Ecological Vulnerability in Wildlife

A conceptual approach to assess impact of environmental stressors

H.J. De Lange
J.J.C. Van der Pol
J. Lahr
J.H. Faber

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Marieke de Lange, Joost van der Pol, Joost Lahr, Jack Faber
Partner 21, Alterra, Wageningen, The Netherlands</td><td rowspan="4"></td></tr>
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H.J. De Lange
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ABSTRACT

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Nature development in the Netherlands is often planned on contaminated soils of former agricultural land and in floodplain areas. We developed a new method to predict ecological vulnerability in wildlife using autecological information. The method was tested for six chemicals: copper, zinc, cadmium, DDT, chlorpyrifos, and ivermectin. Vulnerability to essential metals copper and zinc was correlated with soil and sediment habitat preference. Vulnerability to bioaccumulating substances cadmium and DDT was correlated with higher positions in the food web and with lifespan. Vulnerability to chlorpyrifos and ivermectin was determined by preference for soil habitats. The ecological vulnerability analysis approach facilitates ordinal ranking of vulnerable species, with ecological relevance. It has potential for further developments in risk assessment.

Keywords: ecological risk assessment, wildlife, ecological vulnerability, heavy metals, pesticides, pharmaceuticals

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Phone: + 31 317 474700; fax: +31 317 419000; e-mail: info.alterra@wur.nl

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Contents

Preface

Ecological risk assessment for wildlife is hampered by lack of toxicological sensitivity data. As many wildlife species are rare, threatened or protected, such data may not be acquired at all. However, there is great need for ecotoxicological support with respect to wildlife in decision making in spatial planning and management for nature conservation and development areas (Faber *et al.*, 2004a). Particularly in the Netherlands, decision making for nature development is often confronted with soil contamination, and the feasibility of development plans may be questioned as a result of large uncertainty in traditional ecological risk assessment methods. A new method is now developed to reduce this uncertainty, making use of ecological characteristics in wildlife species in order to assess vulnerability to environmental stressors.

In a preceding pilot study the framework for this vulnerability analysis was conceived and tested for a limited number of contaminants and 'nature target types', representing major cases of concern with stake holding parties in the Netherlands. The present study involved a widening of the ecological array of species, and a thorough analysis of species characteristics to establish major determinants for ecological vulnerability under several scenarios in chemical stressors.

The pilot study was financed by the 'Netherlands Center for Soil Quality Management and Knowledge Transfer', and was completed in collaboration with AquaSense, Dienst Landelijk Gebied (DLG), Provincie Noord-Holland, Stuurgroep Nadere Uitwerking Rivierengebied (NURG) and WEB Natuurontwikkeling.

The present study was financially supported by the European Union (European Commission, Sixth Framework Programme, Priority 1.1.6.3 'Global Change and Ecosystems', Topic VII.1.1.a 'Development of risk assessment methodologies', Integrated Project 'NOMIRACLE' nr 003956), and by the Dutch Ministry of Agriculture, Nature and Food Quality, Kennisbasis, Thema 'Inrichting en gebruik groene en blauwe ruimte' (KB-01).

Expert judgement is essential in our method for vulnerability analysis. We thank the following persons who shared their knowledge and contributed in the selection of ecological characteristics or determination of weight factors in vulnerability analyses: Chris Klok, Nico van den Brink and John Deneer (Alterra), Yolanda Wessels (AquaSense), Marcel van de Leemkule and Kasper Spaan (WEB Natuurontwikkeling), and Harriët de Ruiter (Dienst Landelijk Gebied, present affiliation: Waterschap Rivierenland).

