# Ecological vulnerability analysis of food chains and ecotopes

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ABSTRACT

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Nature development in the Netherlands is often planned on contaminated soils. In a previous study we developed a method to predict ecological vulnerability in wildlife using autecological information. In the present study this method is further elaborated from different angles to assess ecological vulnerability in food webs and terrestrial and aquatic ecotopes in the Netherlands. The method was tested for six chemicals: copper, zinc, cadmium, DDT, chlorpyrifos, and ivermectin. Results indicate that trophic groups differ in vulnerability. Within and between food chains vulnerability is dependent of ecotope, but more so at low trophic levels. Earthworm based food chains are most vulnerable. The method has good potential for application in vulnerability mapping.

Keywords: ecological risk assessment, wildlife, ecological vulnerability, food chain, risk map

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Common Adder (*Vipera berus*), Scarce Large Blue (*Maculinea telejus*) and Black-tailed Godwit (*Limosa limosa*).
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# Contents

# Preface

The research described in this report was financially supported by the European Union (Sixth Framework Programme, Integrated Project NoMiracle), and by the Dutch Ministry of Agriculture, Nature and Food Quality (Kennisbasis-01).

We thank Joost Lahr (Alterra, The Netherlands) for valuable discussions about mapping of ecological vulnerability. Marco Vighi (Università di Milano Bicocca, Italy) and Ad Ragas (Radboud Universiteit Nijmegen, The Netherlands) are thanked for their constructive comments on the draft version of this report.

# Summary

Ecological risk assessment of environmental contamination and other stressors is still in need of methods to predict effects at the ecosystem level. Current methods are largely based on toxicity threshold testing in a limited set of test species. Particularly for wildlife toxicity data are scarce, and extrapolation from laboratory testing is uncertain. Likewise, existing methodology is less able to differentiate for vulnerability between ecosystems. Conservation management and planning thus lack decision support in risk scenario prioritization and feasibility studies for nature on contaminated land.

Aiming to contribute to the development of better suitable assessment methods we have studied ecological vulnerability in food chains, food webs, and ecotopes. To this extent, we used ecological trait data for individual species following a recently developed method of ecological vulnerability analysis of wildlife (De Lange *et al.* 2006). We suggest that vulnerability analysis at the ecotope level may be used in vulnerability mapping, as a complementary approach to risk mapping, and discuss criteria for the adequate use of existing GIS databases to visualize vulnerability in ecosystem receptors.

The ecological vulnerability analysis was developed as a complementary method for traditional ecological risk assessment. Independent of traditional toxicity data, the method uses ecological traits of individual species to assess their exposure to soil contaminants, internal regulation and toxicological sensitivity, and potential for population recovery. The analysis results in a ranking of species, or assemblages of species, based on their relative vulnerability scores. Advantageous features of the method are:

- use of easily available ecological data;
- analysis can be performed for any assemblage of species;
- aquatic and terrestrial species can be compared.

For the purposes of this study, species were grouped in simplified food chains, and individual species vulnerability scores were used to estimate vulnerability of the entire food chain. Ecotope vulnerability was estimated by using habitat preferences of species, and assessing species assemblages accordingly. The following conclusions were drawn from the results:

- food chains differ in ecological vulnerability; the earthworm food chain is most vulnerable;
- homologue food chains in different ecotopes can have different vulnerabilities;
- mammals are generally more vulnerable than birds;
- vulnerability assessment proved consistent with predicted exposure concentrations in modelled food webs;
- vulnerability in species at lower trophic levels will differ between ecotopes, irrespective of the chemical stressor; vulnerability in higher trophic species is less dependent on ecotope.

# 1 Introduction

## 1.1 Background

One of the focus points in the Dutch nature conservation policy is the establishment of a National Ecological Network, comprised of existing nature conservation areas ('core areas') and 'nature development areas'. The latter are areas that are to be turned into nature reserves by ecological engineering and management. Nature development is often situated on former agricultural land and in floodplains of the large rivers. Soils in these areas are likely to be contaminated with a mixture of contaminants at low to moderate concentrations.

It is important to assess whether these contaminated soils may affect the potential for nature development. In spatial planning and nature management, decision support is therefore needed to assess ecological risks to the targets of nature planning, and to assess the relative potential of alternatives in view of local soil contamination. Current methods for risk assessment are insufficient to predict field effects for specific target species as defined in nature development planning and conservation management. An alternative method for ecological risk assessment for conservation targets in contaminated land was developed by Faber *et al.* (2004), and elaborated for wildlife by De Lange *et al.* (2006). This method is called the ecological vulnerability analysis. In this method, ecological traits for individual species of wildlife are used to assess their exposure to soil contaminants, internal regulation and toxicological sensitivity to toxicants, and potential for population recovery from harmful effects at the level of the individual. Sensitivity to toxicants is thus one aspect of ecological vulnerability. Species as well as assemblages of species can then be ranked on the basis of their relative vulnerability.

Advantages of the ecological vulnerability analysis are:
- ecological data for most species are easily available from literature of from expert knowledge;
- analysis can be performed for any selection or combination of species;
- aquatic and terrestrial species can be compared, despite their very different exposure routes.

As traits and behavioural characteristics of individual species are used in the assessment, the present state of development of the method focuses on the species level. While this is useful to support risk assessment for particular species targeted for conservation, there is need to further elaborate the method to support vulnerability assessment at the ecosystem level. In the current report we extend the method to assess ecological vulnerability in food chains, food webs, and ecotopes. In an attempt to increase the general applicability whilst using traits data for particular species we also investigated whether probabilistic modelling of species data can be used to produce generally valid food webs. To this extent we used randomly sampled data to construct 'virtual species' representing trophic groups in food chains.

## 1.2 Research aims

The long-term aim is to develop a knowledge based assessment system to support decision making in spatial planning and management for nature conservation, considering soil contamination and multiple stressors in the environment. The present report focuses on intermediate stages of the project, as described with the following research aims.

***Ecological vulnerability of virtual species***

The approach of creating virtual species and application of these species in probabilistic modelling was followed in order to compare functional groups for vulnerable traits, and rank different food chains representing terrestrial and aquatic environments. Another application could be to rank different nature types ('nature target types' in the Netherlands) on the basis of relative presence of various food chains in these ecosystems.

***Vulnerability analysis of food chains***

For the species in the dataset we gathered information on food preferences. This information on food preferences was used to extrapolate from vulnerability of a single species to vulnerability of a food chain or even food web. With this, we can answer research questions as:

- Are specialist species more vulnerable than generalist feeders?
- Does food preference affect vulnerability?
- Can we apply ecological vulnerability of single species in specific food chains or food webs?

***Vulnerability analysis of different ecotopes***

Each species in the dataset was assigned to one or more ecotopes. This information was used to investigate differences in vulnerability of species present at the different ecotopes. Some species are very specific and occur in only one ecotope, most species occur in more than one ecotope, some species are generalist, with a wide distribution up to eight different ecotopes. The following research questions were addressed:

- Do similar food chains in different ecotopes have different vulnerabilities?
- Is there an interaction between food preference and ecotope in determining ecological vulnerability?

***Use of ecotope vulnerability in risk mapping***

The research described in this report is relevant to provide new methodology for ecological risk assessment in support of management of wildlife and natural environments. Here we attempt to connect the individual species vulnerability to ecological risk mapping. This is strongly linked with NoMiracle workpackage 4.4, where the most appropriate and/or novel techniques for presentation and visualisation of cumulative risks are developed and demonstrated.

## 1.3 Outline of report

Chapter 2 describes the used dataset, which was based on the set of species described in De Lange *et al.* (2006), and extended with nine additional species. Food preference and ecotope preference were gathered for all species.

The ecological vulnerability scores of the individual species are used in a probabilistic modelling effort, described in Chapter 3.

Food preferences and ecotope preferences were used to generate vulnerability assessments of food chains and food webs (Chapter 4) and ecotopes (Chapter 5).

The possibilities to generate maps are explored in Chapter 6, where the vulnerability data is linked with ecological risk mapping as developed in other parts within the NoMiracle project. We conclude with some general remarks in Chapter 7.

# 2 Ecological vulnerability analysis

## 2.1 Species dataset

The ecological vulnerability analysis as described in De Lange *et al.* (2006) is focused on the vulnerability of a single species to several chemical stressors. The method has been developed using data for a set of 135 species, comprised of 'common species' and rare or threatened Dutch nature conservation policy 'target species' of wildlife. In the current study we interpret these individual vulnerability data in the context of food chains and ecotopes. We added nine more species to the dataset; these additional species were selected to incorporate:

- top predator species;
- species used in published food chain models (*e.g.* Loos *et al.*, 2006);
- sufficient representation of mammals over different ecotopes.

The added species were Sparrowhawk, Eagle owl, Pike, Rabbit, Red fox, Common vole, Wood mouse, Common shrew, and Weasel. Data for ecological traits and behavioural characteristics were gathered for these species, and ecological vulnerability was calculated by means of multi-criteria analysis as described in De Lange *et al.* (2006). The ecological vulnerability analysis results in a relative ranking of species on a 0-1 scale, with higher scores representing a higher vulnerability. This exercise was performed for copper, zinc, cadmium, DDT, chlorpyrifos and ivermectin as model chemicals.

The full species list used in this study is given in Appendix 1. Each species is given a code, which consists of an abbreviation of the taxonomic group (see Table 1) and either a number (in case of conservation target species), or a letter (common species).

*Table 1. Species representation in our dataset over taxonomic groups.*

| Taxonomic group | Code | Conservation target species | Common species | Total |
|---|---|---|---|---|
| Mammals | MAM | 8 | 10 | 18 |
| Birds | BIRD | 55 | 13 | 68 |
| Fish | FISH | 6 | 5 | 11 |
| Amphibians | AMPH | 7 | 0 | 7 |
| Reptiles | REP | 5 | 1 | 6 |
| Dragonflies | DFLY | 6 | 1 | 7 |
| Butterflies | BFLY | 24 | 3 | 27 |
| Total | | 111 | 33 | 144 |

## 2.2 Food preference

To assign species to food chains and trophic groups, food preference was assessed for each species in the data set (144 in total). We pragmatically defined 19 different food items, adapted from Luttik *et al.* (1997). These food items included both terrestrial and aquatic sources:

1. plant foliage and detritus
2. nectar
3. fruits and seeds
4. insects (incl. larvae)
5. spiders
6. snails
7. earthworms
8. aquatic insects (incl. larvae)
9. aquatic worms
10. crustaceans
11. zooplankton
12. molluscs
13. aquatic plants
14. reptiles
15. amphibians
16. fish
17. mammals
18. birds
19. carrion

The food preference in different life stages (juvenile and adult) was assessed for each species. For most species, there are no significant changes in food preferences during their life span (*i.e.* no ontogenetic shifts). We therefore chose to use the food preference for adult life stage for further analysis, since this life stage comprised the largest part of the full life span.

From the food preferences of these 144 species, a theoretical food web can be constructed (Figure 1). The many arrows in the graph illustrate that most species feed on multiple food types. In this complex food web the vulnerability scores can be projected. This did not result in a clear visual pattern of food web vulnerability (results for different chemicals shown in Appendix 2). This is likely to be related with the multiple food choices in the web.

## 2.3 Ecotopes

The following ecotopes (abbreviation in brackets) have been distinguished based on the grouping of nature target types in Dutch nature conservation policy (Bal *et al.*, 2001; Appendix 3):

- Dunes (D)
- Heath land, moors and inland dunes (H)

- Marshes (M)
- Forests (F)
- Shrubs and brushes (S)
- Grassland (G)
- Arable land (A)
- Urbanized area (U)
- Lakes, fens, and ponds (freshwater) (L)
- Rivers (R)
- Estuary, aquatic parts (EA)
- Estuary, terrestrial parts (ET)
- Pioneer communities (P)

All species in the dataset were assigned to one or more ecotopes, using information from literature. Presence in ecotopes was scored in two categories: preferred habitat = 2, and likely habitat = 1. The species set per ecotope is given in Appendix 4, including a comparison with nature conservation target listings from Bal *et al.* (2001).

Table 2 gives an overview of the number of species (target and common) from our dataset assigned to each ecotope. We made a comparison for bird species with the current Dutch nature target bird species listing to check how representative our species set is per ecotope. This was done by expressing the number of nature target species in our selection per ecotope as a percentage of the total number of nature target species in the corresponding nature target type. Results are presented in the last column in Table 2. A score of 10 % means that in our species set we covered 10% of the nature target bird species. The calculation was only performed for birds, since this is the largest group. This reveals that the avifauna of the ecotopes under study is covered to different extent, but that coverage generally seems fair (we would tentatively consider 10% as a minimum) except for pioneer systems. Conservation target bird species are best represented in heath land, marshes, shrubs, and estuaries.

## 2.4 Remarks on current dataset

The current selection of species was based on previous studies by Faber *et al.* (2004) and De Lange *et al.* (2006). In Faber *et al.* (2004) 113 target species were selected mostly for riverine nature conservation target types, based on policy target definitions at the time (Bal *et al.* 1995). De Lange *et al.* (2006) extended this selection with 22 common species, and the present study extends the selection with another 9 species. The selected species now cover all ecotopes relevant for the Netherlands (except for marine environment), but the original bias towards riverine ecotopes still persists.

For this study we used the second revised edition of Bal for comparisons. Our selection of species per ecotope does not comprise all species targeted for conservation in Dutch policy. Firstly, as a result of further development in Dutch conservation policy the number of target species was increased from the first edition to the second edition of 'Handboek Natuurdoeltypen' (Bal *et al.*, 1995, 2001). For example, bird target species increased from 64 to 127 species, mammal target species from 16 to 36 species. Other species have lost the status of target species.

Secondly, conservation target species serve as biodiversity indicators, and represent species which are either very rare in number, of international importance, or declining in abundance at a national or European scale. Some of these target species are extinct in The Netherlands (*e.g.* some butterfly species), or have been reintroduced (*e.g.* Beaver, Otter). Whilst conservation target species may not actually be present in the ecotopes, this was a criterion for our selection.

Our dataset of presently 144 species represents both conservation target species and common species as present in a variety of Dutch ecotopes. Obviously, our set does not cover all species in all ecotopes. Rather it should be considered as a working set to illustrate and improve the methodology of ecological vulnerability analysis. Further extension of the database is always possible, and in fact desirable if new types of ecotopes would become subject of study. In the next chapter we further discuss the validity of the use of present data for general interpretations.

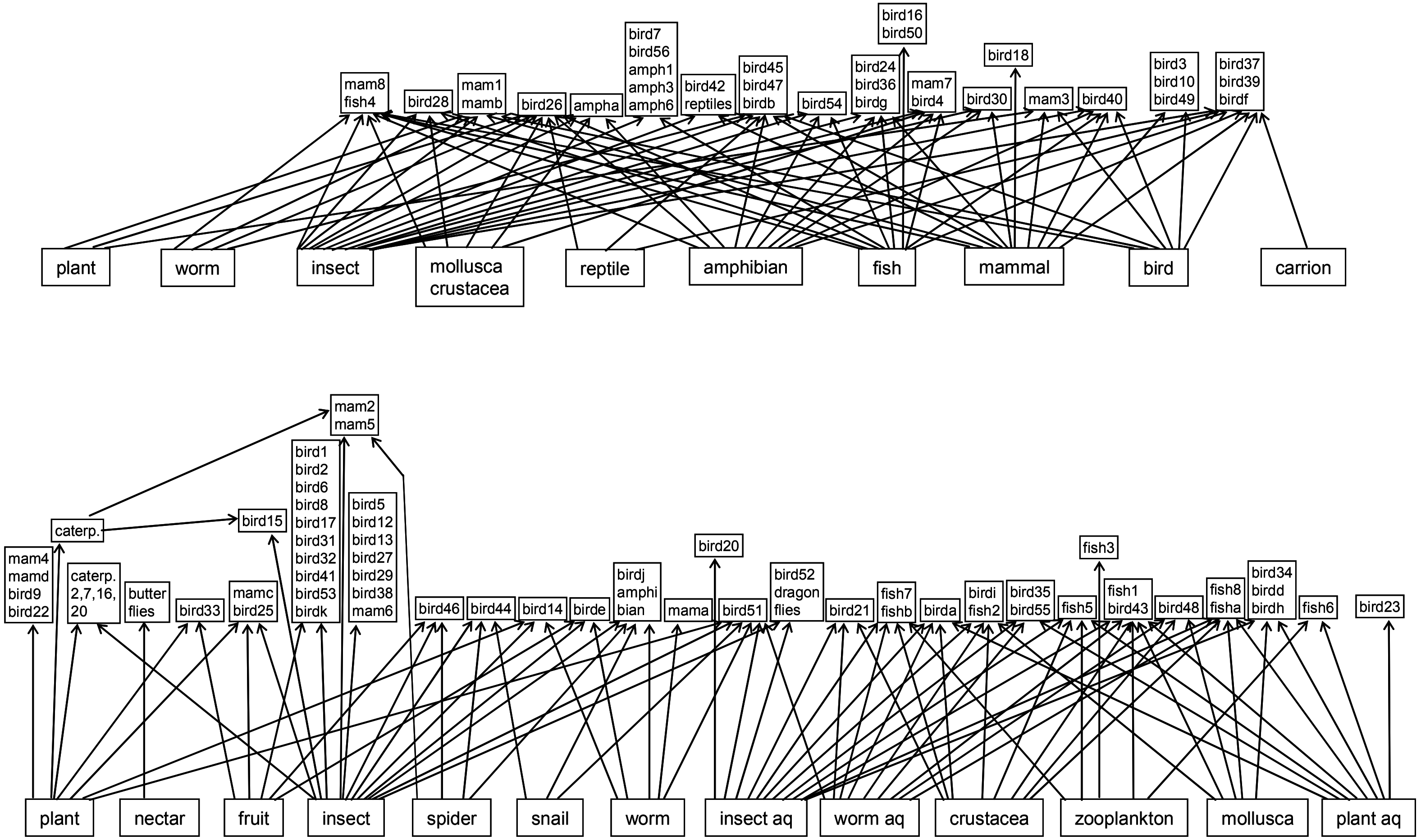

*Figure 1. Constructed food web for 144 species used in the vulnerability analysis. Species codes as in Appendix 1. For visual clarity the food web is split in two. The lower half of the graph represents the food choice of species lower in the food web, the upper half of the graph represents the food choice of predatory species higher in the food web. For clarity purposes, five food types (plant, worm, insect, mollusca and crustacean) are both presented in the lower half and upper half.*

*Table 2. Distribution of species in our dataset over ecotopes, and coverage (%) of ecotope species assemblages as defined in conservation policy in our dataset expressed for birds.*

| Ecotope | Mammals | | Birds | | Fish | | Amphibians | | Reptiles | | Dragonflies | | Butterflies | | % Birds |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | target | common | target | common | target | common | target | common | target | common | target | common | target | common | |
| D | 0 | 4 | 9 | 1 | 0 | 0 | 2 | 0 | 1 | 0 | 0 | 0 | 3 | 1 | 15% |
| H | 0 | 3 | 19 | 1 | 0 | 0 | 1 | 1 | 4 | 1 | 0 | 0 | 5 | 0 | 57% |
| M | 2 | 4 | 21 | 4 | 0 | 0 | 1 | 0 | 0 | 1 | 4 | 0 | 11 | 0 | 39% |
| F | 5 | 6 | 11 | 4 | 0 | 0 | 4 | 0 | 3 | 0 | 0 | 0 | 5 | 2 | 27% |
| S | 4 | 9 | 17 | 3 | 0 | 0 | 3 | 0 | 3 | 1 | 0 | 0 | 9 | 3 | 38% |
| G | 3 | 5 | 23 | 4 | 0 | 0 | 1 | 0 | 2 | 1 | 0 | 0 | 21 | 2 | 28% |
| A | 1 | 4 | 13 | 1 | 0 | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 22% |
| U | 3 | 5 | 4 | 4 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | - |
| L | 2 | 0 | 10 | 6 | 3 | 4 | 7 | 0 | 0 | 0 | 5 | 1 | 0 | 0 | 14% |
| R | 2 | 0 | 7 | 4 | 6 | 5 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 18% |
| EA | 1 | 0 | 7 | 4 | 1 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 39% |
| ET | 0 | 0 | 6 | 2 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 29% |
| P | 0 | 1 | 1 | 1 | 0 | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 4 | 2 | 0% |

# 3 Probabilistic modelling to compare functional groups between ecotopes

## 3.1 Approach

As a first step in our study we examined whether our dataset would allow for wide generalizations regarding ecological vulnerability in food webs. We did that by composing 'virtual species' from randomly sampled data for species representing functional groups in particular food chains. The approach of virtual species was chosen to compare functional groups for vulnerable traits within and between different food chains. As a next step it was thought to rank different ecotopes (Dutch 'nature conservation target types') on the basis of relative presence of various food chains in these ecosystems. This approach was designed to enable the assessment of ecosystem vulnerability particularly with respect to food web interrelations between species.

The appropriateness of the dataset to generate virtual species was assessed in the following manner:

- Species were grouped with food type as preference: for example 12 species in dataset feed on plant foliage (leaves), 23 species feed on earthworms, and 27 species feed on mammals.
- For each group of species, from the available ecological data, the minimum, median and maximum value for each characteristic was calculated (Table 3).
- Multi-criteria analysis was performed to calculate ecological vulnerability scores. For a brief description of the MCA-method see Box 1. This was done three times, with minimum values, median values, and maximum values respectively. This way, minimum vulnerability, median vulnerability and maximum vulnerability scores were obtained. Note: these minimum and maximum scores are worst case scenarios, respectively the lowest and highest possible score when performing a full probability modelling with virtual species. These will be the outer limits in further probabilistic modelling (Table 3).

