Correlation Coefficient*	*Input parameter*	*Spearman Rank Correlation Coefficient*	*Input parameter*	*Spearman Rank Correlation Coefficient*
DDT concentration in the field	0.61	Home range	-0.64	Home range	-0.66	BAF hard bodied invertebrates	0.71	Home range	-0.73	DDT concentration in the field	0.50
Home range	-0.43	BAF birds	0.45	BAF hard bodied invertebrates	0.54	DDT concentration in the field	0.53	BAF birds	0.39	BAF hard bodied invertebrates	0.44
BAF hard bodied invertebrates	0.33	DDT concentration in the field	0.36	DDT concentration in the field	0.35	DDT concentration in the built area	0.27	DDT concentration in the field	0.33	BAF mammals	0.29
DDT concentration in the built area	0.31	BAF hard bodied invertebrates	0.23	DDT concentration in the built area	0.18	DDT concentration in the dipping point and plant landfill	0.18	BAF hard bodied invertebrates	0.19	BAF birds	0.25
DDT concentration in the dipping point and landfill	0.20	DDT concentration in the built area	0.18	BAF seeds	0.12	BAF soft bodied invertebrates	0.03	DDT concentration in the built area	0.17	DDT concentration in the built area	0.25

BAF seeds	0.13	BAF mammals	0.14	DDT concentration in the dipping point and landfill	0.12	Home range	-0.01	BAF seeds	0.15	Home range	-0.25
BAF soft bodied invertebrates	0.05	DDT concentration in the dipping point and plant landfill	0.12	BAF birds	0.05	BAF seeds	0.01	DDT concentration in the dipping point and plant landfill	0.12	BAF seeds	0.20
BAF birds	0.00	BAF seeds	0.10	BAF mammals	0.01			BAF mammals	0.05	DDT concentration in the dipping point and plant landfill	0.17
BAF grass	0.00	BAF soft bodied invertebrates	0.02	BAF soft bodied invertebrates	0.00			BAF soft bodied invertebrates	0.02	BAF soft bodied invertebrates	0.02
BAF mammal	0.00	BAF grass	0.01	BAF grass	0.00			BAF leaves	0.00	BAF leaves	0.01
		BAF leaves	0.00	BAF leaves	0.00			BAF grass	0.00	BAF grass	0.01

Appendix J 7: Results from the sensitivity analysis for scenario 4 after implementing biochar.

Badger		**Common Buzzard**		**Common Raven**		**Great Spotted Woodpecker**		**Red Kite**		**Weasel**	
Input parameter	*Spearman Rank Correlation Coefficient*	*Input parameter*	*Spearman Rank Correlation Coefficient*	*Input parameter*	*Spearman Rank Correlation Coefficient*	*Input parameter*	*Spearman Rank Correlation Coefficient*	*Input parameter*	*Spearman Rank Correlation Coefficient*	*Input parameter*	*Spearman Rank Correlation Coefficient*
DDT concentration in the field	0.74	BAF birds	0.65	BAF hard bodied invertebrates	0.71	DDT concentration in the field	0.62	BAF birds	0.65	DDT concentration in the field	0.57
DDT concentration in the built area	0.37	DDT concentration in the field	0.5	DDT concentration in the field	0.51	BAF hard bodied invertebrates	0.58	DDT concentration in the field	0.51	BAF hard bodied invertebrates	0.37
BAF hard bodied invertebrates	0.25	DDT concentration in the built area	0.25	DDT concentration in the built area	0.25	DDT concentration in the built area	0.31	DDT concentration in the built area	0.26	BAF birds	0.35
DDT concentration in the dipping point and landfill	0.25	BAF hard bodied invertebrates	0.21	DDT concentration in the dipping point and landfill	0.17	DDT concentration in the dipping point and plant landfill	0.20	BAF hard bodied invertebrates	0.21	BAF mammals	0.32
BAF soft bodied invertebrates	0.11	DDT concentration in the	0.17	BAF seeds	0.15	BAF soft bodied invertebrates	0.07	DDT concentration in the dipping	0.17	DDT concentration in the built area	0.29

		dipping point and landfill						point and plant landfill			
BAF seeds	0.09	BAF mammals	0.16	BAF birds	0.11	BAF seeds	0.00	BAF seeds	0.15	DDT concentration in the dipping point and plant landfill	0.19
BAF grass	0.01	BAF seeds	0.09	BAF soft bodied invertebrates	0.02			BAF mammals	0.07	BAF seeds	0.16
BAF birds	0.00	BAF soft bodied invertebrates	0.06	BAF mammals	0.01			BAF soft bodied invertebrates	0.06	BAF grass	0.06
BAF leaves	0.00	BAF grass	0.04	BAF grass	0.00			BAF grass	0.02	BAF leaves	0.04
		BAF leaves	0.02	BAF leaves	0.00			BAF leaves	0.01	BAF soft bodied invertebrates	0.04

Appendix J 8: Results from the sensitivity analysis for scenario 3 after implementing biochar.

Badger		**Common Buzzard**		**Common Raven**		**Great Spotted Woodpecker**		**Red Kite**		**Weasel**	
Input parameter	*Spearman Rank Correlation Coefficient*	*Input parameter*	*Spearman Rank Correlation Coefficient*	*Input parameter*	*Spearman Rank Correlation Coefficient*	*Input parameter*	*Spearman Rank Correlation Coefficient*	*Input parameter*	*Spearman Rank Correlation Coefficient*	*Input parameter*	*Spearman Rank Correlation Coefficient*
DDT concentration in the field	0.70	BAF birds	0.61	BAF hard bodied invertebrates	0.74	BAF hard bodied invertebrates	0.71	BAF birds	0.58	DDT concentration in the field	0.54
BAF hard bodied invertebrates	0.38	DDT concentration in the field	0.49	DDT concentration in the field	0.48	DDT concentration in the field	0.53	DDT concentration in the field	0.51	BAF hard bodied invertebrates	0.47
DDT concentration in the built area	0.35	BAF hard bodied invertebrates	0.31	DDT concentration in the built area	0.24	DDT concentration in the built area	0.27	BAF hard bodied invertebrates	0.30	BAF mammals	0.31
DDT concentration in the dipping point and plant landfill	0.23	DDT concentration in the built area	0.25	DDT concentration in the dipping point and landfill	0.16	DDT concentration in the dipping point and plant landfill	0.18	DDT concentration in the built area	0.26	DDT concentration in the built area	0.27
BAF seeds	0.15	BAF mammals	0.19	BAF seeds	0.16	BAF soft bodied invertebrates	0.03	BAF seeds	0.22	BAF birds	0.27

BAF soft bodied invertebrates	0.05	DDT concentration in the dipping point and landfill	0.17	BAF birds	0.06	BAF seeds	0.01	DDT concentration in the dipping point and landfill	0.17	BAF seeds	0.21
BAF birds	0.00	BAF seeds	0.13	BAF mammals	0.01			BAF mammals	0.08	DDT concentration in the dipping point and landfill	0.18
BAF leaves	0.00	BAF soft bodied invertebrates	0.02	BAF soft bodied invertebrates	0.01			BAF soft bodied invertebrates	0.03	BAF soft bodied invertebrates	0.02
		BAF leaves	0.01	BAF grass	0.00			BAF grass	0.00	BAF leaves	0.01
		BAF grass	0.01	BAF leaves	0.00			BAF leaves	0.00	BAF grass	0.01