Summary

Main conclusions of the Ecological Vulnerability Assessment

- *We developed a new method which incorporates ecological characteristics of wildlife species in ecological risk assessment. The required input is ecological information of species, which is usually easily obtained from literature. Results are ecologically meaningful as actual wildlife species are involved, not "laboratory fauna". In our method species comparisons in risk assessments can be tailor-made to meet the specific questions in nature conservation, e.g. species may be compared for a particular area (site-specific risk assessment, monitoring), or target species may be compared between nature target types (spatial planning of nature development, feasibility studies).*
- *The ecological vulnerability analysis results in a ranking of species by relative vulnerability for specifically tested contaminants. Results indicate that:*
  - *Ecological vulnerability to essential metals (model substances copper and zinc) was strongly correlated with exposure through soil or sediment habitat, and by life history traits reflecting r-strategy.*
  - *Ecological vulnerability to bioaccumulating substances (cadmium and DDT) was correlated with a high trophic level and by life history traits reflecting K-strategy.*
  - *Ecological vulnerability for chlorpyrifos and ivermectin was mostly correlated with exposure through soil habitat.*
- *A comparison between the results of the vulnerability ranking with field data revealed no large inconsistencies.*
- *Considering the advantages and shortcomings of our method, and in view of the consistency of results with field observations, the developed method of ecological vulnerability is a useful and sound innovation to ecological risk assessment.*

Nature development in the Netherlands is often planned on former agricultural land and in floodplain areas along the large rivers. These soils and sediments often are contaminated, in most cases with a mixture of contaminants at low to moderate concentrations. It is important to assess the impact of this 'grey veil' of contaminants on nature development. How can effects be estimated? Are current methods for risk assessment suitable?
Current ecological risk assessment of soil contamination in nature conservation areas is hampered by limitations of traditional toxicological data. These data have been acquired in laboratory experiments testing toxicological sensitivity at the level of individuals, and using test species and test conditions that have limited value for wildlife populations and conditions in the field. Further, little use is made of ecological knowledge that is also available for use in ecological risk assessment, *e.g.* factors determining field exposure to contaminants, physiological mechanisms to regulate internal concentrations, and population resilience. These aspects jointly determine ecological vulnerability under field conditions. Incorporation of these aspects may improve the field relevance of site-specific ecological risk assessment, especially with respect to wildlife and nature conservation areas.

To address these challenges, we developed a new conceptual approach for risk assessment based on ecological vulnerability. Literature data were compiled to

describe specific ecological characteristics of 135 wildlife species. These characteristics were selected to assess exposure to contaminants, internal regulation mechanisms of contaminants, toxicological sensitivity, and population recovery potential.
Correlations between the ecological characteristics and between groupings of species and characteristics were studied using multivariate ordination analysis. The following characteristics always clustered:

- lifetime reproduction, clutch size, and number of clutches per year (reproduction factors);
- lifespan and adult body weight;
- home range and age at reproduction;
- survival to first reproduction (negatively associated with abovementioned reproduction factors).

This can be interpreted that in our species set strategies of fast and high reproduction are separated from investments in large body size and longevity with lower reproduction numbers (r and K-strategies respectively, *sensu* MacArthur & Wilson, 1967). By contrast, the factors describing habitat preference, food preference and behavioural traits were not associated to one another.

The dataset was then used to assess the relative ecological vulnerability of individual species to contaminants using multi-criteria analysis. Vulnerability was studied for different model chemicals, including essential metals (copper, zinc), non-essential metals (cadmium), bioaccumulating organic substances (DDT), pesticides (chlorpyrifos), and veterinary pharmaceuticals (ivermectin). The multi-criteria analysis of species data resulted in a score for each species; these scores were ranked to identify the most vulnerable species for each contaminant. The top rankings showed surprising robustness.

- Vulnerability for essential metals copper and zinc was strongly determined by exposure through habitat: a preference for soil or sediment increases vulnerability.
- Vulnerability for bioaccumulating substances cadmium and DDT was dependent of trophic level and life history strategy: the most vulnerable species were top predators with K-strategy characteristics.
- Vulnerability for chlorpyrifos and ivermectin was mostly determined by exposure through habitat: a preference for soil increases vulnerability.

The results of the multi-criteria analysis and multivariate ordination were integrated to determine which ecological characteristics best predict vulnerability. For biologically essential metals (copper, zinc) exposure through habitat is a risk factor. For non-essential metals (cadmium) K-strategists have a higher vulnerability than r-strategists. The separation of low *vs.* high vulnerability for chlorpyrifos was reversed: r-strategic species were more vulnerable than K-strategic species. Results of the integration of the two approaches are less clear for DDT and ivermectin. For these chemicals, low vulnerability is associated with population resilience. This suggests that population resilience gives a basic level of resistance against chemical stress.