*Table 3. Ecological vulnerability scores for three food chains, calculated for each contaminant with minimum, median and maximum values of ecological traits. Vulnerability scores can range from 0 to 1, with a higher score indicating higher vulnerability.*

| Food chain | Vulnerability score | Cu/Zn | Cd | DDT | Chlorpyrifos | Ivermectin |
|---|---|---|---|---|---|---|
| Foliage based | minimum | 0.40 | 0.24 | 0.27 | 0.35 | 0.33 |
| | median | 0.61 | 0.44 | 0.49 | 0.61 | 0.59 |
| | maximum | 0.81 | 0.70 | 0.79 | 0.84 | 0.83 |
| Earthworm based | minimum | 0.41 | 0.28 | 0.32 | 0.36 | 0.35 |
| | median | 0.65 | 0.54 | 0.59 | 0.67 | 0.63 |
| | maximum | 0.90 | 0.94 | 0.90 | 0.94 | 0.94 |
| Mammals | minimum | 0.38 | 0.26 | 0.30 | 0.35 | 0.33 |
| | median | 0.56 | 0.49 | 0.54 | 0.64 | 0.53 |
| | maximum | 0.95 | 0.91 | 0.91 | 0.94 | 0.94 |

*Box 1. Brief description of the Multi Criteria Analysis.*[1]

**Multi Criteria Analysis in brief**

The description below presents the basic performance of the multi criteria analysis as it is used so far, in this report the MCA is used to calculate vulnerability of 'virtual species'.

Species traits and other autecological characteristics are used to rank a set of wildlife species by vulnerability for a certain chemical. The data used are arranged into four main groups:

A. *External exposure:* characteristics in this main category describe aspects in the biology of species that affect the likeliness and the extent of exposure to the contaminant.
B. *Internal exposure:* characteristics in this main category determine the internal concentration, activity and distribution of a substance within the body.
C. *Effects at individual level:* this main category describes the intrinsic toxicological sensitivity of the individual to the contaminant; this is comparable with traditional toxicological data.
D. *Effects on population level:* characteristics in this main category determine the effects on population level in relation to contaminants, the resistance to adverse effects, and potential for recovery after exposure (resilience).

These data were collected from literature and were checked by expert judgement[1].

Vulnerability scores were calculated per species using the multi-criteria analysis software program BOSdA (Janssen *et al.*, 2000). Weight factors are assigned through expert judgement[1] in order to weigh the relative contribution of each ecological characteristic and each main group to vulnerability given a particular environmental contaminant. This is performed for six chemicals (cadmium, copper, zinc and DDT, Faber *et al.*, 2004) and two additional chemicals (chlorpyrifos and ivermectin, De Lange *et al.*, 2006). An overview of the used ecological characteristics and weight factors are given in Appendix 5.

The characteristics used in the analysis need to be quantified, standardized, and weighed, before they can be used in BOSdA. The direction of effect (increasing or decreasing) on vulnerability has to be determined for each characteristic. The value of a characteristic is compared amongst the species, and is standardized on a scale from 0 to 1. This is the MCA score for that characteristic, where a score of 0 represents not vulnerable, and a score of 1 represents maximum vulnerable. Scores for all characteristics are then multiplied by the weight factor and added to obtain the species vulnerability score.

The multi-criteria analysis results in a score for each species, and these scores are used to rank the species from most vulnerable (top rank, highest score) to least vulnerable (bottom rank, lowest score) for each contaminant. The final MCA score is a weighed average of the scores for the four main categories 'external exposure', 'internal exposure', 'toxicological sensitivity' and 'population effects'.

See De Lange *et al.* (2006) and Faber *et al.* (2004) for a detailed description.

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[1] Expert judgment is used for selection of the ecological characteristics and assessing weight factors for each characteristic. This is described as transparently as possible. One must realize that all models use some form of expert judgment, *e.g.* in selecting characteristics or processes to incorporate in a model. Pros and cons of our method are extensively described in De Lange *et al.* (2006).

Next, an assessment was made on the presence of species in different ecotopes. A further analysis was conducted to test for differences between ecotopes, using the earthworm food chain as an example. Earthworm feeders were selected for each ecotope, and minimum, median and maximum values for vulnerability were calculated, using the approach described above. Results are presented in Figure 2.

Differences between ecotopes in minimum and maximum ecological vulnerability scores for earthworm feeders are mainly caused by the variations in number of species present in specific ecotopes, since for each ecotope a subset of species was used for the calculations.

## 3.2 Pilot probabilistic model

A pilot probabilistic modelling was performed for species feeding on earthworms. First, virtual species were calculated, using the following procedure:

- For the set of earthworm feeders (n=23), minimum and maximum values for each characteristic are gathered.
- Random values are generated for each characteristic, within the limits of minimum and maximum values, using the random number generator in Excel.
- 10 virtual species are generated, ecological vulnerability scores were calculated with the computer program BOSdA for each virtual species.
- Average vulnerability scores are presented in Table 4.

*Table 4. Ecological vulnerability scores for different contaminants averaged for 10 virtual species, compared with the average scores for the 23 earthworm feeders. Standard deviation is given in brackets.*

| | Virtual species | Species in data set |
|---|---|---|
| Cu/Zn | 0.68 (0.04) | 0.41 (0.07) |
| Cd | 0.59 (0.05) | 0.46 (0.04) |
| DDT | 0.58 (0.06) | 0.42 (0.05) |
| Chlorpyrifos | 0.67 (0.05) | 0.45 (0.06) |
| Ivermectin | 0.65 (0.05) | 0.44 (0.06) |

Average ecological vulnerability score in the virtual species is considerable higher than the average value for the actual 23 earthworm feeders in the data set. The scores are slightly higher than when calculated with the median values as calculated in Table 3, see also Figure 2. The difference between the mean value of 10 virtual species and the median value calculated in Table 3 suggests that the distribution of the virtual species is slightly skewed.

An explanation for the large difference between virtual earthworm feeders and actual earthworm feeders may be that for the virtual species, each characteristic was given a random value. In real life, some characteristics are correlated. This was not taken into account in the probability model.

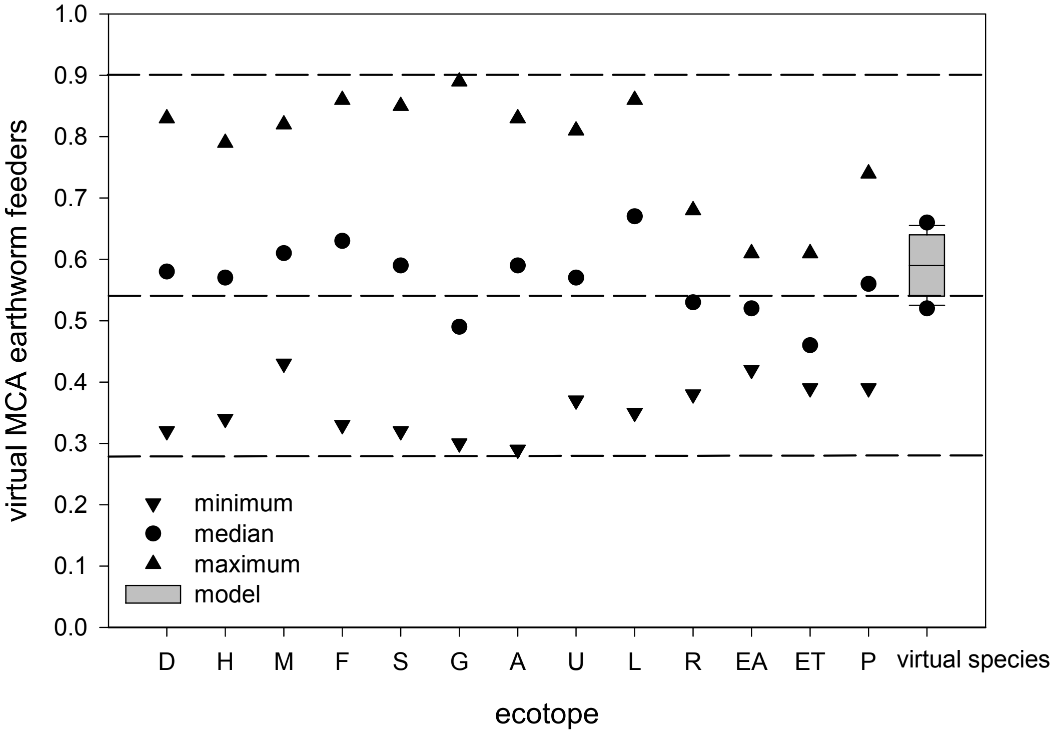

*Figure 2. Ranges of virtual ecological vulnerability scores for cadmium of earthworm feeders present in each ecotope (abbreviations as in §2.3). Dashed lines represent minimum (0.28), median (0.54) and maximum (0.90) vulnerability score of earthworm species in all ecotopes combined. The boxplot represents the results of the pilot probability modelling, using 10 virtual species.*

## 3.3 Discussion of probabilistic modelling

Within the NOMIRACLE project, the use of probabilistic modelling was set out to answer several research questions. These included the comparison of functional groups for vulnerable traits, the ranking of different food chains representing terrestrial and aquatic environments, and the ranking of different nature types ('nature target types' in the Netherlands) on the basis of relative presence of various food chains in these ecosystems. Other research questions that were intended to address with the use of probabilistic modelling were the study into higher trophic levels, *i.e.* predators preying on the four different prey items defined in this report, and/or the apex predator (bird or mammal), present in a specific ecotope. For each trophic level, a further refinement into different ecotopes could then be made.

The results from the pilot probabilistic modelling give however some concern regarding the usefulness of the results. The vulnerability scores calculated in the probabilistic modelling exercise, based on 23 earthworm feeders, was considerable higher than the average of these species in the actual dataset. There may be two underlying causes. First, in our modelling effort, we generated independent random values for each characteristic (within the limits of the actual species data). In the actual dataset several characteristics are not independent, but correlated, restricting the range of vulnerability scores. Second, the random number generator uses a uniform distribution, whereas some of the variables in the species set are skewed. The two causes, biological and statistical, are not studied further, but it is likely that the combination of both has resulted in the difference between 'virtual' species and actual species.

Further, our aim was to be able to distinguish between different ecotopes. Figure 2 shows that, at least for earthworm feeders, the different ecotopes have quite similar virtual earthworm feeders. This is because from the pool of 23 real earthworm feeders, a subset is drawn for each ecotope. The minimum, median and maximum virtual ecological vulnerability scores calculated with a subset for each ecotope lies within the boundaries of the values for all 23 species.

Based on these pilot results it was concluded that the use of probabilistic modelling did not lead to answers on our research questions. Further development of the virtual species and probability model therefore seemed unpromising. As this stage of method development represented a go-no go milestone, we decided against further development. Instead, further activities were focused on assessment of ecological vulnerability in food chains and ecotopes on the basis of actual species data.

# 4 Ecological vulnerability in food chains

## 4.1 From single species to food chains

For the species in the dataset we gathered information on food preferences. This information on food preferences was used to extrapolate from vulnerability of single species to vulnerability of food chains, or entire food webs.

For this purpose, 19 different food types were distinguished (§ 2.2), and species were attributed to a degree of omnivory on the basis of number of preferred food items (Figure 3). Many species in our dataset feed on a single food type, at least during their adult life time that is. These include all butterflies, feeding on nectar, and some predatory birds, feeding specifically on small mammals.
On the other end of the spectrum, there is a limited number of species with a wide food preference (high degree of omnivory). These include some amphibians, fish and mammals.

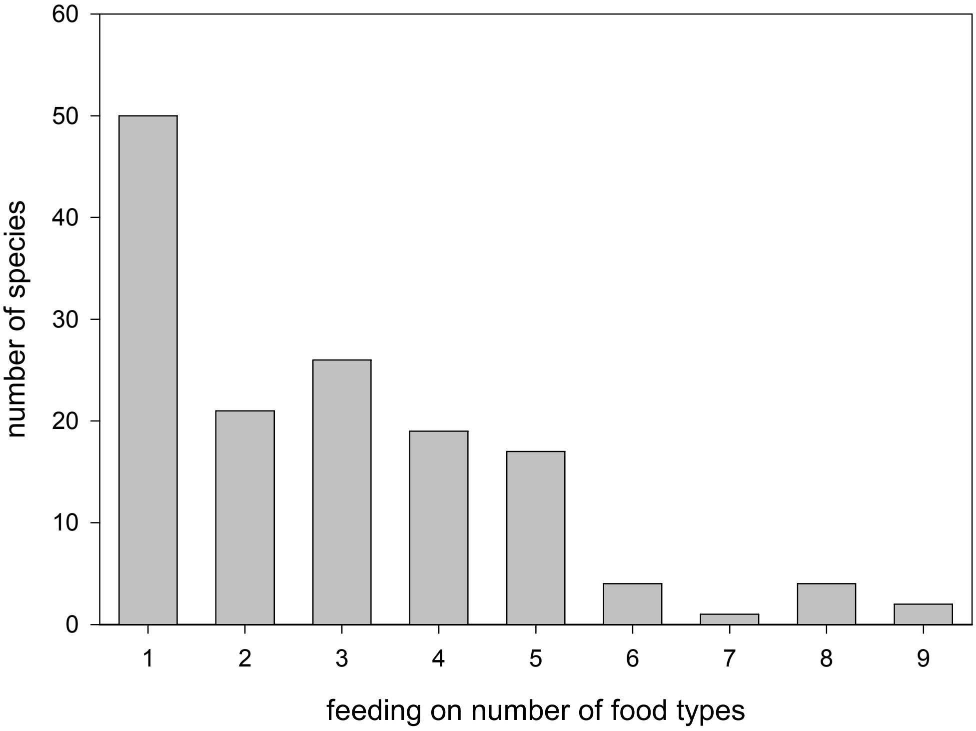

*Figure 3. Histogram of degree of omnivory.*

## 4.2 Are specialist species more vulnerable than generalists?

Using the information on food preferences, we tested whether there was a correlation between number of food preferences (degree of omnivory) and ecological vulnerability. A significant ($p<0.01$) but weak (Pearson $r = 0.26$) positive correlation between vulnerability and omnivory was found for cadmium. This positive correlation stems from the high vulnerability to cadmium of several amphibian species, mammal species like Badger, and bird species like White stork and Savi's warbler, which all have a high degree of omnivory. The high score for ecological vulnerability of these species was determined by other characteristics than food choice. It is therefore considered inappropriate to generalize the suggestion that omnivore species are more vulnerable to cadmium. For other chemicals, no significant correlation was observed between vulnerability and omnivory.

For each food type species were divided in two groups: 'generalists' (3 or more food types) and 'specialists' (1 or 2 food types). Ecological vulnerability scores were compared with a t-test (Appendix 6). Generalists and specialists did not significantly differ in the case of most food types, except for three:

- Plant feeding specialists (foliage or detritus feeders) have lower vulnerability than generalists; this difference was significant for cadmium and DDT.
- Fruit (incl. nectar) specialists are less vulnerable to cadmium, but more vulnerable to copper, zinc and chlorpyrifos. These specialist species include all butterflies and some bird species.
- Predators specialized on mammals are more vulnerable than generalist predators; this difference was significant for DDT, chlorpyrifos and ivermectin. These specialist species include reptiles and apex bird predators.

## 4.3 Ecological vulnerability in simplified food chains

The next step from species data to food chain assessment was made using simplified terrestrial food chains (*cf.* RIVM studies of Jongbloed *et al.*, 1994 and Traas *et al.*, 1996):

(soil) → foliage → bird or mammal → bird or beast of prey
(soil) → seed → bird or mammal → bird or beast of prey
(soil) → insect → bird or mammal → bird or beast of prey
(soil) → worm → bird or mammal → bird or beast of prey

Food preferences were used to assign species to these simple food chains. The ecological vulnerability scores were then compared between trophic groups, and differences were tested in a 2-way ANOVA using food type and taxonomical background (mammal or bird) as factors (Table 5, Figure 4 and Appendix 7).

*Table 5. Average ecological vulnerability scores for species in dataset feeding on one of these food types. Lower case letters indicate homogeneous groups per contaminant after 2-way ANOVA and post-hoc Tukey test (p<0.05).*

| | Chemical stressor | | | | |
|---|---|---|---|---|---|
| Food chain | Cd | Cu, Zn | DDT | Chlorpyrifos | Ivermectin |
| Foliage | 0.39 a | 0.36 ab | 0.32 a | 0.41 | 0.39 ab |
| Seeds | 0.42 ab | 0.35 a | 0.35 ab | 0.40 | 0.38 a |
| Insects | 0.44 bc | 0.36 ab | 0.37 bc | 0.42 | 0.39 ab |
| Worms | 0.47 c | 0.40 b | 0.40 c | 0.44 | 0.44 b |

Significant differences in vulnerability were observed between food chains for all contaminants, except for chlorpyrifos (Table 5). Species feeding on worms are more vulnerable than species feeding on foliage or seeds. This is in agreement with Jongbloed *et al.* (1996), who conclude that the food chain soil - worm - bird or mammal is the most critical for secondary poisoning with cadmium (based on probabilistic modelling of biomagnification in a simplified food web). There was also a significant difference in general between mammal and bird vulnerability for all chemicals, with mammals being more vulnerable than birds. This was independent of the food chain (no significant interaction term). Beasts of prey showed in general higher vulnerabilities than birds of prey, however these differences were not significant (t-test, p>0.05).

Our finding that mammals are more vulnerable than birds seems to contradict earlier findings by Luttik *et al.* (1997), who found that for cadmium, mammals are less sensitive than birds. Their conclusion was based on extrapolation of a limited set of toxicity data to a large set of bird and mammal species, calculating dietary No Effect Concentrations (Luttik *et al.*, 1997). Bioaccumulation in general is assumed to be inversely related with the rate of xenobiotic metabolism, with mammals having a higher rate and thus lower bioaccumulation than birds (Hoffman *et al.*, 1990). However, the higher ecological vulnerability of mammals in our specific food chains may be the result of other aspects than exposure through food and bioaccumulation, such as life history traits and behavioural traits. The species specific combination of all traits together determines the vulnerability of each species. First inspection of the scores per category indicate that it's a combination of both external exposure (category A) and effects on population level (category D) that result in higher vulnerability of mammals.

One must realize that in the calculation of the vulnerability score, the food choice is incorporated in the analyses for accumulating substances (cadmium, DDT, chlorpyrifos and ivermectin; not for copper and zinc). Species feeding on foliage and seeds are scored 1, feeding on worms or insects are scored 3. If the food preference would not have been used in the calculation of the vulnerability, scores for cadmium and DDT would be 0.063 lower, and scores for ivermectin and chlorpyrifos would be 0.029 lower. This would change the results for DDT and cadmium, where the 'seed food chain' then would be the most vulnerable. It won't affect the results for chlorpyrifos and ivermectin; the 'earthworm food chain' would still be the most vulnerable chain for these contaminants.

*Conclusions*

The earthworm food chain is more vulnerable than other food chains, for all chemicals tested. Mammals in these simplified food chains are generally more vulnerable than birds.

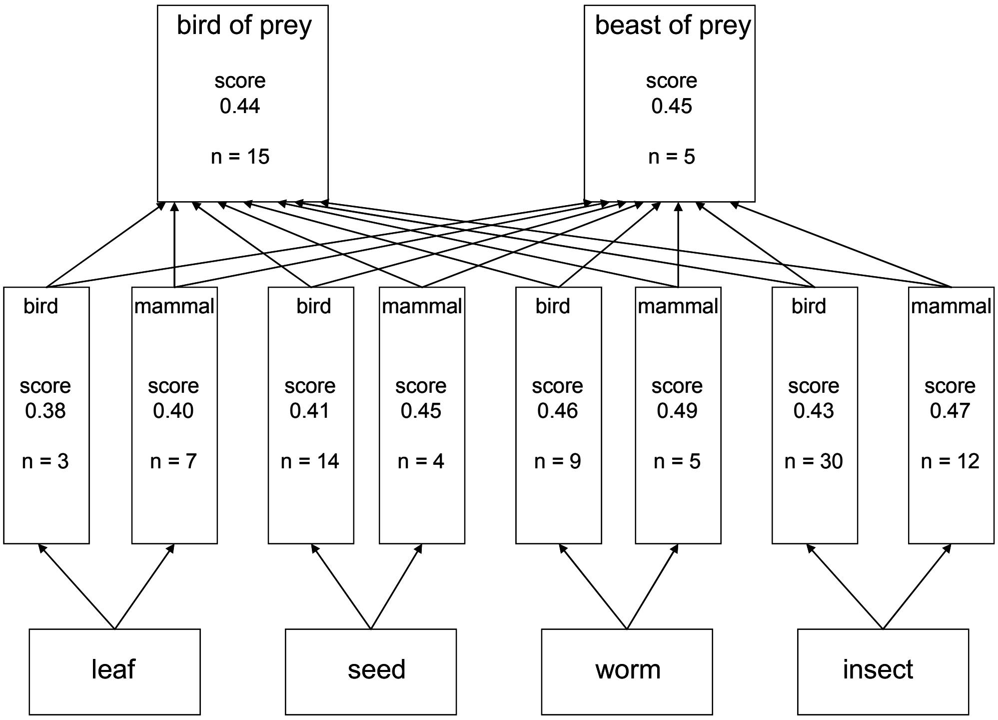

*Figure 4. Average ecological vulnerability scores for cadmium in simplified food chains; n indicates number of species. Figures for other contaminants are shown in Appendix 7.*

## 4.4 Vulnerability in specific food chains and food webs

A common approach to food web studies is to model effects for specific food chains or food webs. The ecological vulnerability scores for each species can be applied in such specific food chains or food webs. Two examples are presented here.

*Example 1: food chain*

Table 6 presents several example food chains, many more can be developed for particular areas of study. The ecological vulnerability of a food chain can be assessed either by the maximum vulnerability of one of the species in the food chain or by the mean of the vulnerability scores. The geometric mean was chosen over arithmetic mean, since it dampens the effect of high variability. (Variability of vulnerability scores was quite low, resulting in almost identical mean values, not further shown here.) For each of these example food chains, the species ecological vulnerability scores are used. Figure 5 illustrates how these vulnerability scores can be compared within the food chain; other examples are given in Appendix 8.

The food chain vulnerabilities calculated by the two methods are given in Table 7, Which one of the two methods is the most suitable to estimate food chain vulnerability partly depends on the research question. However, the maximum value in the chain seems in general to be the best approach (= weakest link principle) (see for example Williams & Martinez, 2000). This is the approach we therefore use.

*Table 6. Example food chains.*

| Food chain | Step 1 | Step 2 | Step 3 | Step 4 |
|---|---|---|---|---|
| 1. plant | caterpillar | Black bird | Buzzard | Eagle owl |
| 2. plant | Common vole | Kestrel | Eagle owl | |
| 3. worm | Common shrew | Little owl | Eagle owl | |
| 4. zooplankton | Stickle back | Twaite shad | Catfish | |
| 5. zooplankton | Stickle back | Ide | Pike | |
| 6. zooplankton | Allis shad | Pike | | |
| 7. aq. worm | Stickle back | Twaite shad | Catfish | |
| 8. aq. worm | Carp | Ide | Pike | |
| 9. aq. worm | Bullhead | Ide | Pike | |

*Table 7. Maximum (max.) and geometric mean (geo. mean) vulnerability for each food chain. For each contaminant, the most vulnerable food chain is indicated in bold.*

| | | | | | Food chain | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | | 1 | 2 | 3 | 4 and 7 | 5 | 6 | 8 | 9 |
| Cd | max. | 0.48 | 0.48 | **0.49** | 0.44 | 0.41 | 0.35 | 0.44 | 0.44 |
| | geo. mean | 0.44 | 0.43 | 0.48 | 0.37 | 0.37 | 0.30 | 0.37 | 0.37 |
| Cu/Zn | max. | 0.42 | 0.37 | 0.41 | **0.51** | 0.50 | 0.35 | 0.43 | 0.58 |
| | geo. mean | 0.36 | 0.34 | 0.39 | 0.45 | 0.41 | 0.32 | 0.39 | 0.43 |
| DDT | max. | 0.43 | 0.40 | 0.43 | **0.44** | 0.42 | 0.35 | **0.44** | **0.44** |
| | geo. mean | 0.40 | 0.36 | 0.41 | 0.39 | 0.37 | 0.31 | 0.37 | 0.37 |
| CPF | max. | **0.55** | 0.46 | 0.52 | 0.46 | 0.46 | 0.32 | 0.39 | 0.54 |
| | geo. mean | 0.45 | 0.43 | 0.49 | 0.37 | 0.37 | 0.27 | 0.35 | 0.39 |
| Ivermectin | max. | 0.51 | 0.46 | **0.52** | 0.46 | 0.46 | 0.30 | 0.37 | **0.52** |
| | geo. mean | 0.40 | 0.37 | 0.43 | 0.37 | 0.36 | 0.27 | 0.33 | 0.37 |

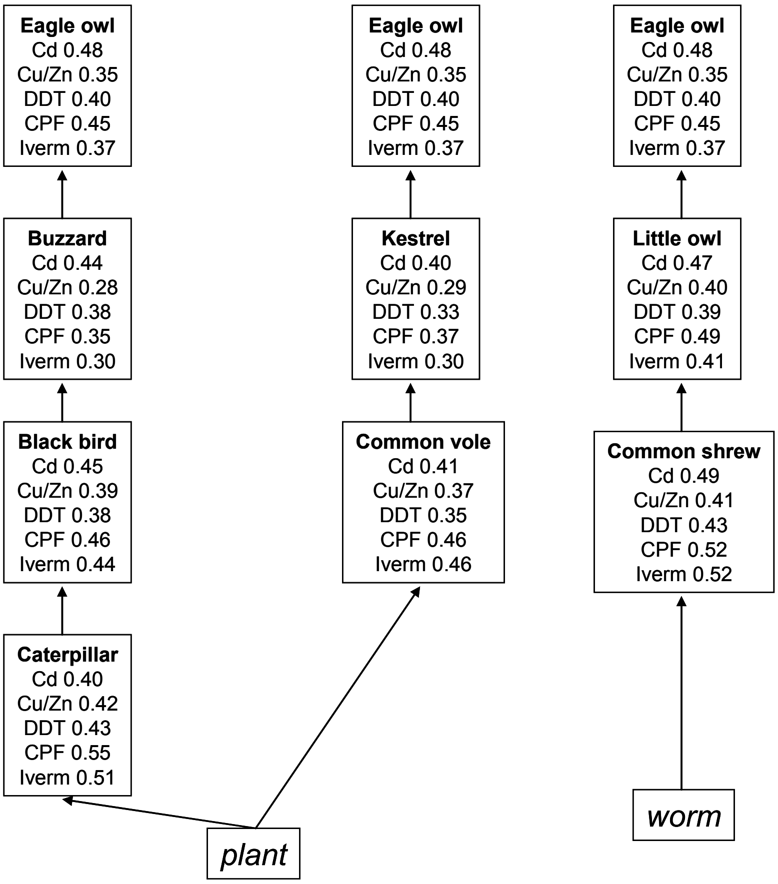

*Figure 5. Comparison of ecological vulnerability scores within example food chains 1, 2 and 3; other examples are given in Appendix 7.*

*Example 2: Food webs*

Loos *et al.* (2006) have described a food web for a floodplain ecosystem, and developed a model to predict exposure to soil contaminants. We used this food web, and added the vulnerability scores (see Figure 6 and Appendix 9). This illustrates that, depending on type of contaminant, either Badger (trophic level 3) or Mole (trophic level 2) is the most vulnerable species in this food web. Other vulnerable species are Weasel and Common shrew.

The model of Loos *et al.* (2006) predicts differences in Predicted Exposure Concentrations of cadmium based on a spatially explicit mobility and exposure, and biomagnification within different food chains. Their model predicts considerably higher mean exposure concentrations for the species Common shrew, Mole, Badger, Weasel and Little owl, than for the other five species (Wood mouse, Bank vole, Common vole, Rabbit and Kestrel). This is in agreement with our vulnerability estimation, where these species have the highest ecological vulnerability score. The vulnerability ranking was consistent for other chemicals as well (Appendix 9).

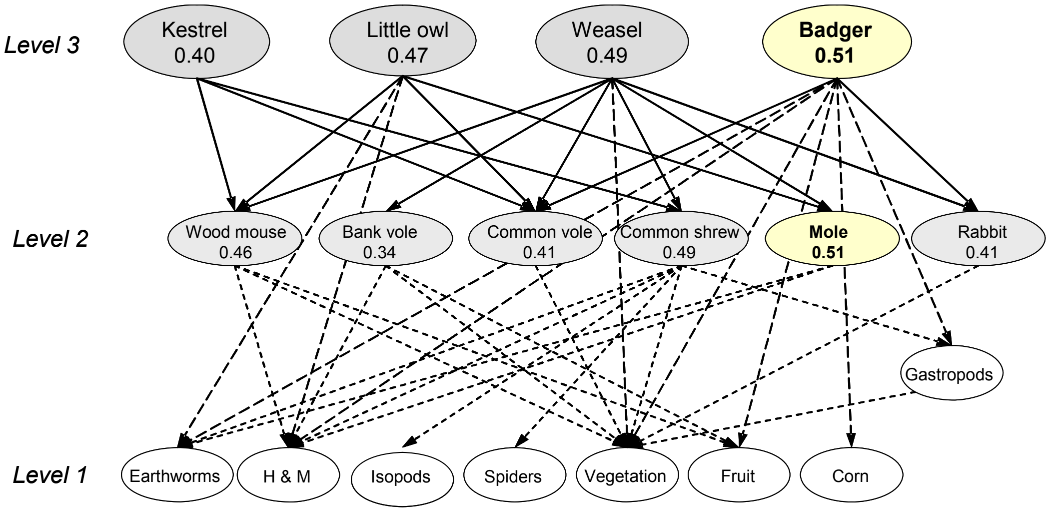

*Figure 6. Ecological vulnerability scores for cadmium superimposed on the food web studied by Loos et al. (2006), with Badger and Mole being characterized by highest vulnerability scores. Examples for other contaminants are given in Appendix 9.*

# 5 Ecological vulnerability of ecotopes

## 5.1 From species to ecotopes

First we investigated the differences in vulnerability of species present at the different ecotopes. Each species in the dataset was assigned to one or more ecotopes. Some species are very specific and occur in only one ecotope, most species occur in more than one ecotope, some species are generalist, with a wide distribution up to eight different ecotopes (Figure 7). The number of ecotope preferences of a species (= degree of omnipresence) is not related with ecological vulnerability scores (results not further shown here).

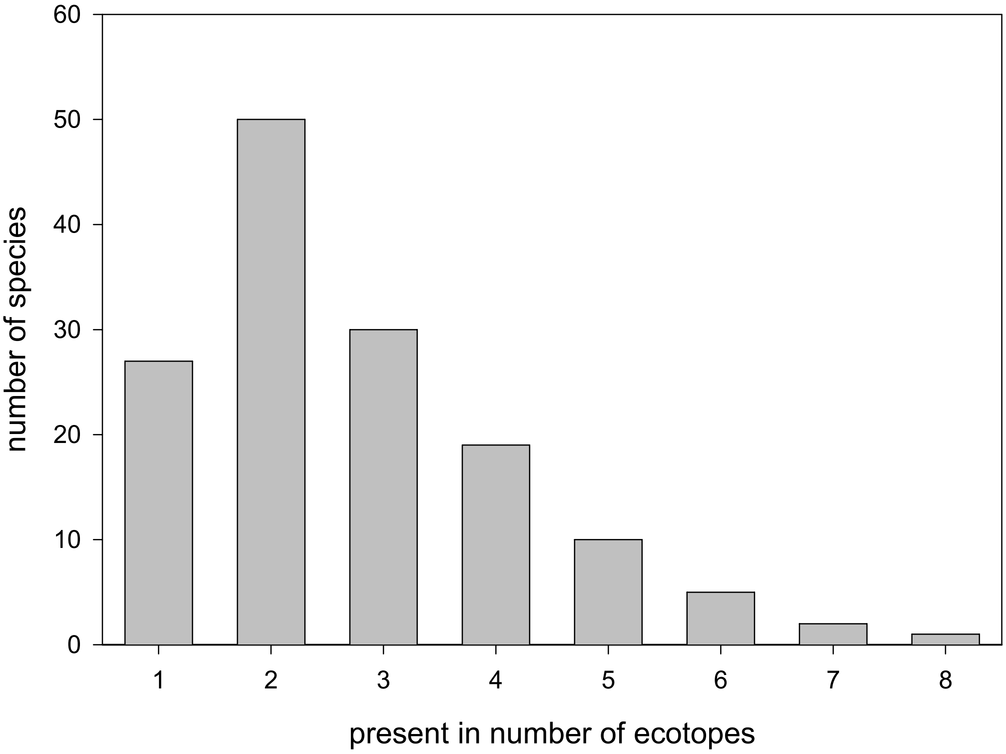

*Figure 7. Histogram of number of species that occur at number of ecotopes.*

## 5.2 Are species in different ecotopes different in vulnerability?

We used specialist species to emphasize differences between ecotopes; these were defined as species present at three or fewer ecotopes. Ecological vulnerability scores of these specialist species were compared using t-tests with a p-level of <0.10. Preliminary analyses showed strong differences between aquatic and terrestrial ecotopes. To focus on differences among terrestrial ecotopes and among aquatic ecotopes, the statistical analysis was performed separately on the set of terrestrial ecotopes, and on the set of aquatic ecotopes. The ecotope 'marshes' was included in both sets, since it consists of a combination of aquatic and terrestrial aspects.

Results terrestrial ecotopes (Figure 8):

- Cadmium: Species in urbanized area are most vulnerable, significantly different from all other ecotopes. Species from grassland are least vulnerable. There are significant differences in vulnerability between species from marshes and grassland species. The number of species assigned to urban ecotope was only six of which three bat species with high vulnerability to cadmium. In contrast, 38 species were assigned to ecotope grassland, which had on average the lowest vulnerability for cadmium.
- Copper/zinc: Species in marshes are most vulnerable; species from arable land are least vulnerable. Significant differences between arable land and marshes, grassland, shrubs, heath, dunes, or urbanized area. Significant differences between shrubs and marshes.
- DDT: Species in arable land are least vulnerable; species in urbanized area are most vulnerable. Significant differences between arable land and marshes, grassland, heath, dunes, urbanized area or pioneer.
- Chlorpyrifos: species in arable land are least vulnerable; species in urbanized areas are most vulnerable. Significant differences between arable land and grassland, shrubs, forest, heath, or urbanized area. Significant difference between pioneer and urbanized area.
- Ivermectin: species in arable land are least vulnerable; species in dunes are most vulnerable. Significant differences between arable land and marshes, grassland, heath, dunes, urbanized area or pioneer. Significant difference between forest and marshes.

Results aquatic ecotopes (Figure 9):

- Cadmium: species in aquatic estuary are least vulnerable; species in terrestrial estuary are most vulnerable. Significant differences between aquatic estuary and marshes, lakes, or terrestrial estuary. Significant difference between terrestrial estuary and marshes or lakes.
- Copper/zinc: species in aquatic estuary are least vulnerable; species in lakes are most vulnerable. Significant differences between aquatic estuary and marshes, lakes or rivers. Significant differences between lakes and marshes or terrestrial estuary.
- DDT: species in aquatic estuary are least vulnerable; species in lakes are most vulnerable. Significant difference between aquatic estuary and all other ecotopes.
- Chlorpyrifos: species in aquatic estuary are least vulnerable; species in marshes are most vulnerable. Significant difference between aquatic estuary and all other ecotopes.
- Ivermectin: species in aquatic estuary are least vulnerable; species in lakes are most vulnerable. Significant difference between aquatic estuary and all other ecotopes.

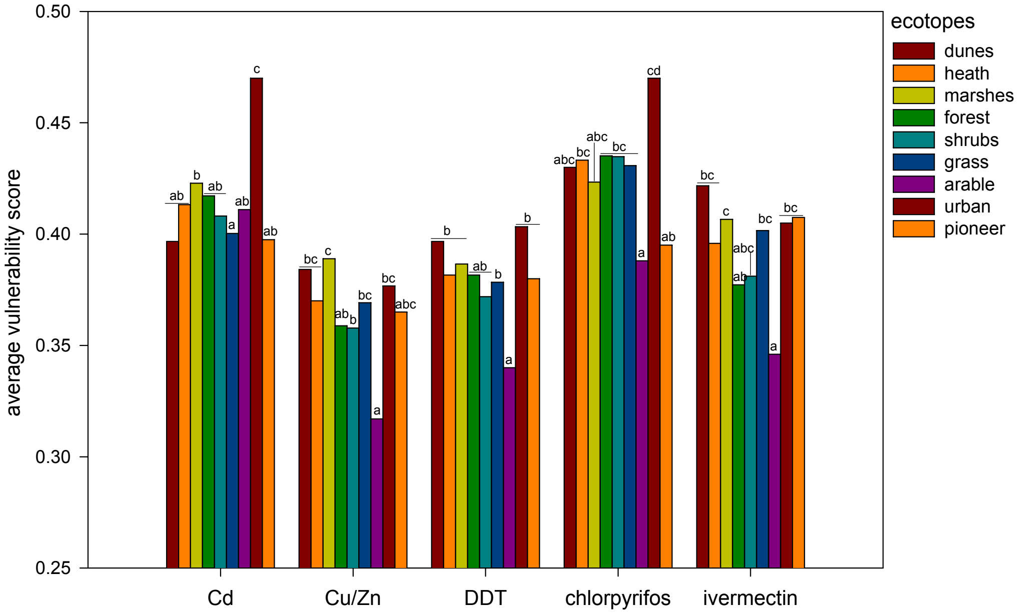

*Figure 8. Average vulnerability scores for specialist species in terrestrial ecotopes. Lower case letters indicate homogeneous groups of similar vulnerability per contaminant (t-test, p<0.10).*

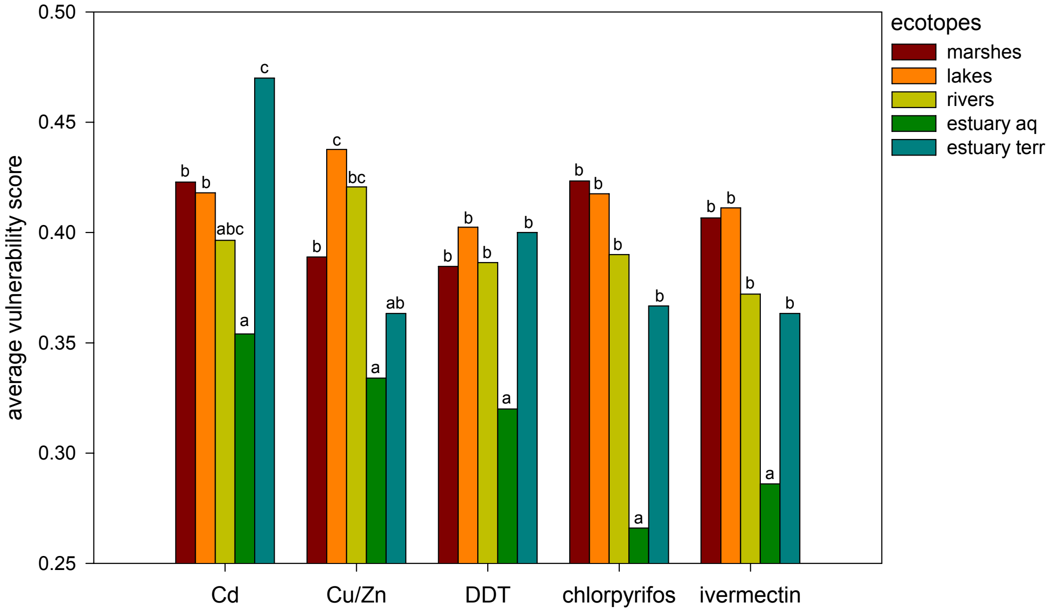

*Figure 9. Average vulnerability scores for specialist species in aquatic ecotopes. Lower case letters indicate homogeneous groups of similar vulnerability per contaminant (t-test, p<0.10).*

## 5.3 Is there an interaction between food chain and ecotope in determining vulnerabilities?

The previous paragraph shows that there are differences in vulnerability between ecotopes. The next question is whether there is an interaction between food chain and ecotope. For this purpose, we aggregated the 19 food types described in § 2.2 into seven bottom-up food types and four top-down (prey) food types. The bottom up food types were fruit (incl. nectar), plant, insect, earthworm, aquatic plant, benthos, and zooplankton. The top down prey types were fish, amphibian, bird, and mammal. For each food type and ecotope combination the vulnerability scores of all species present in the specific ecotope (not limited to specialists as in one factor analysis) were analyzed using a 2-way ANOVA with post-hoc Tukey test. This was done on the bottom-up set (7 food types) and the top-down set (4 prey types). The results of the ANOVA analyses are presented in Tables 8 and 9, and are illustrated in Figures 10 to 13. Please note that the number of species assigned to each ecotope and feeding on a specific food type can differ largely. For example, there is only one plant eater assigned to the ecotope aquatic estuary (Greylag Goose), only two benthos eaters assigned to the ecotope shrubs (one amphibian and one mammal); but there are 35 fruit eaters assigned to the ecotope grassland.

Comparing bottom-up food types:

- species feeding on insects or worms are more vulnerable than species feeding on fruits or plants (comparing terrestrial food types);
- species feeding on benthos are more vulnerable than species feeding on aquatic plants or zooplankton, except for vulnerability for copper/zinc (comparing aquatic food types).
- many differences in ecotope vulnerability depending on contaminant, see Figure 10.

There are few significant interactions between specific ecotopes and food types (tested on subset of species per food type with ecotope as factor in a 1-way ANOVA and post-hoc Tukey test $p<0.05$):

- species feeding on fruits have a significant difference in vulnerability for cadmium between ecotopes (pioneer < dunes, heath, arable and urbanized area);
- species feeding on insects have a significant difference in vulnerability for copper/zinc between ecotopes (arable < lakes);
- benthos feeders have a significant difference in vulnerability for copper/zinc (aquatic estuary, terrestrial estuary, marshes, grassland < forest, shrubs), and for chlorpyrifos (aquatic estuary, terrestrial estuary < forest).

Comparing top-down prey types:

- species preying on birds are less vulnerable than species preying on other prey items (except for chlorpyrifos);
- species preying on mammals have the highest vulnerability for chlorpyrifos and ivermectin;
- species preying on fish have the highest vulnerability for copper/zinc and DDT;
- species preying on amphibians have the highest vulnerability for cadmium;

- only for copper/zinc and chlorpyrifos limited differences between ecotopes were shown, see Figure 12.

*Conclusions*
For species lower in the food chain, ecotope has a significant effect on ecological vulnerability for all contaminants. For higher trophic species, ecotope was only significant for vulnerability to copper/zinc and chlorpyrifos.