- exposure through habitat increases vulnerability to copper, zinc and chlorpyrifos;
- K-strategy characteristics increase vulnerability to cadmium and DDT;

- r-strategy characteristics increase vulnerability to chlorpyrifos;
- no specific characteristics were identified for ivermectin;
- population resilience gives a basic level of resistance.

Toxicological sensitivity was excluded in the present study. More research is needed before this category can be satisfactorily incorporated in the ecological vulnerability assessment. A promising approach is to classify averaged toxicological sensitivity for taxonomic groups, using body burdens. Ecological vulnerability analysis has potential for further development, such as application in risk mapping, food web modeling, random walk modeling, and risk scenario ranking.

1 Ecological risk assessment

1.1 Need for ecological risk assessment of contaminated soils

The total surface area of nature in the Netherlands is approximately 450.000 hectares. Current Dutch policy plans aim to increase this area with 50.000 hectares, of which 10.000 hectares is already realized. Thus, a considerable surface area is still needed to meet the target.
Nature development plans are mostly executed on land previously used for agricultural purposes, and in floodplain areas of the large rivers. A relevant question is whether the abiotic conditions of these areas are suitable for the desired nature types. One aspect that up till now has received limited attention in these nature development plans is soil contamination. This should be an area of concern, since the soils and sediments of these agricultural and floodplain areas are likely to be contaminated, in most cases with a mixture of persistent contaminants at low to moderate concentrations. This is also known as a 'grey veil' of contaminants.
It is important to know what the impact is of this 'grey veil' of contaminants on nature development. How can this impact be estimated? Are current methods for risk assessment suitable to predict field effects?

1.2 Current methods of ecological risk assessment

Current methods in risk assessment focus on sensitivity of groups of laboratory animals (*i.c.* lab derived LC_{50}, EC_{50} and NOEC values). A widely acknowledged major source of uncertainty in risk assessment is the difference in toxicity between species, which can exceed two orders of magnitude (Traas *et al.*, 1996; Luttik *et al.*, 2005). A common procedure to obtain a community risk level is to extrapolate from measured LC_{50} or NOEC values, dividing the lowest LC_{50} or NOEC by a safety factor (as described in Sijm *et al.*, 2002). Some argue that the species sensitivity distribution (SSD) is a more refined approach to quantify between species variation in toxicological sensitivity in order to obtain a community risk level (Posthuma *et al.*, 2002; Luttik *et al.*, 2005).
The SSD can be used in a predictive way for site specific ecological risk assessment, by calculating the potentially affected fraction (PAF) of species (Traas *et al.*, 2002). This is an extrapolated measure of ecological risk to a theoretical community. Other ecotoxicological models currently under consideration for ecological risk assessment in the Netherlands are all effect models, either based on statistical distributions (*e.g.* SSD), mechanisms, or expert database (Posthuma *et al.*, 2005).

1.3 Challenges in ecological risk assessment

A drawback of current methods is that they focus on laboratory derived toxicological sensitivity values, leaving a large body of ecological knowledge unused. Another major drawback is that there are several statistical and ecological uncertainties when toxicological sensitivities are extrapolated to field effects (Van den Brink *et al.*, 2002). Statistical uncertainties are that the distribution of species sensitivities may not be adequately modelled by the chosen statistical procedure, and that the sample of species may not be representative. Ecological uncertainties are that the sensitivity of a species in the laboratory may not reflect the situation in the field; and that the protection of the prescribed percentile of species may not ensure appropriate protection of field ecosystems (Van den Brink *et al.*, 2002).
When ecological risk assessment is applied to assess the potential for nature management targets on contaminated soils (either in nature conservation or development), information is needed on ecological vulnerability to contaminants of species which are currently present in nature areas, or whose presence is targeted for in nature development plans. Ecological risk assessment should therefore aim to assess the magnitude of effects on biota in the field at the population, community and ecosystem level. The ecological vulnerability of the species community is to be assessed in terms of specific exposures to contaminants, internal regulation mechanisms, and toxicological sensitivities for the contaminants, and species characteristics that may determine population recovery from chemical impact.
Posthuma and co-authors (2005) already signalled that what is currently missing in risk assessment is an exposure model. In our opinion, other important aspects which also are currently underrepresented are aspects of toxicokinetics (physiological mechanisms by which an organism can regulate internal concentrations of toxicants), and effects on population level, including the potential for population recovery while effects occur at individual level (*i.e.* species resilience at population level).

Several challenges can be identified in current methods for risk assessment:

- *Limited availability of toxicological data for vertebrates:*
  There is a limited number of 'popular' test species, such as Mallard Duck (*Anas platyrhynchos*), Chicken (*Gallus domesticus*), Sheep (*Ovis amon aries*), and Common Rat (*Rattus norvegicus*), for which a large set of (eco)toxicological data is available. Potentially affected fractions of wildlife species are derived from these test species; however, these may have limited value for wildlife.
- *Importance of internal regulation mechanisms:*
  There are various physiological mechanisms by which an organism can regulate the internal concentration of a toxicant, such as storage in organs and fat, detoxification and excretion. These mechanisms regulate the body burden, and may prevent the occurrence of effects, or delay exceedance of toxicological thresholds. The duration of most standardized tests for acute and chronic toxicity is short with respect to the lifespan of the test organism, and internal equilibrium concentrations will not be attained in all cases.
- *Extrapolation of individual sensitivity to population effects:*
  Acute LD_{50} or LC_{50} values give a reasonable indication for toxicological sensitivity of individual species, but often have limited use for risk assessment under field

conditions (Linder & Joermann, 2001). For example, life history traits that determine the population growth rate may prevent effects to occur at population level or influence the potential for population recovery. Therefore, population-level assessments provide a better measure of response to toxicants than assessments of individual-level effects (Sibly *et al.*, 2005).

- *Secondary poisoning and food chain responses:*
  Laboratory experiments result in direct effects of toxicants on certain species, without taking into account the indirect effect of secondary poisoning on higher trophic levels in the food chain. Especially for accumulating toxicants this route can be more effective than direct exposure effects. This problem can be approached with bioaccumulation models, such as described by Traas *et al.* (1996) and Jongbloed *et al.* (1996). However, these models also are limited by scarcity in ecotoxicological data and make assumptions that sometimes cannot be substantiated with factual data.
- *Ecological relevance of statistical distributions:*
  From the SSD the fraction of species potentially affected by a certain exposure level can be computed, but this cannot answer the question which species will be affected in particular (Van der Hoeven, 2004)? The SSD method has been criticized for this lack of ecological relevance (Forbes & Calow, 2002).

To address these uncertainties, we developed a method for risk assessment based on ecological vulnerability. Ecological traits are used to assess exposure to contaminants, internal regulation mechanisms of contaminants, toxicological sensitivity, and population recovery potential. All these aspects may determine the rate of exposure and effect, and may be assessed in combination to predict the ecological vulnerability of species to contaminants.

Our method has the following advantages:

- ecological data for most species are easily available from literature or from expert knowledge;
- analysis can be performed for any selection of species, composing real life communities or theoretical assemblages; these species are then ranked by relative vulnerability;
- aquatic and terrestrial species can be compared; this is not possible with LC_{50} values since these two groups have very different exposure routes.

The ecological vulnerability analysis method is developed for single contaminants. In future it may be adapted to facilitate assessment for mixtures of contaminants, and for other stressors.

1.4 Research aims

The long-term aim is to develop a knowledge based system using ecological species characteristics which can be used to support decision making in nature management, considering soil contamination, and multiple stressors in the environment. This report focuses on intermediate stages in the project, which can be phrased by the following research questions.

RQ1: Can we define meaningful groups of ecological species characteristics?
For this study we have gathered a large dataset of ecological species characteristics for 135 wildlife species, describing autecological traits, toxicokinetics, toxicological sensitivity, and population characteristics. Some of the characteristics are likely to be correlated, for example since they describe various aspects of life history. Can we define groups of characteristics? Can a group be represented by one characteristic? This is analysed by means of principal component analysis.