*Table 8. ANOVA results bottom-up food types; asterisk indicates significant effect ($p<0.10$).*

| Factor | Contaminant | df | F | p-value |
|---|---|---|---|---|
| Food type | Cd | 6 | 16.227 | * 0.000 |
| | Cu/Zn | 6 | 4.892 | * 0.000 |
| | DDT | 6 | 12.022 | * 0.000 |
| | Chlorpyrifos | 6 | 5.113 | * 0.000 |
| | Ivermectin | 6 | 6.084 | * 0.000 |
| Ecotope | Cd | 12 | 1.621 | * 0.082 |
| | Cu/Zn | 12 | 4.618 | * 0.000 |
| | DDT | 12 | 3.056 | * 0.000 |
| | Chlorpyrifos | 12 | 6.936 | * 0.000 |
| | Ivermectin | 12 | 3.865 | * 0.000 |
| Food type * ecotope | Cd | 47 | 1.245 | 0.135 |
| | Cu/Zn | 47 | 1.356 | * 0.063 |
| | DDT | 47 | 1.111 | 0.291 |
| | Chlorpyrifos | 47 | 1.376 | * 0.055 |
| | Ivermectin | 47 | 1.051 | 0.386 |

*Table 9. ANOVA results top-down prey types; asterisk indicates significant effect ($p<0.10$).*

| Factor | Contaminant | df | F | p-value |
|---|---|---|---|---|
| Prey type | Cd | 3 | 1.492 | 0.218 |
| | Cu/Zn | 3 | 0.980 | 0.403 |
| | DDT | 3 | 1.558 | 0.201 |
| | Chlorpyrifos | 3 | 0.579 | 0.629 |
| | Ivermectin | 3 | 1.278 | 0.283 |
| Ecotope | Cd | 12 | 0.638 | 0.808 |
| | Cu/Zn | 12 | 4.017 | * 0.000 |
| | DDT | 12 | 1.159 | 0.314 |
| | Chlorpyrifos | 12 | 1.262 | 0.243 |
| | Ivermectin | 12 | 1.114 | 0.350 |
| Prey type * ecotope | Cd | 28 | 0.379 | 0.998 |
| | Cu/Zn | 28 | 1.012 | 0.454 |
| | DDT | 28 | 0.654 | 0.909 |
| | Chlorpyrifos | 28 | 0.533 | 0.975 |
| | Ivermectin | 28 | 0.419 | 0.996 |

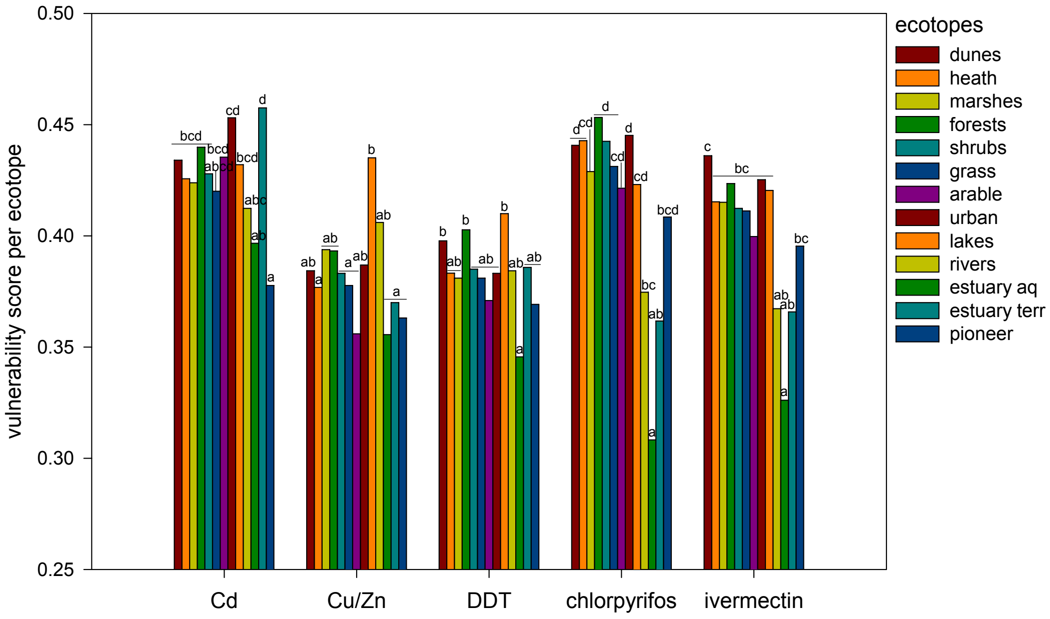

*Figure 10. Average vulnerability scores of bottom-up species per ecotope. Lower case letters indicate homogeneous groups of similar vulnerability per contaminant (ANOVA and post-hoc Tukey test p<0.05).*

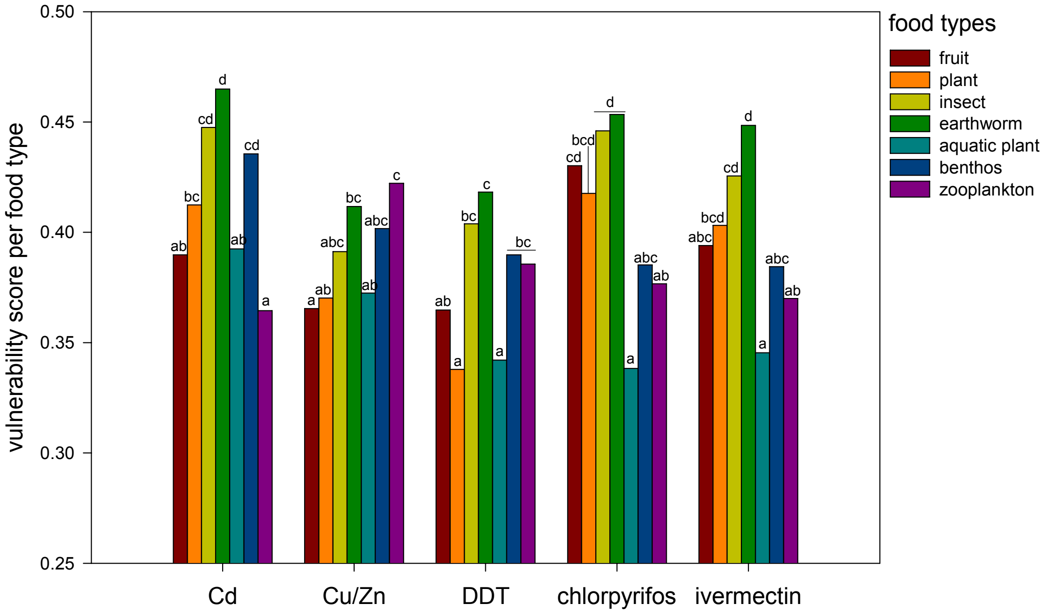

*Figure 11. Average vulnerability scores of bottom-up species per food type. Lower case letters indicate homogeneous groups of similar vulnerability per contaminant (ANOVA and post-hoc Tukey test p<0.05).*

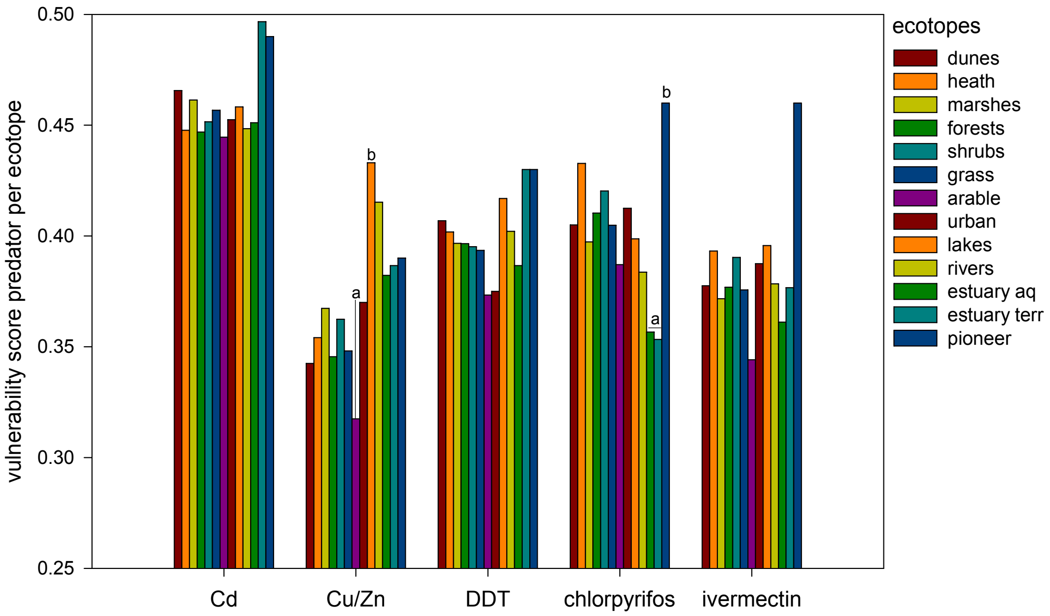

*Figure 12. Average vulnerability scores of top-down predators per ecotope. Lower case letters indicate homogeneous groups of similar vulnerability per contaminant (ANOVA and post-hoc Tukey test p<0.05). Only groups a and b are shown for clarity of the graph, all other ecotopes are group ab.*

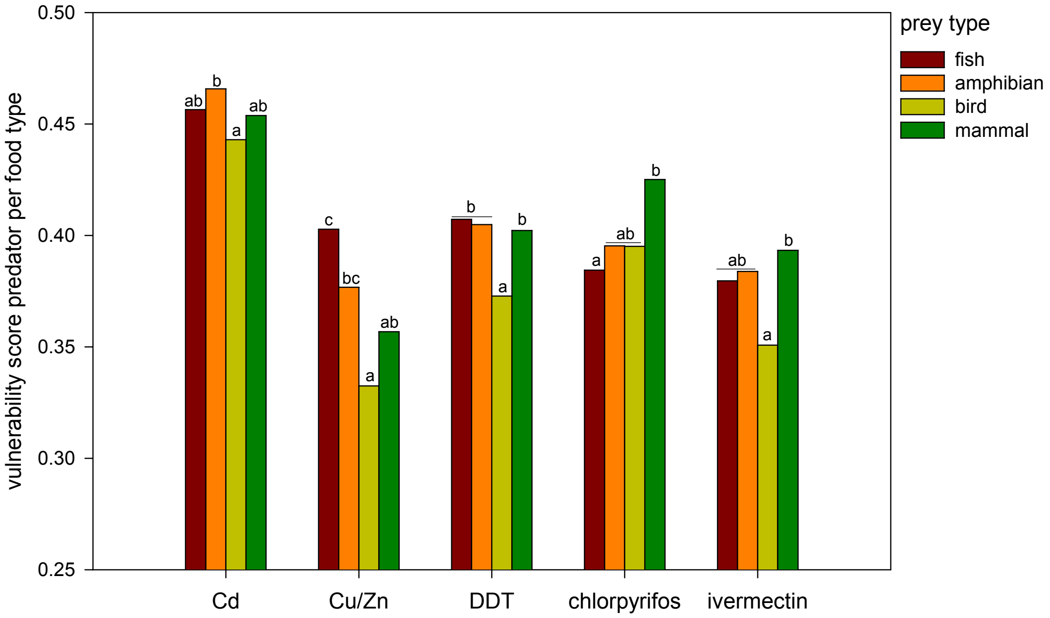

*Figure 13. Average vulnerability scores of top-down predators per food type. Lower case letters indicate homogeneous groups of similar vulnerability per contaminant (ANOVA and post-hoc Tukey test p<0.05).*

# 6 Towards vulnerability mapping

## 6.1 Linkage with ecotope maps

The results obtained from vulnerability assessment may be used to visualize the spatial distribution of ecological vulnerability. Data generated by our method of ecological vulnerability assessment can be used in mapping in the following ways:

1. vulnerability of particular species of wildlife combined with the spatial distribution of that species;
2. vulnerability of ecotopes combined with the distribution of ecotopes;
3. overlay of vulnerability maps of different contaminants to generate general vulnerability hot spots (highly vulnerable areas).

Whilst vulnerability can be assessed at the species level as well as at the ecosystem level, a vulnerability map would seem more useful for general purposes since it is based on a set of parameters rather than a single endpoint, and based on multiple stressors rather than a single factor. Therefore, we have focussed on the development of vulnerability map methodology on the basis of ecotopes rather than individual wildlife species. Further, the spatial distribution of species is likely to already be affected by stressors, whilst ecotopes predict the potential effect of stressors. The use of ecotopes as assemblage level is appealing since ecotope maps are available. In our approach ecotope maps are interpreted in terms of vulnerability to produce vulnerability maps.

For this purpose, suitable ecotope maps should be selected. Maps must be selected for flexibility to incorporate new information, such as vulnerability scores, to be added to the mapping criteria. In addition, existing maps are only suitable if the classification of ecotopes can be aggregated or separated into the ecotopes that we have used in our study. In general, GIS-maps are ideal for this purpose because they are based on a database that can be adjusted to the level of information needed.

Species in the vulnerability analysis database are assigned to ecotopes (Chapter 5, Appendix 4). Based on this assignment the individual species' vulnerability scores can be used to calculate average vulnerability scores for ecotopes (or any other assemblage of species). Vulnerability in ecotopes can thus be discerned on a relative basis (Chapter 5), and mapped accordingly.

If an existing GIS-database with spatial distribution of ecotopes could be used (possibly after rearranging to facilitate compatibility of ecotope classification with our study), our vulnerability scoring can be represented in a geographical map. This would result in a map depicting ecotope vulnerability specific for a particular chemical stressor. Maps may be combined to integrate vulnerability over various stressors.

The use of existing maps and databases is desirable beyond debate. However, many different databases have been produced for different purposes (policy-making, management, research), on the basis of different criteria (land use, land cover, soil types, agricultural crops, nature conservation targets, hydrology, infrastructure, etc.), at different scales (national, regional or local), and for different end-users. Particularly the scale of data and the purpose for mapping tend to prevent unrestricted adoption of any existing database for mapping ecological vulnerability as developed for our ecotope classification system. Criteria for selection and use need to be recognized.

## 6.2 Suitability of available ecotope maps

To create a vulnerability map the following aspects are needed:
- list of species and assignment of species to ecotopes;
- list of ecotopes with a description;
- list of species vulnerability scores;
- map (with underlying database) with ecotopes;
- translation of available map-units into ecotopes.

The first three aspects of this list are covered in this report. Since it would be rather demanding to create new GIS-maps fulfilling all the needs for this project is, we will rather be looking in first instance for existing databases and maps, which effectively fulfil our needs or can be adjusted accordingly. A listing of existing maps that can potentially be used is presented in Table 10.

Maps that are suitable for the production of a vulnerability map should satisfy the following conditions:
- possibility for translation of map-units into ecotopes;
- coverage of the entire landscape including urban, agricultural and natural ecotopes;
- the underlying database should be adjustable for the particular purpose of mapping;
- mapping scale should suit the purpose of the map (and ideally should be adjustable).

An overview of available GIS databases and maps, and applicability to be used for vulnerability assessment and mapping at the level of ecotopes is presented in Table 10. The main question for the applicability of existing maps for vulnerability mapping is the possibility to translate ‘our’ ecotopes into existing classes or units. This is a prerequisite because many of the encountered classifications partly overlap or differ from our classification of ecotopes. Moreover, because maps have been created for a certain purpose, they focus on that subject (for instance Urban Planning) and the classification is very detailed to this purpose, and less detailed to another. None of the data-based GIS-maps fits perfect into our data. There are three possibilities to solve this problem:
1. adjust our data to the classification in an existing database;
2. adjust the classification in an existing database to our data;
3. combine several databases.

The first approach is possible but will be labour intensive. It would involve the assignment of all species to new classifications, and literature research and consultation of specialists would be needed. At present, the second option is the most likely, but the translation from ecotope to existing classes should be carefully considered. A third possibility would be to combine several databases into one so that the classification of units would be similar to our ecotope classification. Irrespective of the technical feasibility of this approach, copyright issues are likely to obstruct this option in practice.

The choice for the use of a database will not only be determined by the ability to translate ecotopes into existing classes. Other factors will also play a role in this choice. Scale is for instance an important factor. If a map is used for local management of an area, a database that works with a 1:100.000 scale (like the CORINE-database) will not satisfy the needs of the user because he needs information on a much smaller scale (like the TOP10Smart or the LGNx database). But if a map is used on national scale (for policy making) the scale of 1:100.000 is suitable, and the choice will be different. For the Netherlands, 'landcover' or 'land use' maps are available on different scales (and with different legends). For most European countries there is the CORINE-database, it was not further investigated whether these countries also have more detailed maps available that can be used for the purposes of the vulnerability analysis.

*Table 10. Overview of available GIS databases and maps, and applicability to be used for our research aims.*

| Map | Description | Applicability |
|---|---|---|
| Top10Smart (Runhaar *et al.*, 2005) | 2.5 x 2.5 meter scale-independent grid map of the Netherlands (complete). Land use is main discriminating factor.<br>Division into 4 main units, each divided into 43 units. | Maps are possible up to 1:10.000. Higher scales are possible. Easy to use database, but difficult to group units into ecotopes because of a very extensive division of urban land use units and a far less detailed division of agriculture and natural land use units. These units are important for the species used in this report. Relatively cheap to use. |
| LGNx (Hazeu, 2005) | 25 x 25 meter grid map of the Netherlands (complete). Landuse is the main discriminating factor. Division into 39 forms of land use. Is used for national survey of soil use mainly in agriculture. Different versions (x) are available | Is mainly used for agriculture. Therefore this part is very detailed. Natural land-use is far less detailed described. Easy to use database, but difficult to aggregate map-units into ecotopes. Very expensive. Map is actualized every year and based on satellite images. |
| Top10Vector (Van Leeuwen, 2004) | 1:10.000 scale map of boundaries of all land-sections of the Netherlands (complete). Surfaces are calculated. Soil-use is added as option and harmonized for the Netherlands Land use is divided into 37 units, mainly Urban units because the maps are used to establish legal land-property. Is used by the Dutch Government. Continuous process of updating. | Very detailed description of Urban land use. Less detail on agriculture and nature. Division not only on land use but also on geographical information. (for instance 'North Sea' is a separate class). Too detailed for this report on urban land use and is less detailed on agricultural and natural use. |
| CBS (CBS website) | Based on the TOP10Vector database, but with additional information on almost every subject necessary for the Government (health, economics etc.). Very extended database, mostly used for statistics of policy in the Netherlands | Uses the same division as Top10Vector and therefore less applicable for use in this report. Data are online available. |
| CORINE Land Cover (CORINE, 1999) | Database of land use of 25 European countries on a scale of 1:100.000. Division of land use into 5 main classes and a subdivision into several classes (44 in total). Based on satellite images. Not the same detail as the national databases, but a pivot between local and European level. | Is applicable on a regional scale, not on a local scale. Class division is good usable for this project although some translation is necessary. Promising for use. |

## 6.3 Risk mapping *vs.* vulnerability mapping

From the point of view of the spatial distribution of stressors, environmental hazard or risk is traditionally mapped on the basis of distribution of chemicals. Most hazard and risk maps are extrapolations from observed concentrations in the environment. Risks are determined by comparing actual environmental concentrations with toxic effect thresholds that are derived from laboratory testing. While results obtained in single species-single compound laboratory tests may be translated to field populations only with great difficulty, many test species may not even be found in the area of concern (see De Lange *et al.* (2006) for a wider discussion of laboratory to field extrapolation).

From the point of view of the environment receiving stress, the receptor side, ecosystem vulnerability can also be used for predicting where undesired effects are likely to occur. Vulnerability mapping is therefore a useful complementary approach to risk mapping. Vulnerability maps generated following our approach would be a new tool to recognize vulnerable areas, since ecological characteristics can be used of locally representative fauna. Other possible applications are to combine vulnerability with soil contamination maps, which will result in a relative risk map; or combining vulnerability with potentially affected fraction (PAF) maps, which will result in an estimate of absolute risk.

A combined use of risk maps and vulnerability maps is expected to facilitate an easy recognition of areas (ecotopes) that need extra care and protection, and what the underlying drivers and receptors are. Local protection goals can be adjusted to such data. For different chemicals and other stressors maps can be overlain to locate so-called 'soft-spots' where vulnerability is high for multiple substances.

With this the aim of the present study, to develop methodology for vulnerability mapping, is achieved. The actual construction of vulnerability maps will be reported elsewhere. Vulnerability and risk mapping is further developed within the NoMiracle project in Work Package 4.4.

# 7 Concluding remarks

***The concept of virtual species***

The results from the pilot probabilistic modelling gave some concern regarding the usefulness and realism. The vulnerability of a virtual earthworm feeding species as calculated in the probabilistic modelling exercise was consistently and considerably higher than the scores for 23 representative species. Underlying causes of this difference may be either biological (correlation between traits) or statistical (distribution of values). The exercise also showed that different ecotopes have quite similar virtual earthworm feeders, since they were a subset of the same set of species. Since our objective was to be able to distinguish between different ecotopes, the concept of virtual species to generalize vulnerability in particular trophic groups in food chains was considered unpractical and liable to bias. We decided against further development.

***Vulnerability in food chains and food webs***

The number of food preferences showed limited relation with ecological vulnerability. For most food types there was no significant difference in ecological vulnerability scores between generalists and specialists feeders.

A comparison between different simplified food chains showed that, irrespective of chemical stressor, the earthworm food chain is more vulnerable than others. Mammals in these simplified food chains were generally more vulnerable than birds.

The ecological vulnerability scores for individual species can be 'plugged' in existing model food webs used in ecological risk assessment. For example, we compared our assessment for a floodplain food web with results from modelling to predict biomagnified exposure to soil contaminants in predators (Loos *et al.*, 2006). Vulnerability assessment for species in this food web showed that, depending on type of contaminant, either Badger (trophic level 3) or Mole (trophic level 2) was the most vulnerable. Other vulnerable species were Weasel and Common shrew. These were also the species that had the highest predicted exposure concentration for cadmium. This shows that our vulnerability estimation is consistent with the predicted exposure.

***Vulnerability of different ecotopes***

To test whether ecological vulnerability may differ between ecotopes, we studied species with a restricted choice of habitat (defined as specialist species). Comparison of specialist species assemblages over the ecotopes showed that ecotopes can differ in their vulnerability. Within the set of terrestrial ecotopes, dunes and urbanized area are the most vulnerable ecotopes. Within the set of aquatic ecotopes, lakes, marshes and the terrestrial part of estuaries were the most vulnerable.

To study whether there is interaction between food chain and ecotope, seven bottom-up food types and four top-down (prey) food types were used with ecotopes in a 2-way ANOVA. Using the bottom-up set resulted in many significant differences. In the top-down set, fewer significant differences were shown. From this it may be concluded that for species lower in the food chain, irrespective of contaminant, ecological vulnerability is significantly associated with type of ecotope. For higher trophic species this is less the case.

Validation of the obtained ecological vulnerability results is hampered by conceptual difficulties. At present, there is no clear-cut way to validate the relative ecological vulnerability of a species or an ecotope with a variable that can be measured in the field. It is possible, however, to verify the relative results from our method with field observations. This was done in De Lange *et al.* (2006) and in the current report, showing that our results have no inconsistencies with field observations and other model results.

***Future research***

As indicated in § 6.2, several databases are available for creating vulnerability maps for the Netherlands or Europe. We aim to select a few of these databases and produce vulnerability maps at different scales. This work will be part of NoMiracle research package 4.4., and possibly may contribute to the master cases.

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# Appendix 1 - List of species names and codes

Species codes are an abbreviation of the taxonomic group, followed by a number for target species or a letter for common species, based on Bal *et al.* (1995). An asterisk indicates that the species in the current Dutch policy (Bal *et al.*, 2001) has changed its status. The List is alphabetically ordered on the English names per group of organisms.

| English name | Dutch name | Latin name | Code |
|---|---|---|---|
| *Amphibians* | | | |
| Alpine Newt | Alpenwatersalamander | *Triturus alpestris* | AMPH1 |
| Common Spadefoot | Knoflookpad | *Pelobates fuscus* | AMPH4 |
| Great Crested Newt | Kamsalamander | *Triturus cristatus* | AMPH3 |
| Green Treefrog | Boomkikker | *Hyla arborea* | AMPH2 |
| Natterjack Toad | Rugstreeppad | *Bufo calamita* | AMPH5 |
| Palmate Newt | Vinpootsalamander | *Triturus helveticus* | AMPH6 |
| Poolfrog | Kleine Groene Kikker | *Rana lessonae* | AMPHa * |
| *Dragonflies* | | | |
| Common Blue Damselfly | Watersnuffel | *Enallagma cyathigerum* | DFLYa |
| Green Hawker | Groene Glazenmaker | *Aeshna viridis* | DFLY2 |
| Hairy Dragonfly | Glassnijder | *Brachytron pratense* | DFLY3 |
| Norfolk Damselfly | Donkere Waterjuffer | *Coenagrion armatum* | DFLY4 |
| Norfolk Hawker | Vroege Glazenmaker | *Aeshna isosceles* | DFLY1 |
| Scarce Chaser | Bruine Korenbout | *Libellula fulva* | DFLY5 |
| Siberian Winter Damselfly | Noordse Winterjuffer | *Sympecma paedisca* | DFLY6 |
| *Reptiles* | | | |
| Common Adder | Adder | *Vipera berus* | REP1 |
| Grass Snake | Ringslang | *Natrix natrix* | REP4 |
| Sand Lizard | Zandhagedis | *Lacerta agilis* | REP5 |
| Slow Worm | Hazelworm | *Anguis fragilus* | REP3 |
| Smooth Snake | Gladde Slang | *Coronella austriaca* | REP2 |
| Viviparous Lizard | Levendbarende hagedis | *Lacerta/Zootoca vivipara* | REPa |
| *Fishes* | | | |
| Allis Shad | Elft | *Alosa alosa* | FISH3 * |
| Barbel | Barbeel | *Barbus barbus* | FISH1 |
| Bullhead | Rivierdonderpad | *Cottus gobio* | FISH7 |
| Carp | Karper | *Cyprinus carpio* | FISHa |
| Catfish | Europese Meerval | *Silurus glanis* | FISH4 |
| Ide | Winde | *Leuciscus idus* | FISH8 |
| Pike | Snoek | *Esox lucius* | FISHc |
| Stone Loach | Bermpje | *Noemacheilus barbatulus* | FISH2 |
| Three-spined Stickleback | Driedoornig Stekelbaarsje | *Gasterosteus aculeatus* | FISHb |
| Twaite Shad | Fint | *Alosa fallax* | FISH5 |
| White Bream | Kolblei | *Abramis bjoerkna* | FISH6 * |
| *Butterflies* | | | |
| Alcon Blue | (Heide)gentiaan blauwtje | *Maculinea alcon* | BFLY2 |
| Brimstone | Citroentje | *Gonepteryx rhamni* | BFLYc |
| Brown Argus | Bruin blauwtje | *Aricia agestis* | BFLY5 |
| Brown Hairstreak | Sleedoornpage | *Thecla betulae* | BFLY18 |
| Chequered Skipper | Bont dikkopje | *Carterophalus palaemon* | BFLY4 |
| Dark Green Fritillary | Grote Parelmoervlinder | *Argynnis aglaja* | BFLY10 |
| Dusky Large Blue | Donker pimpernelblauwtje | *Maculinea nausithous* | BFLY7 |
| Glanville Fritillary | Veldparelmoervlinder | *Melitaea cinxia* | BFLY22 |
| Grizzled skipper | Aardbeivlinder | *Pyrgus malvae* | BFLY1 |
| Large Blue | Tijmblauwtje | *Maculinea arion* | BFLY20 |
| Large Chequered Skipper | Spiegeldikkopje | *Heteropterus morpheus* | BFLY19 |
| Large Copper | Grote Vuurvlinder | *Lycaena dispar* | BFLY24 |
| Large Tortoiseshell | Grote Vos | *Nymphalis polychloros* | BFLY11 |
| Large White | Groot Koolwitje | *Pieris brassicae* | BFLYb |
| Marsh Fritillary | Moerasparelmoervlinder | *Euphydryas aurinia* | BFLY15 |
| Mazarine Blue | Klaverblauwtje | *Polyommatus semiargus* | BFLY12 |

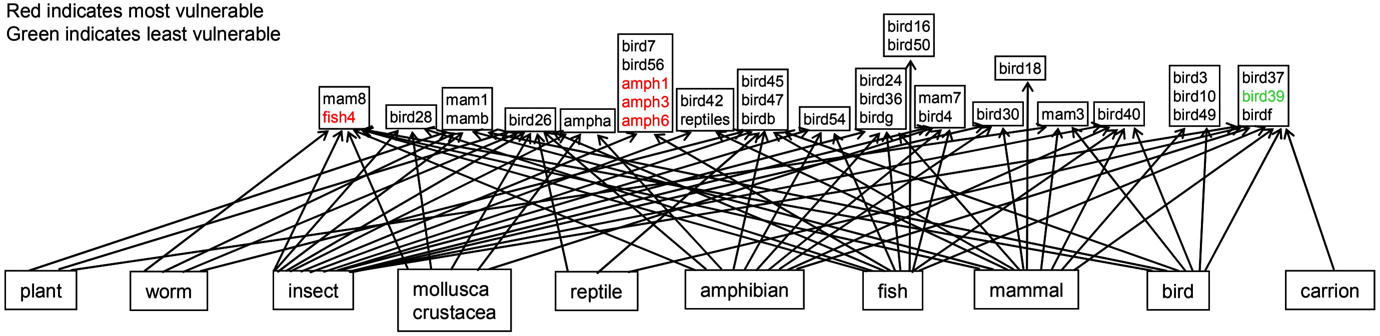
| English name | Dutch name | Latin name | Code |
|---|---|---|---|
| Niobe Fritillary | Duinparelmoervlinder | *Argynnis niobe* | BFLY8 |
| Pearl-Bordered Fritillary | Zilvervlek | *Boloria euphrosyne* | BFLY3 |
| Pearly Heath | Tweekleurig Hooibeestje | *Coenonympha arcania* | BFLY21 |
| Purple-edged Copper | Rode Vuurvlinder | *Lycaena hippothoe* | BFLY17 |
| Queen of Spain Fritillary | Kleine Parelmoervlinder | *Issoria lathonia* | BFLY13 |
| Red Admiral | Atalanta | *Vanessa atalanta* | BFLYa |
| Scarce Large Blue | Pimpernelblauwtje | *Maculinea telejus* | BFLY16 |
| Scooty Copper | Bruine vuurvlinder | *Lycaena tityrus* | BFLY6 |
| Silver-spotted Skipper | Kommavlinder | *Hesperia comma* | BFLY14 |
| Small Pearl-Bordered Fritillary | Zilveren maan | *Clossiana selene* | BFLY23 |
| Small Skipper | Geelsprietdikkopje | *Thymelicus sylvestris* | BFLY9 |
| *Birds* | | | |
| Arctic Tern | Noordse Stern | *Sterna paradisaea* | BIRD28 |
| Avocet | Kluut | *Recurvirostra avosetta* | BIRD21 |
| Barn Owl | Kerkuil | *Tyto alba* | BIRD18 |
| Bearded Tit | Baardmannetje | *Panurus biarmicus* | BIRD1 |
| Bittern | Roerdomp | *Botarus stellaris* | BIRD40 |
| Black Grouse | Korhoen | *Tetrao tetrix* | BIRD22 |
| Black Tern | Zwarte Stern | *Chlidonias niger* | BIRD56 |
| Blackbird | Merel | *Turdus merula* | BIRDd |
| Black-tailed Godwit | Grutto | *Limosa limosa* | BIRD14 |
| Bluethroat | Blauwborst | *Luscinia svecica* | BIRD2 |
| Buzzard | Buizerd | *Buteo buteo* | BIRDb * |
| Common Tern | Visdief | *Sterna hirundo* | BIRD50 |
| Coot | Meerkoet | *Fulica atra* | BIRDg |
| Corncrake | Kwartelkoning | *Crex crex* | BIRD25 |
| Eagle owl | Oehoe | *Bubo bubo* | BIRDl |
| Garganey | Zomertaling | *Anas querquedula* | BIRD55 |
| Golden Oriole | Wielewaal | *Oriolus oriolus* | BIRD53 * |
| Great Grey Shrike | Klapekster | *Lanius excubitor* | BIRD19 |
| Great Reed Warbler | Grote Karekiet | *Acrocephalus arundinaceus* | BIRD13 |
| Green Woodpecker | Groene Specht | *Picus viridis* | BIRD12 |
| Grey Heron | Blauwe Reiger | *Ardea cinerea* | BIRDf |
| Greylag Goose | Grauwe Gans | *Anser anser* | BIRD9 |
| Hen Harrier | Blauwe kiekendief | *Circus cyaneus* | BIRD3 |
| Hooded Crow | Kraai | *Corvus corone* | BIRDe |
| Hoopoe | Hop | *Upupa epops* | BIRD15 |
| Kestrel | Torenvalk | *Falco tinnunculus* | BIRD47 |
| Kingfisher | Ijsvogel | *Alcedo atthis* | BIRD16 |
| Lapwing | Kievit | *Vanellus vanellus* | BIRDi |
| Little Bittern | Woudaapje | *Ixobrychus minutis* | BIRD54 |
| Little Grebe | Dodaars | *Tachybaptus ruficollis* | BIRD4 |
| Little Owl | Steenuil | *Athene noctua* | BIRD45 |
| Little Ringed Plover | Kleine Plevier | *Charadrius dubius* | BIRD20 * |
| Little Tern | Dwergstern | *Sterna albifrons* | BIRD7 |
| Mallard | Wilde eend | *Anas platyrhynchos* | BIRDa |
| Montagu's Harrier | Grauwe kiekendief | *Circus pygargus* | BIRD10 |
| Night Heron | Kwak | *Nycticorax nycticorax* | BIRD24 |
| Nightjar | Nachtzwaluw | *Caprimulgus europaeus* | BIRD27 |
| Northern Wheatear | Tapuit | *Oenanthe oenanthe* | BIRD46 |
| Ortolan Bunting | Ortolaan | *Emberiza hotulana* | BIRD31 |
| Oystercatcher | Scholekster | *Haematopus ostralegus* | BIRDh * |
| Partridge | Patrijs | *Perdix perdix* | BIRD33 |
| Pintail | Pijlstaart | *Anas acuta* | BIRD34 |
| Purple Heron | Purperreiger | *Ardea purpurea* | BIRD36 |
| Raven | Raaf | *Corvus corax* | BIRD37 |
| Red Kite | Rode Wouw | *Milvus milvus* | BIRD39 |
| Red-backed Shrike | Grauwe Klauwier | *Lanius collurio* | BIRD11 |
| Red-crested Pochard | Krooneend | *Netta rufina* | BIRD23 |
| Redshank | Tureluur | *Tringa totanus* | BIRD48 |
| Ruff | Kemphaan | *Philomachus pugnax* | BIRD17 |
| Sand Martin | Oeverzwaluw | *Riparia riparia* | BIRD29 |
| Savi's Warbler | Snor | *Locustella luscinioides* | BIRD44 |
| Sedge Warbler | Rietzanger | *Acrocephalus schoenobaenus* | BIRD38 |
| Short-eared Owl | Velduil | *Asio flammeus* | BIRD49 |
| Shoveler | Slobeend | *Anas clypeata* | BIRD43 * |

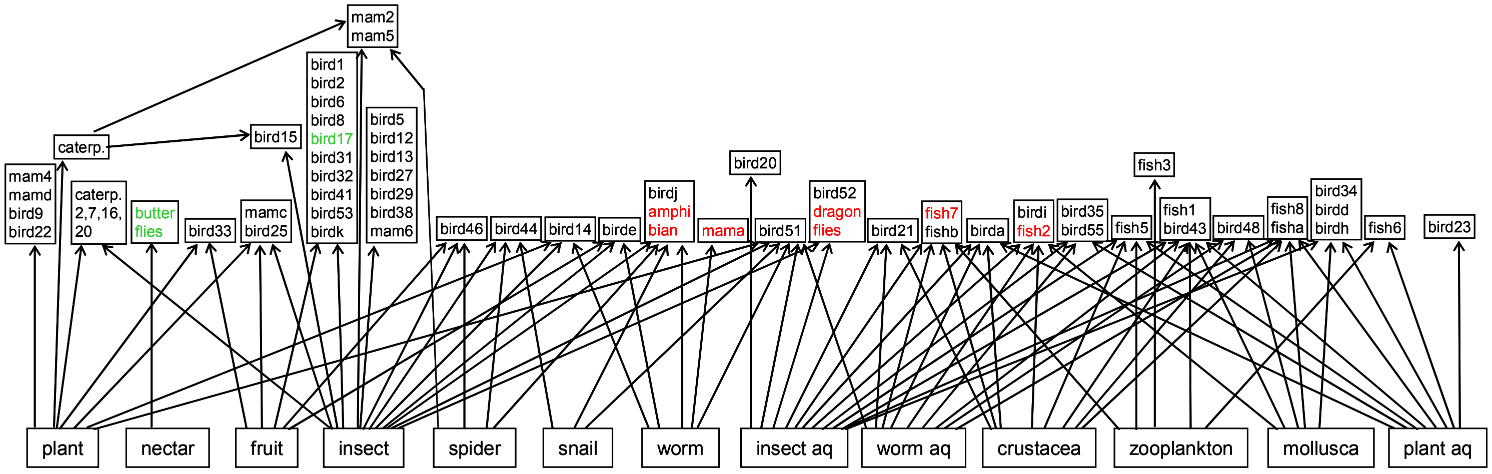
| English name | Dutch name | Latin name | Code |
|---|---|---|---|
| Snipe | Watersnip | *Gallinago gallinago* | BIRD52 |
| Sparrowhawk | Sperwer | *Accipiter nisus* | BIRDk |
| Spoonbill | Lepelaar | *Platalea leucorodia* | BIRD26 |
| Spotted Crake | Porseleinhoen | *Porzana porzana* | BIRD35 |
| Stonechat | Roodborsttapuit | *Saxicola troquata* | BIRD41 |
| Tawny Pipit | Duinpieper | *Anthus campestris* | BIRD6 |
| Tufted Duck | Kuifeend | *Aythya fuligula* | BIRDc |
| Water Rail | Waterral | *Rallus aquaticus* | BIRD51 * |
| Whinchat | Paapje | *Saxicola rubreta* | BIRD32 |
| White Stork | Ooievaar | *Ciconia ciconia* | BIRD30 |
| Whitethroat | Grasmus | *Sylvia communis* | BIRDj * |
| Woodchat Shrike | Roodkopklauwier | *Lanius senator* | BIRD42 |
| Wryneck | Draaihals | *Jynx torquilla* | BIRD5 |
| Yellowhammer | Geelgors | *Emberiza citrinella* | BIRD8 |
| *Mammals* | | | |
| Badger | Das | *Meles meles* | MAM1 |
| Bank Vole | Rosse woelmuis | *Clethrionomys glareolus* | MAMc |
| Common Rat | Bruine rat | *Rattus norvegicus* | MAMb |
| Common shrew | Bosspitsmuis | *Sorex araneus* | MAMi |
| Common Vole | Veldmuis | *Microtus arvalis* | MAMg |
| Field Vole | Aardmuis | *Microtus agrestis* | MAMd |
| Geoffroy's Bat | Ingekorven Vleermuis | *Myotis emarginatus* | MAM5 |
| Greater Mouse-eared Bat | Vale Vleermuis | *Myotis myotis* | MAM6 |
| Mole | Mol | *Talpa europaea* | MAMa |
| Natterer's Bat | Franjestaart | *Myotis nattereri* | MAM2 |
| Northern Vole | Noordse woelmuis | *Microtus oeconomus* | MAM4 |
| Northern Water Shrew | Waterspitsmuis | *Neomys fodiens* | MAM7 |
| Otter | Otter | *Lutra lutra* | MAM8 |
| Pine Marten | Boommarter | *Martes martes* | MAM3 |
| Rabbit | Konijn | *Oryctolagus cuniculus* | MAMe |
| Red Fox | Vos | *Vulpes vulpes* | MAMf |
| Weasel | Wezel | *Mustela nivalis* | MAMj |
| Wood Mouse | Bosmuis | *Apodemus sylvaticus* | MAMh |

# Appendix 2 – Projection of ecological vulnerability scores in theoretical food webs

## Vulnerability to Cu/Zn

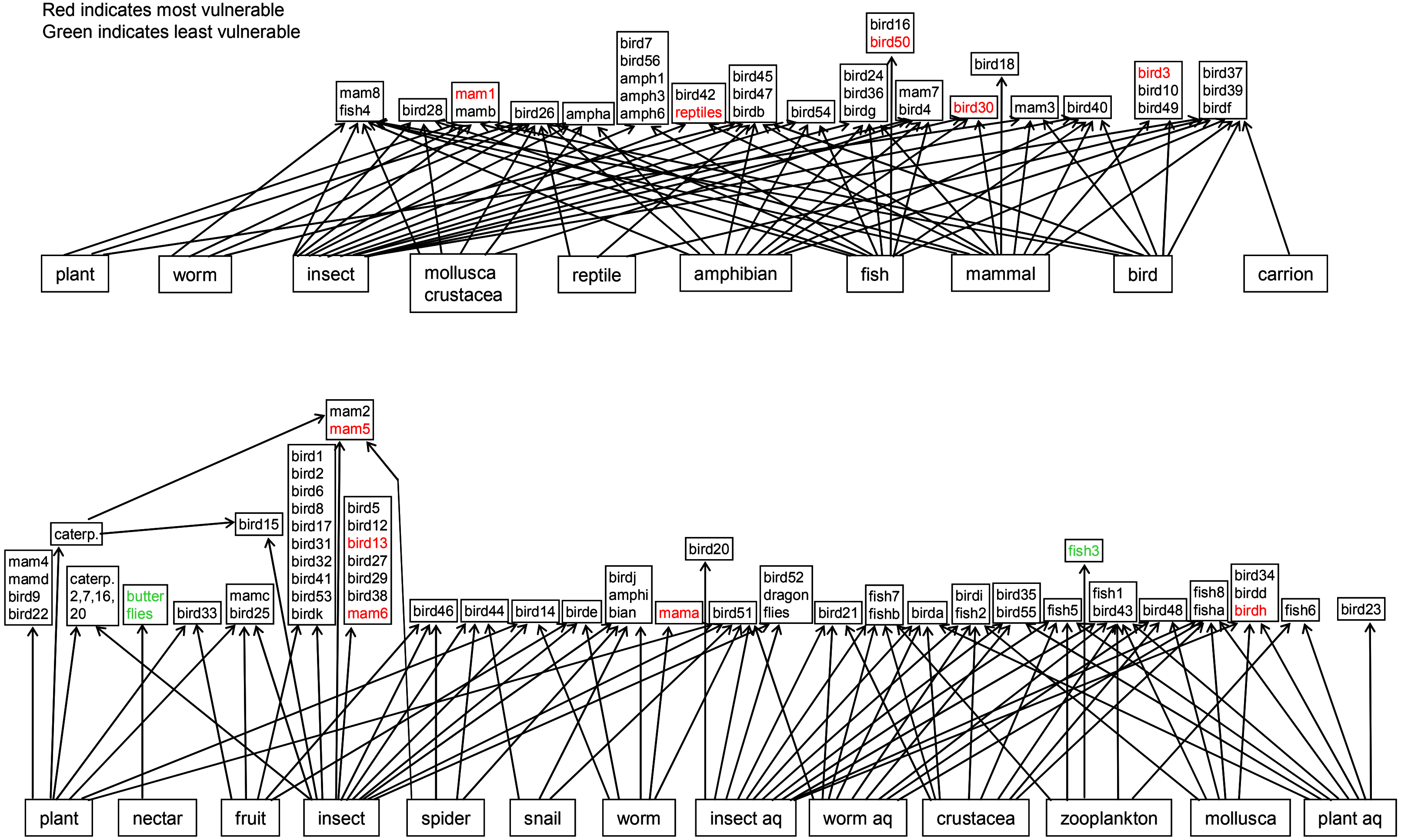
Red indicates most vulnerable
Green indicates least vulnerable