RQ2: How to use species characteristics in ecological risk assessment?
Current risk assessment has its limitations, and a new method is needed which incorporates available ecological knowledge and which will have better field relevance. We developed a conceptual approach, in which we use expert judgement to make qualitative predictions by means of a multi-criteria analysis of the ecological vulnerability of wildlife species to selected contaminants.
We make an assessment which ecological characteristics determine the vulnerability for a specific toxicant. We consider autecological traits, toxicokinetics, toxicological sensitivity, and population characteristics. Values for these ecological characteristics are gathered from available literature for 135 wildlife species.
The impact of each characteristic is estimated by weight factors, which are established using expert judgement. All characteristics combined predict the ecological vulnerability for that contaminant. This procedure is performed for several types of toxicants:

- essential metals (copper and zinc);
- non-essential bioaccumulating metals (cadmium);
- bioaccumulating organic substances (DDT);
- lipophilic substances with potential for detoxification (chlorpyrifos and ivermectin).

The ecological vulnerability analysis results in a ranking of species from most to least vulnerable to a particular contaminant.

RQ3: Can we use (groups of) ecological characteristics to predict ecological vulnerability?
The groups of characteristics are compared with the vulnerability ranking to assess correlations. Can we recognize (groups of) characteristics that may be used to predict ecological vulnerability?

RQ4: Are the results of this new method in line with current knowledge and ecological risk assessment?
The derived species ranking is an ordinal ranking. Evaluation of this ranking is important to verify that the conceptual model results are in agreement with field observations. Does our method truly identify the most vulnerable species?
We compare the vulnerability rankings with field observations and with estimates of toxicological sensitivities.

Embedding in EU Integrated Project 'NOMIRACLE'
NOMIRACLE is an Integrated Project under the Sixth Framework Programme, aimed to develop novel methods to better evaluate environmental risks. The study described in this report is embedded in work package 4.2; the objective of this work package is to develop new methods and models that explicitly address temporal and spatial dimensions of cumulative risks for human and ecological receptors. Our research is focused on the relationship between species traits and vulnerability to environmental stressors. Wildlife species data have been made available to our partners in WP4.2 for spatially explicit modelling and random walk models of the food web in Dutch river floodplains. Our methods will provide complementary assessments.
The vulnerability analysis may be further developed for application in multiple stress risk assessment. In a more general sense, the results of our present study provide input in the identification of critical ecological pathways and parameters for ecological risk assessment.

1.5 Outline of this report

The flow chart in Figure 1 illustrates the outline of this report and coherence between the research activities. The main text gives an overview of the vulnerability analysis and discussion of the results. In the Appendices detailed descriptions of the used methods and results are given.
We have gathered a dataset of 135 species with 40 ecological characteristics to answer the research questions. This dataset was used for two approaches in a fundamentally different way:

- The principal component analysis was used to estimate groupings of characteristics and species, by using *mathematical relations* to calculate ordination diagrams based on a *correlation* matrix of the characteristics. This is described in Chapter 2, addressing the first research question.
- In the multi-criteria analysis to estimate ecological vulnerability, *weights* are given to each characteristic using *expert judgement*. This is described in Chapter 3, addressing the second research question. Here we present the most vulnerable species for six studied contaminants.
- In Chapter 4 both approaches are combined, thereby addressing the third research question. We analyse which ecological traits can be used to predict ecological vulnerability.
- In Chapter 4 we evaluate the vulnerability ranking with literature data on toxicological sensitivities and field effects of soil contamination, addressing the fourth research question.
- In Chapter 5 we conclude with some general remarks and an evaluation of the methodology. Here we also present an outlook to future research.

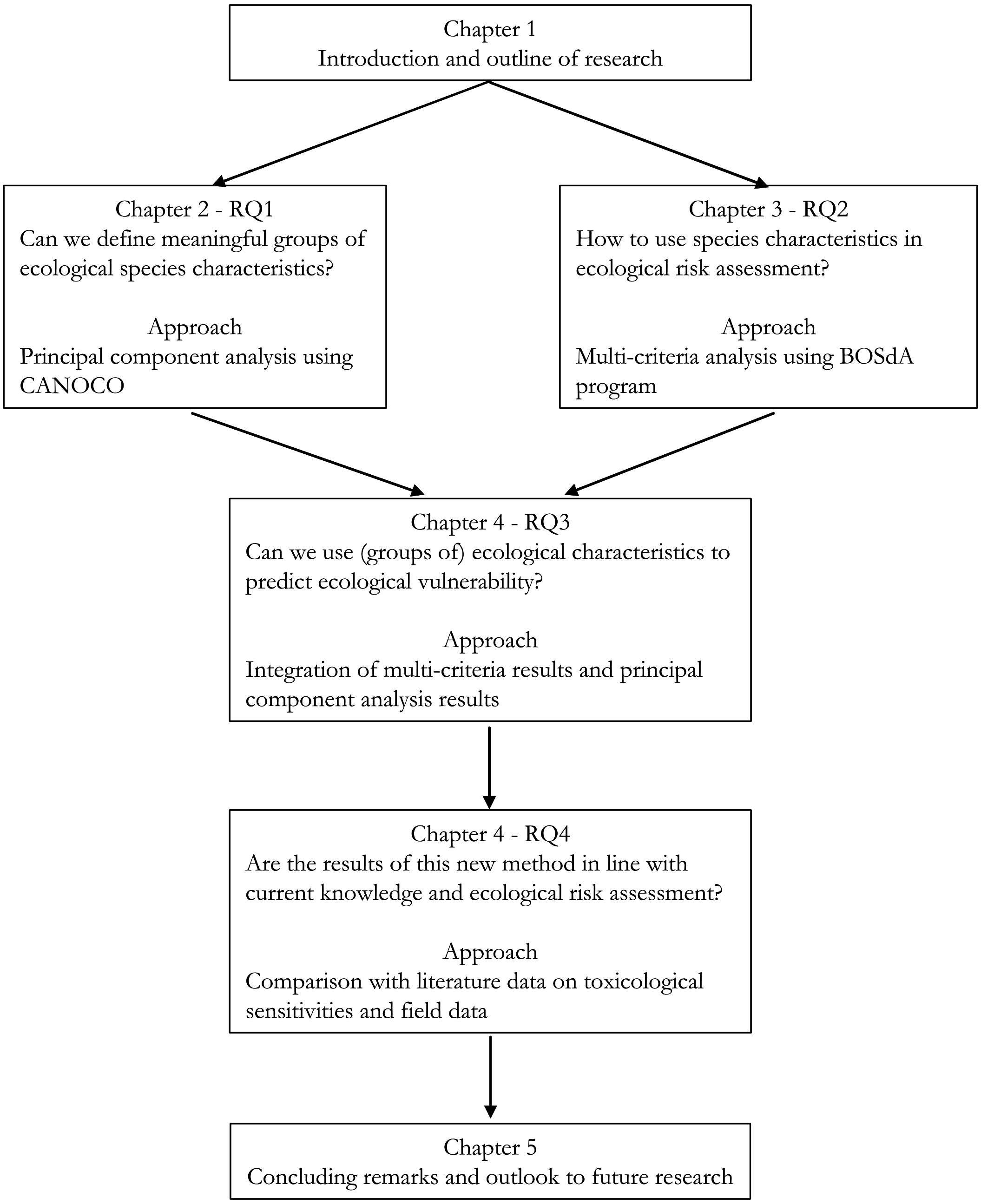

Figure 1. Flow chart illustrating the coherence between research questions (RQ) and method approaches, in sequence of presentation in this report.

2 Ecological characteristics

2.1 Assessing species and ecological characteristics

A large set of ecological species characteristics was gathered in our study, describing autecological traits, toxicokinetics, toxicological sensitivity, and population characteristics, for 135 species of wildlife.
The species were selected from nature target types as defined in the 'Handbook Nature Target Types' (Bal *et al.*, 1995). This Handbook describes the biodiversity targets for Dutch nature types that can be realised with appropriate management. 'Target species' are considered biodiversity indicators for the degree of development of these nature target types, and represent species which are either very rare in number, of international importance, or declining in abundance at a national or European scale. They may belong to different taxonomic groups. For our study target species were selected for nature target types in predominantly fluvial areas, as extensive nature development is planned for these diffusely contaminated regions in The Netherlands. Several 'common species' were also included in this dataset, in order not to narrow down the analysis to a possibly limited range of characteristics typical for rare and declining species; the additional species are common for fluvial nature types in The Netherlands.
The resulting dataset contained 135 species, belonging to seven taxonomic groups (Table 1). A complete description of the species list 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 target species), or a letter (common species).