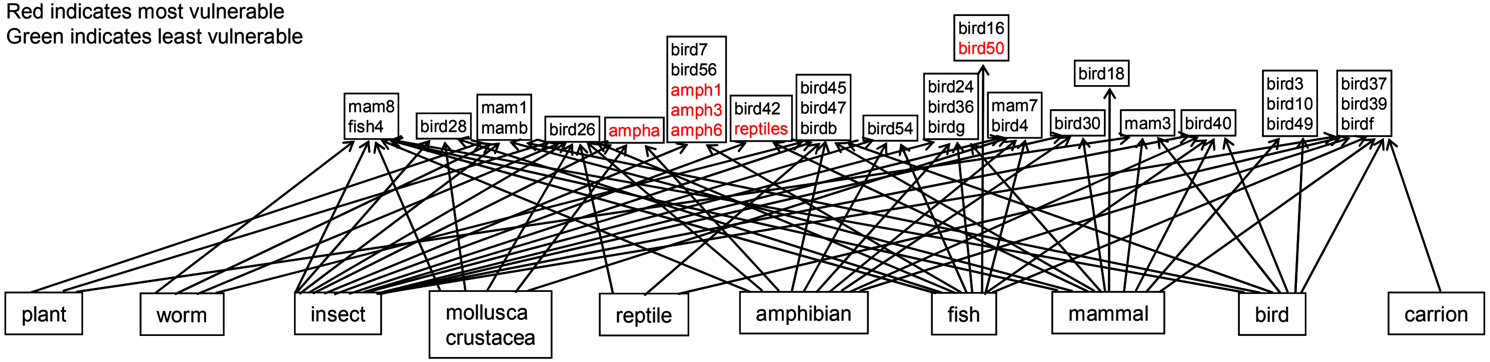
# Vulnerability to Cd

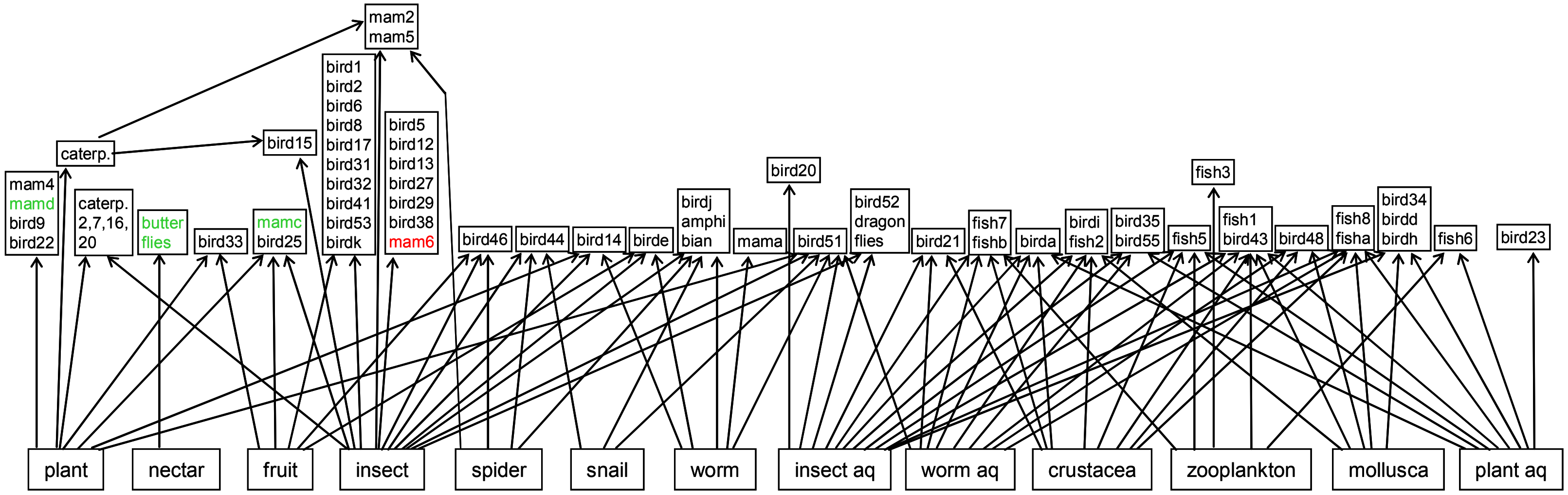
Red indicates most vulnerable
Green indicates least vulnerable



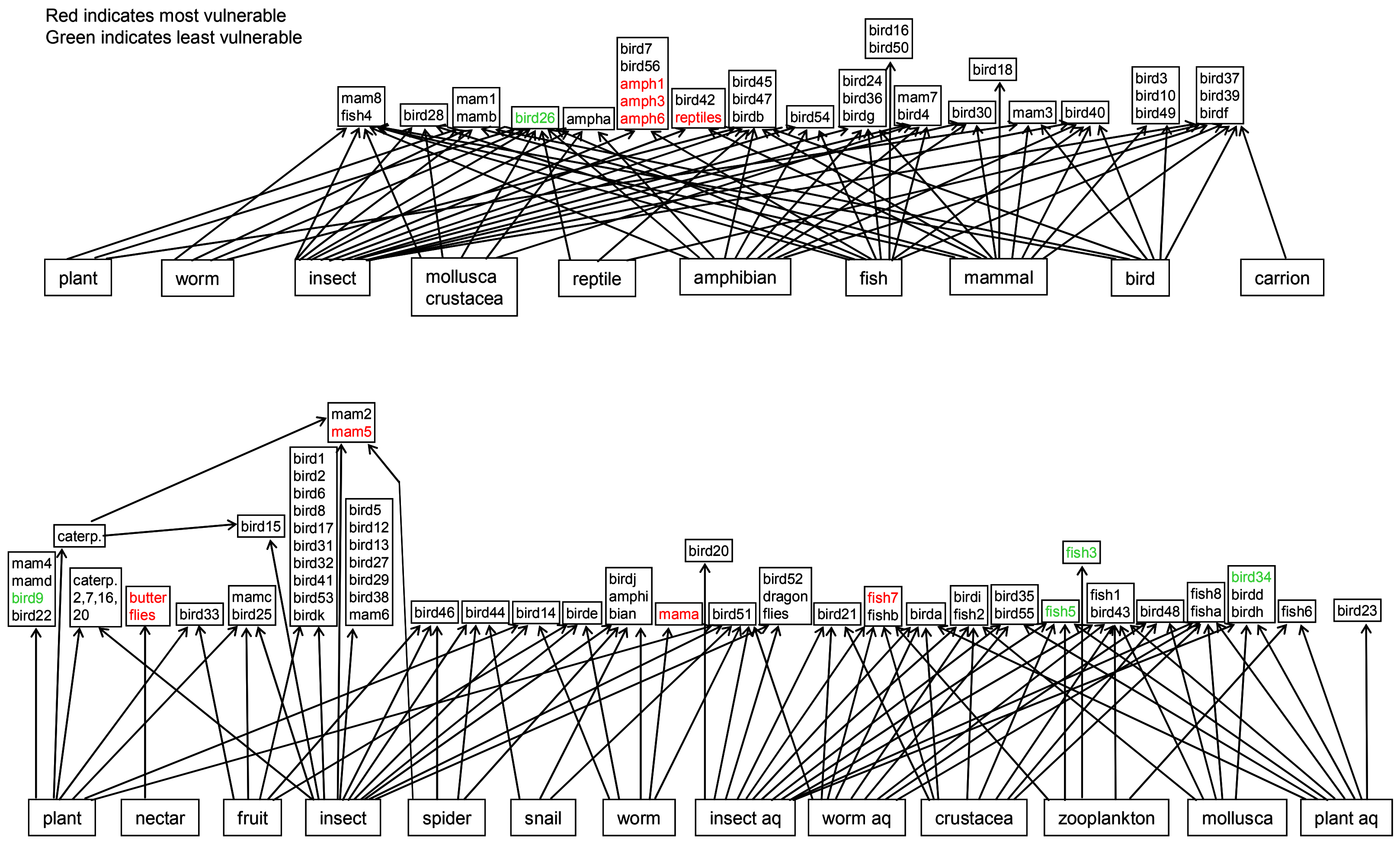
# Vulnerability to DDT

Red indicates most vulnerable
Green indicates least vulnerable





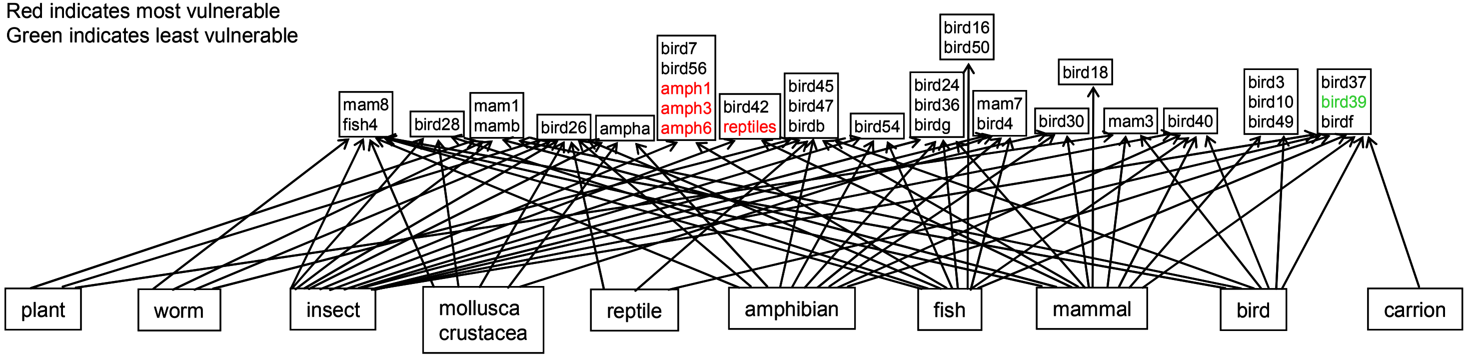
# Vulnerability to Chlorpyrifos

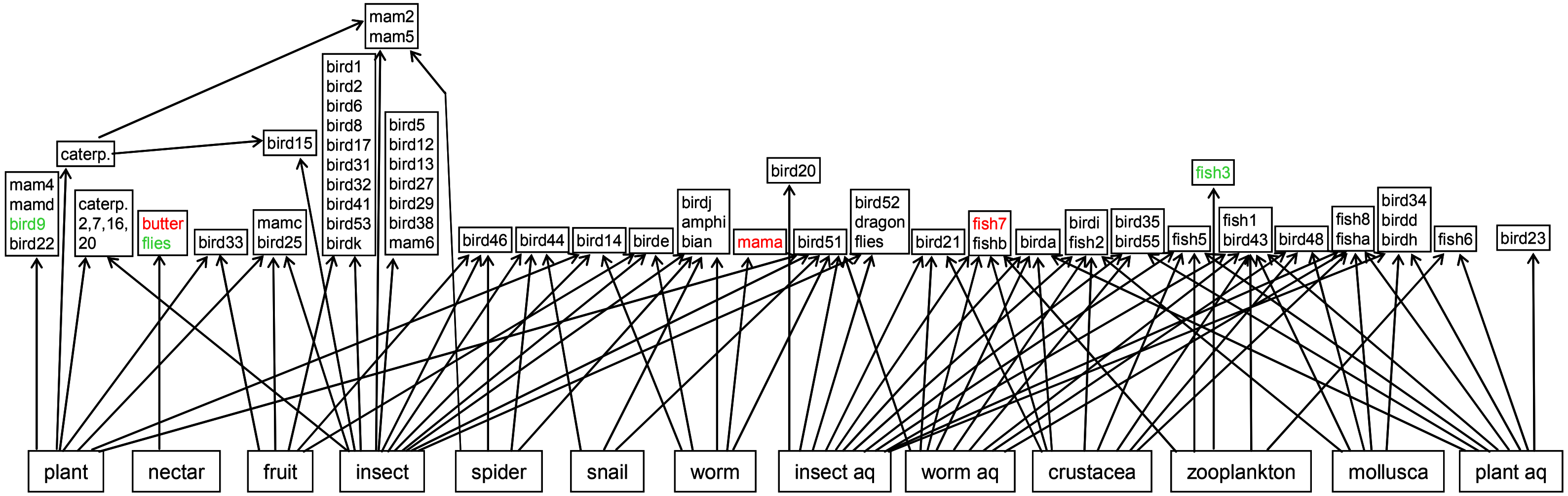


Red indicates most vulnerable
Green indicates least vulnerable

# Vulnerability to Ivermectin

Red indicates most vulnerable
Green indicates least vulnerable





# Appendix 3 - Ecotope classification

The ecotope classification was based on the grouping of nature target types for half-natural landscapes (Bal *et al.*, 2001, main group 3, chapter 4.3) with some slight adaptations, following the grouping of ecosystems in the 'Natuurcompendium' published by the Milieu en Natuur Planbureau (http://www.mnp.nl/mnc/x-nl-1-d.html); and the systematics of nature types for Flanders (http://www.inbo.be/content/ page.asp?pid=BIO_NT_start).

*Conversion table from ecotopes for half-natural landscapes (Bal et al., 2001) to ecotope used in this report. For each ecotope the number of nature target types is given in brackets.*

| ecotopes from half-natural landscapes described in Bal *et al.* (2001) | ecotope used in this report |
|---|---|
| stromende wateren (12 types) | rivers |
| | estuary, aquatic parts |
| stilstaande wateren (11 types) | freshwater lakes, fens, and ponds |
| moerassen (5 types) | marshes |
| graslanden (13 types) | grassland |
| | estuary, terrestrial parts |
| heide en hoogveen (5 types) | heath land, moors and inland dunes |
| pioniergemeenschappen (5 types) | pioneer communities |
| | arable land |
| struwelen en beheerde bossen (9 types) | shrubs and brushes |
| opgaande bossen (9 types) | forests |
| *no corresponding nature type* | urbanized area |

# Appendix 4 - Species presence in ecotopes

Presence in ecotopes is scored in two categories: preferred habitat = 2, and likely habitat = 1. The species selection per ecotope is compared with nature target species from Bal *et al.* (2001), for the corresponding nature target types. Only species with a high preference for a nature target type were used in this comparison. The list is alphabetically ordered.

**Dunes**

| Species | Code | Presence | In nature target type 1.3 and 2.12 |
|---|---|---|---|
| Blackbird | BIRDd | 1 | |
| Brown Argus | BFLY5 | 1 | x |
| Buzzard | BIRDb | 1 | x |
| Common shrew | MAMi | 1 | |
| Common Spadefoot | AMPH4 | 2 | |
| Common Tern | BIRD50 | 2 | x |
| Hen Harrier | BIRD3 | 1 | x |
| Large White | BFLYb | 1 | |
| Little Tern | BIRD7 | 2 | x |
| Montagu's Harrier | BIRD10 | 1 | x |
| Natterjack Toad | AMPH5 | 2 | x |
| Niobe Fritillary | BFLY8 | 2 | x |
| Northern Wheatear | BIRD46 | 1 | x |
| Oystercatcher | BIRDh | 2 | x |
| Queen of Spain Fritillary | BFLY13 | 2 | x |
| Rabbit | MAMe | 2 | |
| Sand Lizard | REP5 | 2 | x |
| Short-eared Owl | BIRD49 | 2 | x |
| Tawny Pipit | BIRD6 | 1 | |
| Weasel | MAMj | 1 | |
| Wood mouse | MAMh | 1 | |

Comparison with Bal *et al.* (2001), nature target type Dunes (1.3 and 2.12):
Mammals: 0 out of 5 nature target species
Birds: 8 out of 40 nature target species

## Heath land and inland dunes

| Species | Code | Presence | In nature target type 3.42, 3.43, 3.44, 3.45 and 3.46 |
|---|---|---|---|
| Alcon Blue | BFLY2 | 2 | x |
| Barn Owl | BIRD18 | 1 | x |
| Black Grouse | BIRD22 | 2 | |
| Blackbird | BIRDd | 1 | |
| Buzzard | BIRDb | 2 | |
| Common Adder | REP1 | 2 | x |
| Common shrew | MAMi | 1 | |
| Dark Green Fritillary | BFLY10 | 1 | |
| Field Vole | MAMd | 1 | |
| Great Grey Shrike | BIRD19 | 2 | x |
| Green Woodpecker | BIRD12 | 1 | |
| Hen Harrier | BIRD3 | 1 | |
| Hooded Crow | BIRDe | 1 | |
| Hoopoe | BIRD15 | 1 | x |
| Montagu's Harrier | BIRD10 | 2 | x |
| Natterjack Toad | AMPH5 | 2 | x |
| Nightjar | BIRD27 | 2 | x |
| Northern Wheatear | BIRD46 | 2 | x |
| Partridge | BIRD33 | 2 | x |
| Poolfrog | AMPHa | 1 | |
| Raven | BIRD37 | 2 | |
| Red-backed Shrike | BIRD11 | 2 | x |
| Sand Lizard | REP5 | 2 | x |
| Scooty Copper | BFLY6 | 2 | x |
| Silver-spotted Skipper | BFLY14 | 1 | x |
| Slow Worm | REP3 | 1 | |
| Small Pearl-Bordered Fritillary | BFLY23 | 1 | |
| Smooth Snake | REP2 | 2 | x |
| Stonechat | BIRD41 | 2 | x |
| Tawny Pipit | BIRD6 | 2 | x |
| Viviparous Lizard | REPa | 2 | |
| Wood mouse | MAMh | 1 | |
| Woodchat Shrike | BIRD42 | 2 | |
| Wryneck | BIRD5 | 1 | x |
| Yellowhammer | BIRD8 | 2 | x |

Comparison with Bal *et al.* (2001), nature target type Heath land (3.42, 3.43, 3.44, 3.45 and 3.46):
Mammals: 0 out of 0 nature target species
Birds: 12 out of 21 nature target species

## Marshes

| Species | Code | Presence | In nature target type 3.24, 3.25, 3.26, 3.27, and 3.28 |
|---|---|---|---|
| Bearded Tit | BIRD1 | 2 | x |
| Bittern | BIRD40 | 2 | x |
| Black Tern | BIRD56 | 2 | |
| Bluethroat | BIRD2 | 2 | x |
| Buzzard | BIRDb | 2 | |
| Chequered Skipper | BFLY4 | 1 | |
| Common Rat | MAMb | 1 | |
| Common shrew | MAMi | 1 | |
| Coot | BIRDg | 2 | |
| Dark Green Fritillary | BFLY10 | 2 | x |
| Dusky Large Blue | BFLY7 | 2 | x |
| Field Vole | MAMd | 1 | |
| Garganey | BIRD55 | 2 | x |
| Great Crested Newt | AMPH3 | 1 | |
| Great Reed Warbler | BIRD13 | 2 | x |
| Green Hawker | DFLY2 | 2 | |
| Greylag Goose | BIRD9 | 2 | x |
| Grizzled skipper | BFLY1 | 2 | |
| Hairy Dragonfly | DFLY3 | 2 | x |
| Hen Harrier | BIRD3 | 2 | x |
| Lapwing | BIRDi | 1 | |
| Large Chequered Skipper | BFLY19 | 2 | x |
| Large Copper | BFLY24 | 2 | x |
| Little Bittern | BIRD54 | 2 | x |
| Little Grebe | BIRD4 | 2 | x |
| Mallard | BIRDa | 1 | |
| Marsh Fritillary | BFLY15 | 2 | |
| Night Heron | BIRD24 | 2 | x |
| Norfolk Damselfly | DFLY4 | 2 | x |
| Norfolk Hawker | DFLY1 | 2 | x |
| Northern Vole | MAM4 | 2 | x |
| Otter | MAM8 | 1 | x |
| Oystercatcher | BIRDh | 2 | |
| Purple Heron | BIRD36 | 2 | x |
| Purple-edged Copper | BFLY17 | 2 | |
| Ruff | BIRD17 | 1 | x |
| Savi's Warbler | BIRD44 | 2 | x |
| Scarce Large Blue | BFLY16 | 2 | |
| Sedge Warbler | BIRD38 | 2 | x |
| Short-eared Owl | BIRD49 | 2 | x |
| Small Pearl-Bordered Fritillary | BFLY23 | 2 | x |
| Small Skipper | BFLY9 | 1 | |
| Snipe | BIRD52 | 2 | x |
| Spoonbill | BIRD26 | 2 | x |
| Spotted Crake | BIRD35 | 2 | x |
| Viviparous Lizard | REPa | 1 | |
| Water Rail | BIRD51 | 2 | |
| Weasel | MAMj | 1 | |

Comparison with Bal *et al.* (2001), nature target type Marshes (3.24, 3.25, 3.26, 3.27 and 3.28):
Mammals: 2 out of 9 nature target species
Birds: 18 out of 46 nature target species

## Forests

| Species | Code | Presence | In nature target type 3.60, 3.61, 3.62, 3.63, 3.64, 3.65, 3.66, 3.67, 3.68, and 3.69 |
|---|---|---|---|
| Alpine Newt | AMPH1 | 2 | x |
| Badger | MAM1 | 2 | x |
| Bank Vole | MAMc | 2 | |
| Black Grouse | BIRD22 | 1 | |
| Blackbird | BIRDd | 2 | |
| Bluethroat | BIRD2 | 1 | |
| Brimstone | BFLYc | 2 | |
| Buzzard | BIRDb | 2 | x |
| Common shrew | MAMi | 2 | |
| Geoffroy's Bat | MAM5 | 2 | x |
| Golden Oriole | BIRD53 | 2 | |
| Grass Snake | REP4 | 1 | |
| Great Crested Newt | AMPH3 | 1 | |
| Greater Mouse-eared Bat | MAM6 | 2 | x |
| Green Woodpecker | BIRD12 | 2 | x |
| Hooded Crow | BIRDe | 1 | |
| Hoopoe | BIRD15 | 2 | x |
| Large Chequered Skipper | BFLY19 | 1 | |
| Large Tortoiseshell | BFLY11 | 1 | |
| Mazarine Blue | BFLY12 | 1 | |
| Mole | MAMa | 2 | |
| Natterer's Bat | MAM2 | 2 | x |
| Nightjar | BIRD27 | 1 | x |
| Palmate Newt | AMPH6 | 2 | |
| Pearl-Bordered Fritillary | BFLY3 | 2 | |
| Pine Marten | MAM3 | 2 | x |
| Poolfrog | AMPHa | 1 | |
| Rabbit | MAMe | 2 | |
| Raven | BIRD37 | 2 | x |
| Red Admiral | BFLYa | 1 | |
| Red Kite | BIRD39 | 1 | x |
| Slow Worm | REP3 | 2 | x |
| Small Skipper | BFLY9 | 1 | |
| Smooth Snake | REP2 | 1 | |
| Sparrowhawk | BIRDk | 2 | |
| Weasel | MAMj | 2 | |
| Whitethroat | BIRDj | 2 | |
| Wood mouse | MAMh | 2 | |
| Wryneck | BIRD5 | 2 | x |
| Yellowhammer | BIRD8 | 1 | x |

Comparison with Bal *et al.* (2001), nature target type Forests (3.61, 3.62, 3.63, 3.64, 3.65, 3.66, 3.67, 3.68 and 3.69):
Mammals: 5 out of 20 nature target species
Birds: 8 out of 30 nature target species

**Shrubs and brushes**

| Species | Code | Presence | In nature target type 3.52, 3.53, 3.54, 3.55, 3.56, 3.57, 3.58, and 3.59 |
|---|---|---|---|
| Badger | MAM1 | 2 | x |
| Bank Vole | MAMc | 1 | |
| Barn Owl | BIRD18 | 2 | x |
| Blackbird | BIRDd | 1 | |
| Bluethroat | BIRD2 | 1 | x |
| Brimstone | BFLYc | 2 | |
| Brown Hairstreak | BFLY18 | 2 | x |
| Buzzard | BIRDb | 2 | x |
| Chequered Skipper | BFLY4 | 2 | |
| Common Rat | MAMb | 1 | |
| Common shrew | MAMi | 2 | |
| Common Spadefoot | AMPH4 | 1 | |
| Common vole | MAMg | 1 | |
| Field Vole | MAMd | 2 | |
| Grass Snake | REP4 | 2 | x |
| Great Crested Newt | AMPH3 | 2 | x |
| Great Grey Shrike | BIRD19 | 2 | x |
| Greater Mouse-eared Bat | MAM6 | 1 | |
| Green Treefrog | AMPH2 | 2 | x |
| Grizzled skipper | BFLY1 | 1 | |
| Hen Harrier | BIRD3 | 2 | |
| Hooded Crow | BIRDe | 2 | |
| Kestrel | BIRD47 | 2 | x |
| Large Chequered Skipper | BFLY19 | 1 | |
| Large Tortoiseshell | BFLY11 | 2 | x |
| Large White | BFLYb | 2 | |
| Mazarine Blue | BFLY12 | 1 | |
| Mole | MAMa | 2 | |
| Montagu's Harrier | BIRD10 | 1 | x |
| Natterer's Bat | MAM2 | 1 | x |
| Nightjar | BIRD27 | 2 | x |
| Northern Water Shrew | MAM7 | 1 | |
| Northern Wheatear | BIRD46 | 2 | |
| Pearl-Bordered Fritillary | BFLY3 | 1 | x |
| Pearly Heath | BFLY21 | 2 | x |
| Rabbit | MAMe | 1 | |
| Red Admiral | BFLYa | 2 | |
| Red-backed Shrike | BIRD11 | 2 | x |
| Sand Martin | BIRD29 | 1 | |
| Sedge Warbler | BIRD38 | 2 | |
| Slow Worm | REP3 | 2 | x |
| Small Skipper | BFLY9 | 2 | x |
| Smooth Snake | REP2 | 2 | x |
| Sparrowhawk | BIRDk | 1 | |
| Stonechat | BIRD41 | 2 | x |
| Tawny Pipit | BIRD6 | 1 | |
| Viviparous Lizard | REPa | 2 | |
| Weasel | MAMj | 2 | |
| Whitethroat | BIRDj | 2 | x |
| Wood mouse | MAMh | 2 | |
| Wryneck | BIRD5 | 1 | x |
| Yellowhammer | BIRD8 | 2 | x |

Comparison with Bal *et al.* (2001), nature target type Shrubs (3.52, 3.53, 3.54, 3.55, 3.56, 3.57, 3.58, and 3.59):
Mammals: 2 out of 21 nature target species
Birds: 12 out of 32 nature target species

### Arable land

| Species | Code | Presence | In nature target type 3.50 and 3.51 |
|---|---|---|---|
| Badger | MAM1 | 1 | x |
| Barn Owl | BIRD18 | 1 | |
| Buzzard | BIRDb | 2 | |
| Common shrew | MAMi | 1 | |
| Common Spadefoot | AMPH4 | 1 | |
| Common vole | MAMg | 2 | |
| Corncrake | BIRD25 | 1 | |
| Field Vole | MAMd | 1 | |
| Hen Harrier | BIRD3 | 1 | |
| Hooded Crow | BIRDe | 2 | |
| Kestrel | BIRD47 | 2 | |
| Little Owl | BIRD45 | 2 | |
| Ortolan Bunting | BIRD31 | 2 | x |
| Partridge | BIRD33 | 1 | x |
| Raven | BIRD37 | 2 | |
| Red Kite | BIRD39 | 2 | |
| Red-backed Shrike | BIRD11 | 1 | |
| Whinchat | BIRD32 | 1 | |
| Wood mouse | MAMh | 1 | |
| Woodchat Shrike | BIRD42 | 1 | |

Comparison with Bal *et al.* (2001), nature target type arable land (within pioneer communities (3.50 – 3.51):
Mammals: 1 out of 2 nature target species
Birds: 2 out of 9 nature target species

**Grassland**

| Species | Code | Presence | In nature target type 3.29, 3.30, 3.31, 3.32, 3.33, 3.34, 3.35, 3.36, 3.37, 3.38, 3.39, 3.40, and 3.41 |
|---|---|---|---|
| Alcon Blue | BFLY2 | 2 | |
| Badger | MAM1 | 1 | x |
| Barn Owl | BIRD18 | 1 | x |
| Black Grouse | BIRD22 | 1 | x |
| Black Tern | BIRD56 | 1 | x |
| Blackbird | BIRDd | 1 | |
| Black-tailed Godwit | BIRD14 | 2 | x |
| Brown Argus | BFLY5 | 2 | x |
| Buzzard | BIRDb | 2 | x |
| Chequered Skipper | BFLY4 | 2 | |
| Common shrew | MAMi | 1 | |
| Common Spadefoot | AMPH4 | 1 | |
| Common vole | MAMg | 2 | |
| Corncrake | BIRD25 | 2 | x |
| Dark Green Fritillary | BFLY10 | 2 | x |
| Dusky Large Blue | BFLY7 | 2 | x |
| Field Vole | MAMd | 1 | |
| Glanville Fritillary | BFLY22 | 2 | x |
| Grey Heron | BIRDf | 2 | |
| Greylag Goose | BIRD9 | 1 | x |
| Grizzled skipper | BFLY1 | 2 | x |
| Hen Harrier | BIRD3 | 1 | x |
| Hooded Crow | BIRDe | 2 | |
| Kestrel | BIRD47 | 2 | x |
| Lapwing | BIRDi | 2 | |
| Large Blue | BFLY20 | 2 | |
| Large Copper | BFLY24 | 1 | |
| Large White | BFLYb | 1 | |
| Little Owl | BIRD45 | 2 | x |
| Marsh Fritillary | BFLY15 | 2 | x |
| Mazarine Blue | BFLY12 | 2 | x |
| Mole | MAMa | 2 | |
| Montagu's Harrier | BIRD10 | 2 | x |
| Niobe Fritillary | BFLY8 | 1 | x |
| Northern Vole | MAM4 | 1 | x |
| Northern Water Shrew | MAM7 | 1 | x |
| Northern Wheatear | BIRD46 | 1 | x |
| Oystercatcher | BIRDh | 2 | x |
| Partridge | BIRD33 | 2 | x |
| Pearl-Bordered Fritillary | BFLY3 | 1 | |
| Pearly Heath | BFLY21 | 1 | x |
| Purple-edged Copper | BFLY17 | 2 | x |
| Queen of Spain Fritillary | BFLY13 | 1 | x |
| Raven | BIRD37 | 2 | |
| Red Admiral | BFLYa | 1 | |
| Red Kite | BIRD39 | 2 | x |
| Redshank | BIRD48 | 2 | x |
| Ruff | BIRD17 | 2 | x |
| Sand Martin | BIRD29 | 1 | x |
| Scarce Large Blue | BFLY16 | 2 | x |
| Scooty Copper | BFLY6 | 2 | x |
| Short-eared Owl | BIRD49 | 1 | x |
| Silver-spotted Skipper | BFLY14 | 2 | |
| Slow Worm | REP3 | 1 | |
| Small Pearl-Bordered Fritillary | BFLY23 | 1 | x |
| Small Skipper | BFLY9 | 2 | x |
| Smooth Snake | REP2 | 1 | |
| Viviparous Lizard | REPa | 2 | |
| Weasel | MAMj | 1 | |
| Whinchat | BIRD32 | 2 | x |
| White Stork | BIRD30 | 2 | x |
| Woodchat Shrike | BIRD42 | 1 | x |

Comparison with Bal *et al.* (2001), nature target type grassland (3.29 – 3.41):
Mammals: 3 out of 8 nature target species
Birds: 22 out of 78 nature target species

### Urbanized area

| Species | Code | Presence | No matching nature target type |
|---|---|---|---|
| Blackbird | BIRDd | 2 | |
| Common Rat | MAMb | 2 | |
| Common shrew | MAMi | 1 | |
| Coot | BIRDg | 2 | |
| Geoffroy's Bat | MAM5 | 1 | |
| Greater Mouse-eared Bat | MAM6 | 1 | |
| Green Woodpecker | BIRD12 | 1 | |
| Grey Heron | BIRDf | 2 | |
| Mallard | BIRDa | 2 | |
| Mole | MAMa | 1 | |
| Natterer's Bat | MAM2 | 1 | |
| Rabbit | MAMe | 1 | |
| Raven | BIRD37 | 2 | |
| Whitethroat | BIRDj | 1 | |
| Wood mouse | MAMh | 1 | |
| Wryneck | BIRD5 | 1 | |

No comparison possible with Bal *et al.* (2001).

**Lakes, fens, and ponds (freshwater)**

| Species | Code | Presence | In nature target type 3.13, 3.14, 3.15, 3.16, 3.17, 3.18, 3.19, 3.20, 3.21, 3.22, and 3.23 |
|---|---|---|---|
| Alpine Newt | AMPH1 | 2 | x |
| Carp | FISHa | 2 | |
| Catfish | FISH4 | 2 | x |
| Common Blue Damselfly | DFLYa | 2 | |
| Common Spadefoot | AMPH4 | 2 | x |
| Common Tern | BIRD50 | 2 | x |
| Coot | BIRDg | 2 | |
| Garganey | BIRD55 | 2 | x |
| Great Crested Newt | AMPH3 | 2 | x |
| Green Treefrog | AMPH2 | 2 | x |
| Grey Heron | BIRDf | 2 | |
| Hairy Dragonfly | DFLY3 | 2 | x |
| Ide | FISH8 | 1 | x |
| Little Grebe | BIRD4 | 1 | x |
| Little Ringed Plover | BIRD20 | 2 | |
| Little Tern | BIRD7 | 1 | |
| Mallard | BIRDa | 2 | |
| Natterjack Toad | AMPH5 | 2 | x |
| Norfolk Damselfly | DFLY4 | 2 | x |
| Norfolk Hawker | DFLY1 | 2 | x |
| Northern Water Shrew | MAM7 | 2 | x |
| Otter | MAM8 | 2 | x |
| Oystercatcher | BIRDh | 2 | |
| Palmate Newt | AMPH6 | 2 | x |
| Pike | FISHc | 2 | |
| Pintail | BIRD34 | 2 | x |
| Poolfrog | AMPHa | 2 | x |
| Red-crested Pochard | BIRD23 | 2 | x |
| Savi's Warbler | BIRD44 | 1 | |
| Scarce chaser | DFLY5 | 2 | x |
| Shoveler | BIRD43 | 2 | |
| Siberian Winter Damselfly | DFLY6 | 2 | x |
| Spoonbill | BIRD26 | 1 | x |
| Stone Loach | FISH2 | 1 | |
| Three-spined Stickleback | FISHb | 2 | |
| Tufted Duck | BIRDc | 2 | |
| White Bream | FISH6 | 2 | |
| White Stork | BIRD30 | 2 | |

Comparison with Bal *et al.* (2001), nature target type freshwater (3.13 – 3.23):
Mammals: 2 out of 14 nature target species
Birds: 6 out of 42 nature target species

## Rivers

| Species | Code | Presence | In nature target type 3.1, 3.2, 3.3, 3.4, 3.5, 3.6, 3.7, 3.8, 3.9, 3.10, and 3.11 |
|---|---|---|---|
| Allis Shad | FISH3 | 2 | |
| Barbel | FISH1 | 2 | x |
| Bullhead | FISH7 | 2 | x |
| Carp | FISHa | 1 | |
| Catfish | FISH4 | 1 | x |
| Common Tern | BIRD50 | 2 | |
| Coot | BIRDg | 2 | |
| Grey Heron | BIRDf | 2 | |
| Ide | FISH8 | 2 | x |
| Kingfisher | BIRD16 | 2 | x |
| Little Tern | BIRD7 | 1 | |
| Mallard | BIRDa | 2 | |
| Northern Water Shrew | MAM7 | 1 | x |
| Otter | MAM8 | 2 | |
| Oystercatcher | BIRDh | 2 | |
| Pike | FISHc | 1 | |
| Sand Martin | BIRD29 | 2 | x |
| Spoonbill | BIRD26 | 1 | |
| Stone Loach | FISH2 | 2 | x |
| Three-spined Stickleback | FISHb | 1 | |
| Tufted Duck | BIRDc | 2 | |
| Twaite Shad | FISH5 | 1 | x |
| White Bream | FISH6 | 2 | |
| White Stork | BIRD30 | 2 | |

Comparison with Bal *et al.* (2001), nature target type freshwater streams and rivers (3.1 – 3.11):
Mammals: 1 out of 6 nature target species
Birds: 2 out of 11 nature target species

## Estuary, aquatic part

| Species | Code | Presence | In nature target type 3.12, 1.4b, 1.4c, 2.16b, 2.16c |
|---|---|---|---|
| Allis Shad | FISH3 | 2 | |
| Avocet | BIRD21 | 1 | x |
| Common Tern | BIRD50 | 2 | x |
| Coot | BIRDg | 2 | |
| Grey Heron | BIRDf | 2 | |
| Greylag Goose | BIRD9 | 1 | x |
| Little Tern | BIRD7 | 2 | x |
| Mallard | BIRDa | 2 | |
| Otter | MAM8 | 1 | |
| Oystercatcher | BIRDh | 2 | x |
| Pintail | BIRD34 | 2 | x |
| Spoonbill | BIRD26 | 1 | x |
| Tufted Duck | BIRDc | 2 | |
| Twaite Shad | FISH5 | 2 | x |

Comparison with Bal *et al.* (2001), nature target type estuary (3.12, 1.4 and 2.16):
Mammals: 0 out of 0 nature target species
Birds: 7 out of 18 nature target species

### Estuary, terrestrial part

| Species | Code | Presence | In nature target type 1.4a, 2.16a |
|---|---|---|---|
| Arctic Tern | BIRD28 | 2 | |
| Avocet | BIRD21 | 2 | x |
| Common Tern | BIRD50 | 1 | x |
| Little Tern | BIRD7 | 2 | x |
| Mallard | BIRDa | 2 | |
| Oystercatcher | BIRDh | 2 | x |
| Redshank | BIRD48 | 2 | x |
| Tufted Duck | BIRDc | 2 | |

Comparison with Bal *et al.* (2001), nature target type estuary (1.4 and 2.16):
Mammals: 0 out of 0 nature target species
Birds: 5 out of 17 nature target species

### Pioneer communities

| Species | Code | Presence | In nature target type 3.47, 3.48, 3.49, 3.50, and 3.51 |
|---|---|---|---|
| Avocet | BIRD21 | 2 | |
| Brown Argus | BFLY5 | 1 | |
| Grizzled skipper | BFLY1 | 1 | |
| Large White | BFLYb | 1 | |
| Little Ringed Plover | BIRD20 | 2 | |
| Natterjack Toad | AMPH5 | 1 | x |
| Queen of Spain Fritillary | BFLY13 | 1 | |
| Red Admiral | BFLYa | 1 | |
| Small Skipper | BFLY9 | 2 | |
| Weasel | MAMj | 1 | |

Comparison with Bal *et al.* (2001), nature target type pioneer communities (3.47 – 3.51):
Mammals: 0 out of 2 nature target species
Birds: 0 out of 27 nature target species

# Appendix 5 – Ecological traits in multi-criteria analysis

| | Effect on vulnerability | Cu/Zn | Cd | DDT | Chlorpyrifos | Ivermectin |
|---|---|---|---|---|---|---|
| *Main category A: external exposure* | | *0.333* | *0.333* | *0.333* | *0.333* | *0.333* |
| Habitat choice | ↑ | 0.500 | 0.071 | 0.071 | 0.258 | 0.258 |
| Maximum life-span | ↑ | 0 | 0.214 | 0.214 | 0.032 | 0.032 |
| Log home-range | ↓ | 0.250 | 0.143 | 0.143 | 0.129 | 0.194 |
| Food preference | ↑ | 0 | 0.286 | 0.286 | 0.129 | 0.129 |
| Food needs | ↑ | 0 | 0.143 | 0.143 | 0.065 | 0.065 |
| Hibernation | ↓ | 0.125 | 0.071 | 0.071 | 0.000 | 0.065 |
| Season dependent presence | ↑ | 0.125 | 0.071 | 0.071 | 0.258 | 0.129 |
| Home-range < contaminant | ↑ | 0 | 0 | 0 | 0.129 | 0.129 |
| *Main category B: internal exposure* | | *0.333* | *0.333* | *0.333* | *0.333* | *0.333* |
| Log Field Metabolic Rate | ↓ | 0.200 | 0.125 | 0.133 | 0.364 | 0.364 |
| Hibernation | ↑ | 0 | 0.125 | 0.200 | 0.000 | 0.000 |
| Season dependent presence | ↓ | 0 | 0.125 | 0.200 | 0.000 | 0.000 |
| Storage organs | ↓ | 0 | 0.375 | 0.200 | 0.091 | 0.091 |
| Excretion mechanisms | ↓ | 0.800 | 0.125 | 0.133 | 0.182 | 0.182 |
| Detoxification mechanisms | ↓ | 0 | 0.125 | 0.133 | 0.364 | 0.364 |
| *Main category C: individual effects* | | *0* | *0* | *0* | *0* | *0* |
| Toxicological sensitivity | ↑ | 1 | 1 | 1 | 1 | 1 |
| *Main category D: population effects* | | *0.333* | *0.333* | *0.333* | *0.333* | *0.333* |
| Age at first reproduction | ↑ | 0.176 | 0.176 | 0.176 | 0.176 | 0.176 |
| Log total number offspring | ↓ | 0.176 | 0.176 | 0.176 | 0.176 | 0.176 |
| Survival until first reproduction | ↓ | 0.176 | 0.176 | 0.176 | 0.176 | 0.176 |
| Dispersal capacity | ↑ | 0.294 | 0.294 | 0.294 | 0.294 | 0.294 |
| Living-area patchy or dense | ↑ | 0.118 | 0.118 | 0.118 | 0.118 | 0.118 |
| Territory behaviour | ↑ | 0.059 | 0.059 | 0.059 | 0.059 | 0.059 |

As shown in the table, main category C is not used in this vulnerability analysis because of the unavailability of relevant literature on the toxicity of the tested substances to the species in the analysis. In BOSdA the weighing-factor for this main category is therefore 0. If data on the toxicity become available, it is simply a change of the weighing factor that makes main category C part of the analysis.

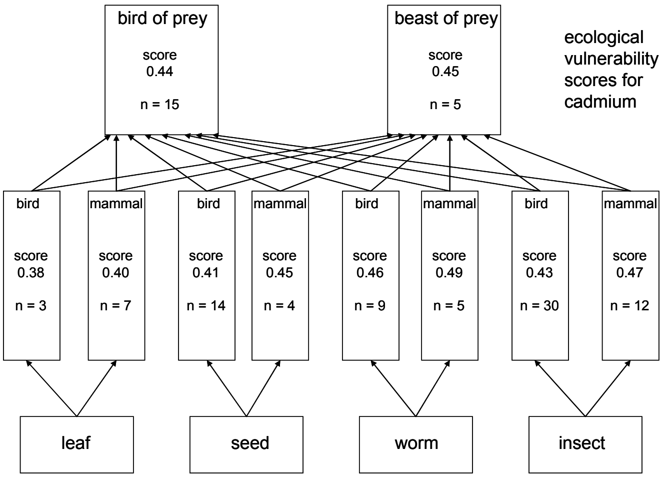
The three remaining categories are weighed in the same proportion, so each of these categories contributes the same to the vulnerability. Within each category, the aspects are weighed differently per substance. The values of these weighing factors are based on the knowledge and experience of experts.

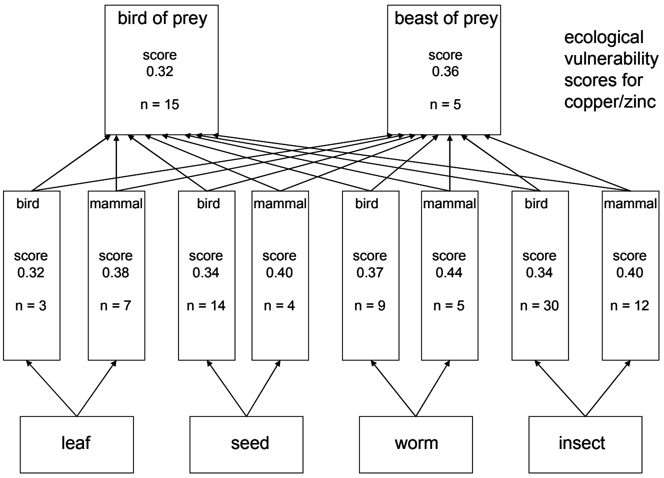
# Appendix 6 – T-test results

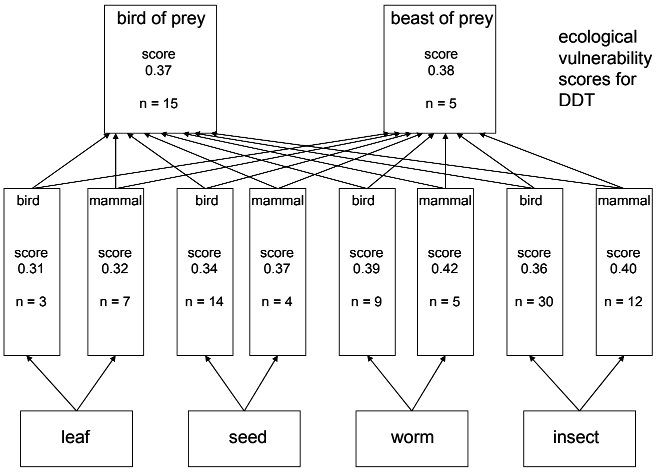
T-test results comparing vulnerability score of generalist feeders and specialist feeders on different food types, shading indicates $p < 0.05$.

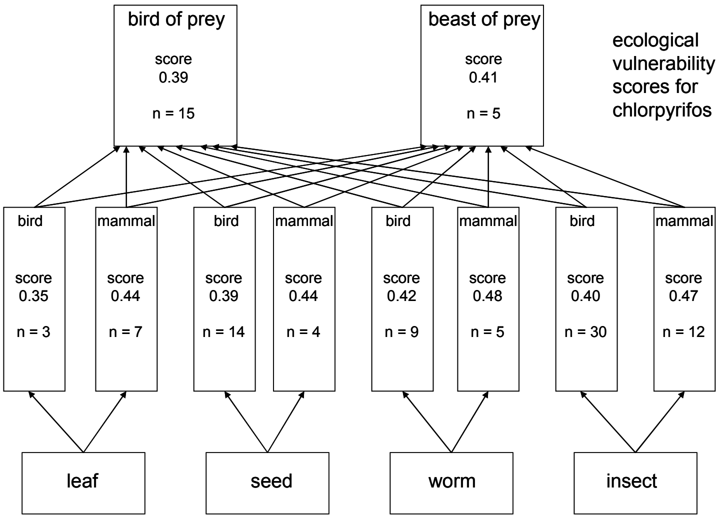
| Food type | Contaminant | Generalist | Specialist | t-test p-value |
|---|---|---|---|---|
| earthworm | Cd | 0.45 | 0.47 | 0.26 |
| | Cu/Zn | 0.42 | 0.39 | 0.45 |
| | DDT | 0.42 | 0.40 | 0.32 |
| | CPF | 0.46 | 0.43 | 0.40 |
| | ivermectin | 0.44 | 0.44 | 0.79 |
| plant | Cd | 0.44 | 0.37 | 0.02 |
| | Cu/Zn | 0.39 | 0.34 | 0.06 |
| | DDT | 0.36 | 0.30 | 0.04 |
| | CPF | 0.43 | 0.39 | 0.37 |
| | ivermectin | 0.42 | 0.37 | 0.11 |
| fruit/nectar/seeds | Cd | 0.42 | 0.37 | 0.00 |
| | Cu/Zn | 0.34 | 0.38 | 0.05 |
| | DDT | 0.34 | 0.37 | 0.07 |
| | CPF | 0.40 | 0.45 | 0.02 |
| | ivermectin | 0.37 | 0.40 | 0.16 |
| insect | Cd | 0.44 | 0.44 | 0.80 |
| | Cu/Zn | 0.39 | 0.40 | 0.55 |
| | DDT | 0.39 | 0.41 | 0.27 |
| | CPF | 0.43 | 0.45 | 0.10 |
| | ivermectin | 0.41 | 0.42 | 0.71 |
| benthos | Cd | 0.43 | 0.43 | 0.99 |
| | Cu/Zn | 0.40 | 0.40 | 0.93 |
| | DDT | 0.39 | 0.38 | 0.59 |
| | CPF | 0.40 | 0.39 | 0.72 |
| | ivermectin | 0.39 | 0.39 | 0.90 |
| aquatic plants | Cd | 0.38 | 0.41 | 0.41 |
| | Cu/Zn | 0.38 | 0.36 | 0.58 |
| | DDT | 0.36 | 0.33 | 0.56 |
| | CPF | 0.32 | 0.35 | 0.53 |
| | ivermectin | 0.31 | 0.38 | 0.08 |
| zooplankton | Cd | 0.40 | 0.33 | 0.55 |
| | Cu/Zn | 0.44 | 0.40 | 0.76 |
| | DDT | 0.42 | 0.35 | 0.49 |
| | CPF | 0.40 | 0.35 | 0.72 |
| | ivermectin | 0.38 | 0.35 | 0.85 |
| fish | Cd | 0.43 | 0.46 | 0.23 |
| | Cu/Zn | 0.40 | 0.38 | 0.54 |
| | DDT | 0.40 | 0.40 | 0.97 |
| | CPF | 0.39 | 0.37 | 0.57 |
| | ivermectin | 0.37 | 0.37 | 1.00 |
| amphibian | Cd | 0.47 | 0.45 | 0.25 |
| | Cu/Zn | 0.39 | 0.37 | 0.54 |
| | DDT | 0.42 | 0.39 | 0.24 |
| | CPF | 0.40 | 0.38 | 0.47 |
| | ivermectin | 0.39 | 0.36 | 0.41 |
| birds | Cd | 0.44 | 0.43 | 0.63 |
| | Cu/Zn | 0.36 | 0.31 | 0.12 |
| | DDT | 0.38 | 0.36 | 0.39 |
| | CPF | 0.39 | 0.40 | 0.61 |
| | ivermectin | 0.36 | 0.33 | 0.22 |
| mammals | Cd | 0.44 | 0.45 | 0.53 |
| | Cu/Zn | 0.35 | 0.37 | 0.33 |
| | DDT | 0.38 | 0.43 | 0.02 |
| | CPF | 0.39 | 0.46 | 0.01 |
| | ivermectin | 0.36 | 0.43 | 0.03 |

# Appendix 7 – Average ecological vulnerability scores in simplified food chains

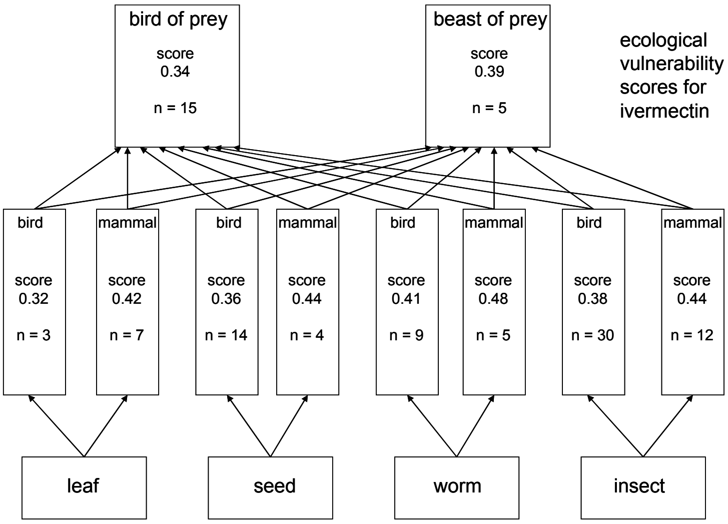






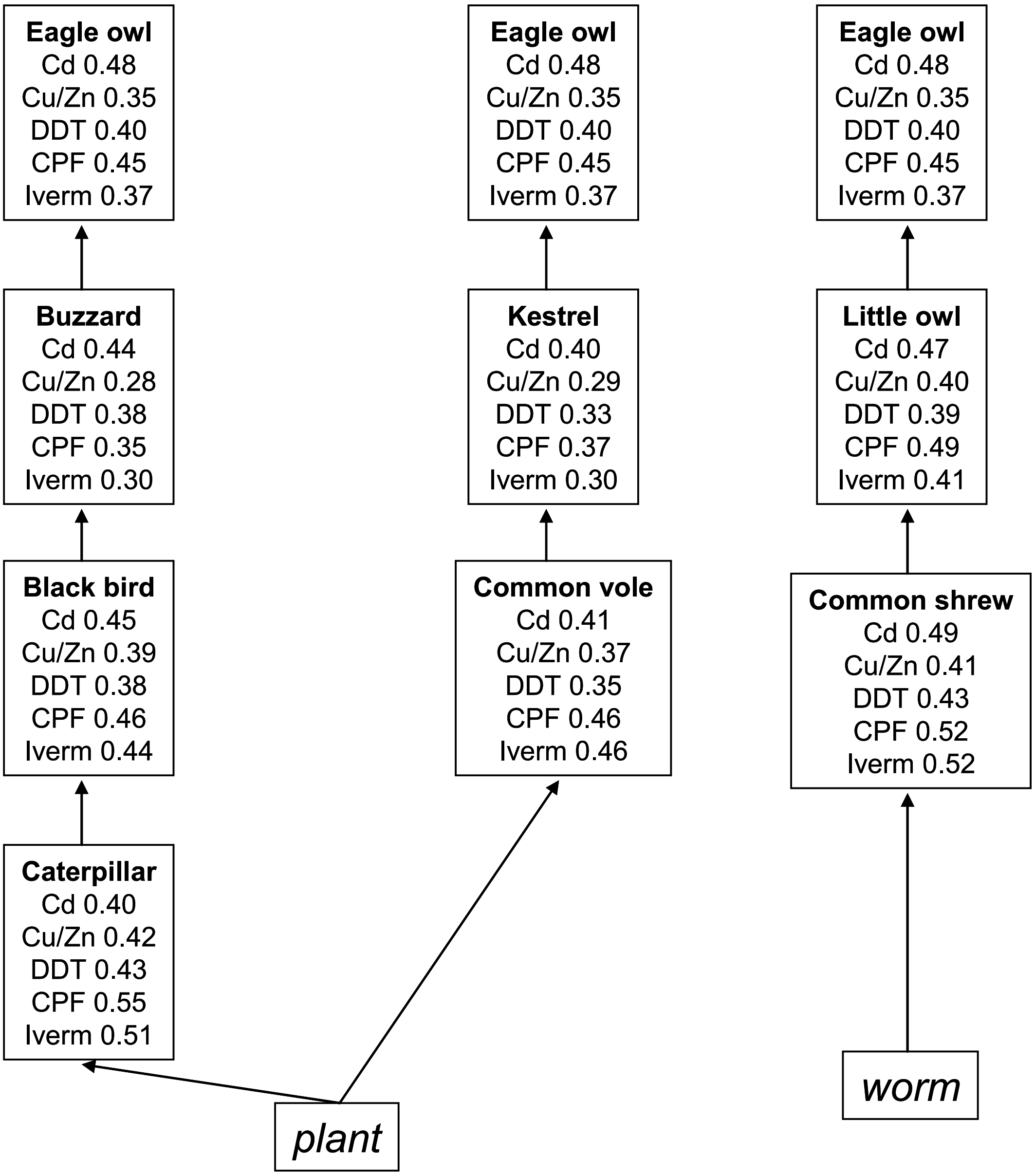


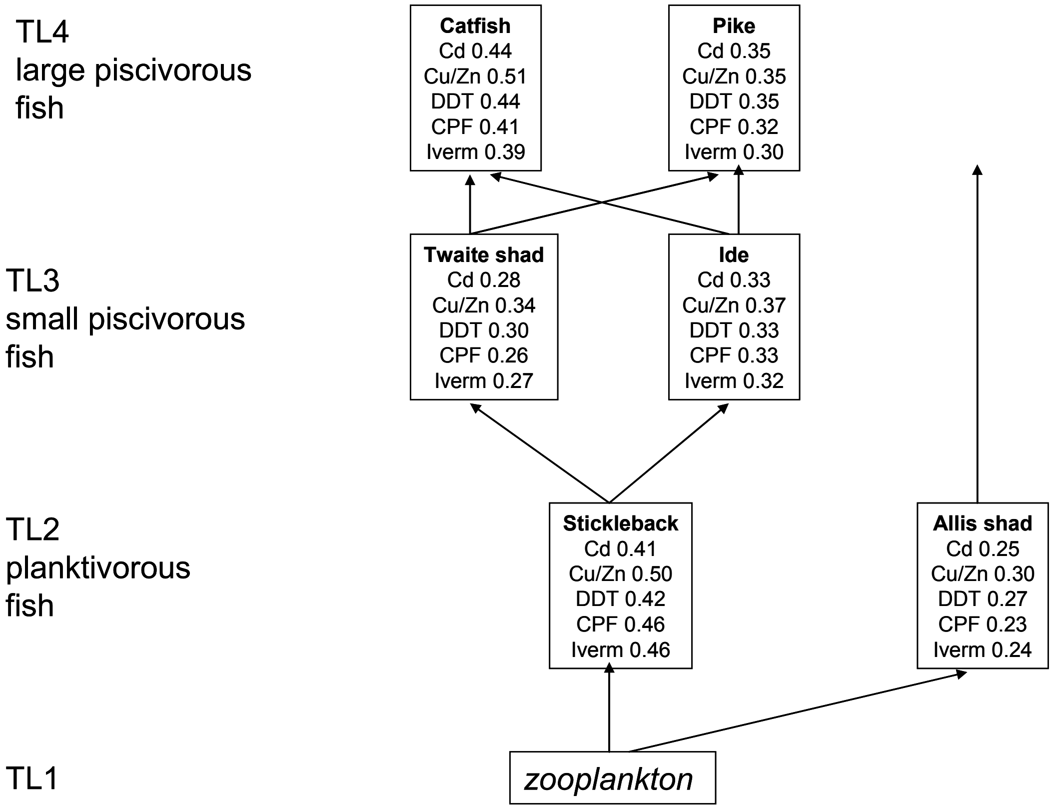
ecological vulnerability scores for chlorpyrifos

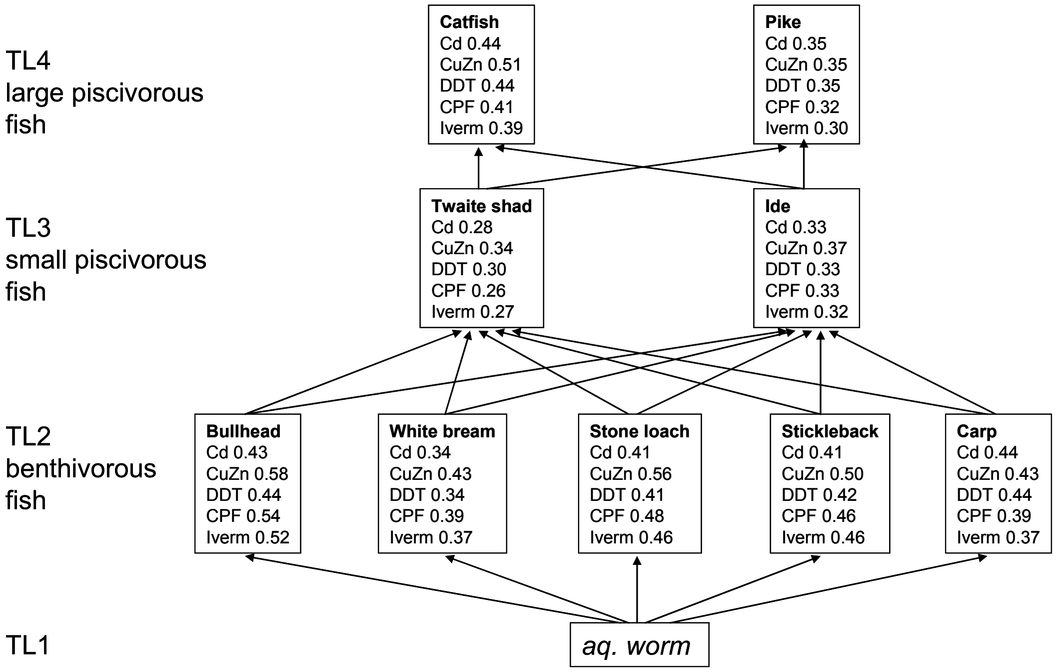


ecological vulnerability scores for ivermectin

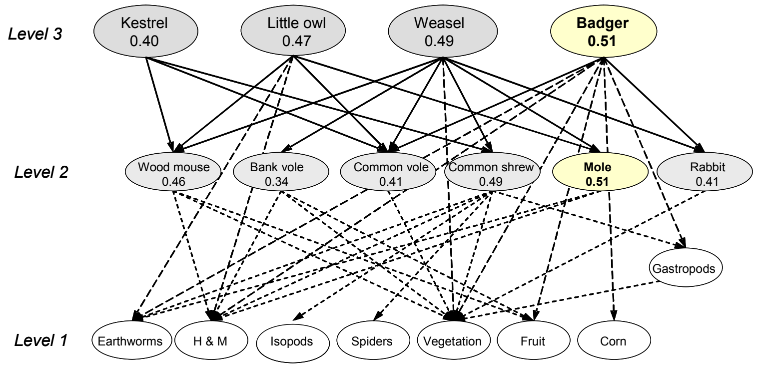
## Appendix 8 - Comparison of ecological vulnerability scores within example food chains



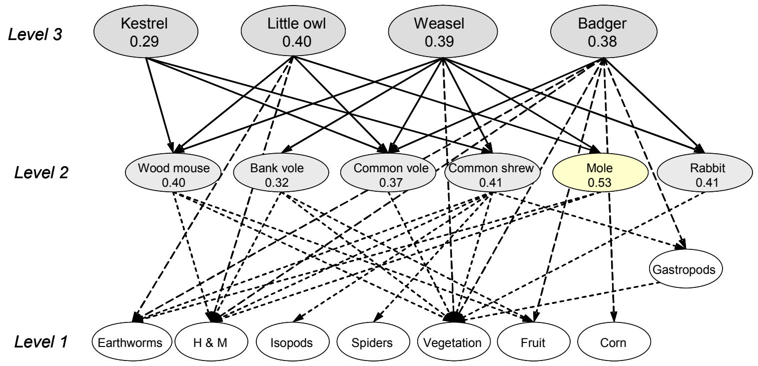

TL4
large piscivorous
fish
TL3
small piscivorous
fish
TL2
planktivorous
fish
TL1
Catfish
Cd 0.44
Cu/Zn 0.51
DDT 0.44
CPF 0.41
Iverm 0.39
Pike
Cd 0.35
Cu/Zn 0.35
DDT 0.35
CPF 0.32
Iverm 0.30
Twaite shad
Cd 0.28
Cu/Zn 0.34
DDT 0.30
CPF 0.26
Iverm 0.27
Ide
Cd 0.33
Cu/Zn 0.37
DDT 0.33
CPF 0.33
Iverm 0.32
Stickleback
Cd 0.41
Cu/Zn 0.50
DDT 0.42
CPF 0.46
Iverm 0.46
Allis shad
Cd 0.25
Cu/Zn 0.30
DDT 0.27
CPF 0.23
Iverm 0.24
zooplankton


TL4
large piscivorous
fish
TL3
small piscivorous
fish
TL2
benthivorous
fish
TL1
Catfish
Cd 0.44
CuZn 0.51
DDT 0.44
CPF 0.41
Iverm 0.39
Pike
Cd 0.35
CuZn 0.35
DDT 0.35
CPF 0.32
Iverm 0.30
Twaite shad
Cd 0.28
CuZn 0.34
DDT 0.30
CPF 0.26
Iverm 0.27
Ide
Cd 0.33
CuZn 0.37
DDT 0.33
CPF 0.33
Iverm 0.32
Bullhead
Cd 0.43
CuZn 0.58
DDT 0.44
CPF 0.54
Iverm 0.52
White bream
Cd 0.34
CuZn 0.43
DDT 0.34
CPF 0.39
Iverm 0.37
Stone loach
Cd 0.41
CuZn 0.56
DDT 0.41
CPF 0.48
Iverm 0.46
Stickleback
Cd 0.41
CuZn 0.50
DDT 0.42
CPF 0.46
Iverm 0.46
Carp
Cd 0.44
CuZn 0.43
DDT 0.44
CPF 0.39
Iverm 0.37
aq. worm

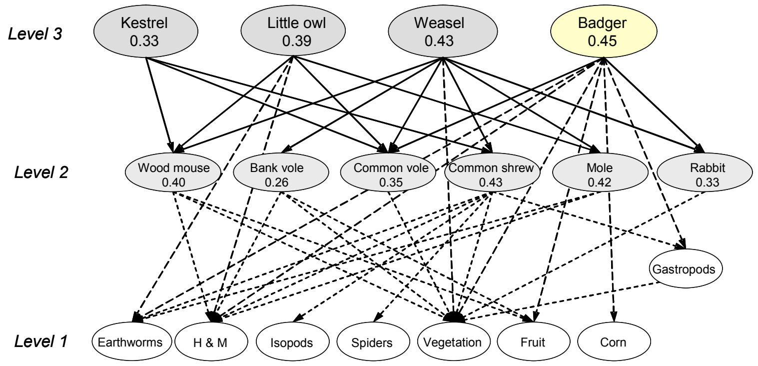
# Appendix 9 - Comparison of ecological vulnerability scores within example food webs



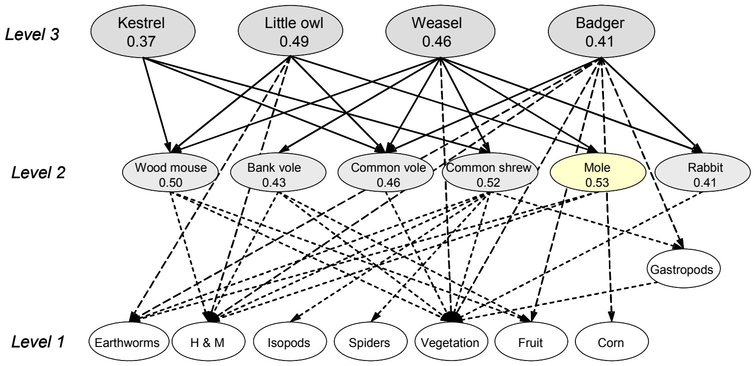
Ecological vulnerability scores for cadmium



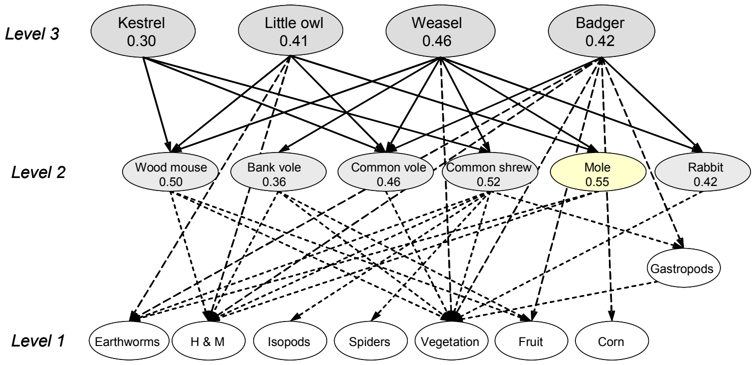
Ecological vulnerability scores for copper/zinc



Ecological vulnerability scores for DDT



Ecological vulnerability scores for chlorpyrifos



Ecological vulnerability scores for ivermectin