Table 1. Species representation over taxonomic groups.

Taxonomic group	Code	Nature target species	Common species	Total
Birds	BIRD	56	10	66
Butterflies	BFLY	24	3	27
Mammals	MAM	8	4	12
Fish	FISH	8	2	10
Amphibians	AMPH	6	1	7
Dragonflies	DFLY	6	1	7
Reptiles	REP	5	1	6
Total		113	22	135

As far as we considered necessary for a species description for ecological risk assessment, specific ecological characteristics data were gathered. Thus, data on life history, feeding biology, distribution, toxicokinetics, toxicological sensitivity, and population characteristics were compiled for these species. The resulting dataset was a closed matrix of 135 species and 40 ecological characteristics (Appendix 2).
We applied multivariate statistics to analyse for ecological patterns in the data. We used ordination analysis to infer clustering of characteristics and clustering of species with similar characteristics within our dataset. This information can later be used to

recognize vulnerable species or groups of species. Further, the relative contribution to vulnerability by the different characteristics can be estimated.

Ordination analysis was performed using canonical correspondence analysis (Canoco for Windows 4.5; Ter Braak & Šmilauer, 2002). The different species were considered 'samples', and the characteristics of each species were considered 'species' in this analysis. The set of 40 characteristics consisted of both factors (*e.g.* preference for a particular food type, expressed either as yes or no) and variables (*e.g.* maximum lifespan, a value between 10 and 600 months). The factors were scored 0 or 1, and the variables were log(x+1) transformed to obtain comparable ranges for analysis.
A detrended correspondence analysis (DCA) was performed to analyse the length of gradients, a measure of how unimodal the species responses are along an ordination axis. This resulted in short gradients, therefore the linear method of principal components analysis (PCA) was considered appropriate for this dataset. The following options within Canoco were chosen: scaling was focused on interspecies correlations, species scores were divided by standard deviation, and species were centred and standardized. These choices resulted in a standardized PCA based on a correlation matrix (Ter Braak & Šmilauer, 2002).

Some characteristics have strong correlations, see Appendix 3. The most important correlations were:
- Habitat preference or food preference at different life stages: most species have the same habitat or food preference during their life.
- Duration of adult life and maximum lifespan: for most species the adult stage is the largest part of the maximum lifespan.
- Energy intake and weight: energy intake is estimated using body weight in mathematical relations (see Appendix 4).

These correlations resulted in overlapping directions in the ordination plot. We therefore omitted the factor or variable which was closest to the origin and thus with the lowest influence on the ordination.

2.2 Assemblages of species and characteristics

2.2.1 Ordination of species and characteristics

Ordination of the total dataset with species characteristics (Figure 2) resulted in a separation of the different animal groups. Fishes, amphibians and dragonflies were positioned in the upper right quadrant, butterflies in the lower right quadrant, birds in the two left quadrants, and mammals and reptiles were positioned close to the origin (Figure 2). Common species showed positioning at the edges of their respective species cluster. Carp (*Cyprinus carpio*, FISHa) had an outlier position, in the upper right corner. This species exhibits a mixture of r and K-strategy characteristics (*sensu* MacArthur & Wilson, 1967), it has a large body weight and long life span (typical for K-strategists), but also a large clutch size, high life time reproduction, and low survival of juveniles to first reproduction (typical for r-strategists).

The first axis in the PCA ordination is interpreted as representing r-strategy versus K-strategy. Characteristics related with r-strategy (high reproduction, low survival to first reproduction) are roughly pointing to the right; characteristics related with K-strategy (high survival to first reproduction, long duration of adult stage, large body weight) are roughly pointing to the left. The second axis in the ordination plot is interpreted as habitat preferences; aquatic species are positioned in the upper half of the plot, terrestrial species in the lower half of the plot. The third axis (not shown here) roughly represented food preference.

The ordination resulted in strong clusters of taxonomic groups. It is worthwhile to perform the ordination analysis for each taxonomic group separately, to take away the taxonomic influence on the ordination, and zoom in on ecological characteristics within each group. This detailed analysis could only be performed with birds and butterflies; the number of species in the other taxonomic groups was too low to perform the multivariate analysis.

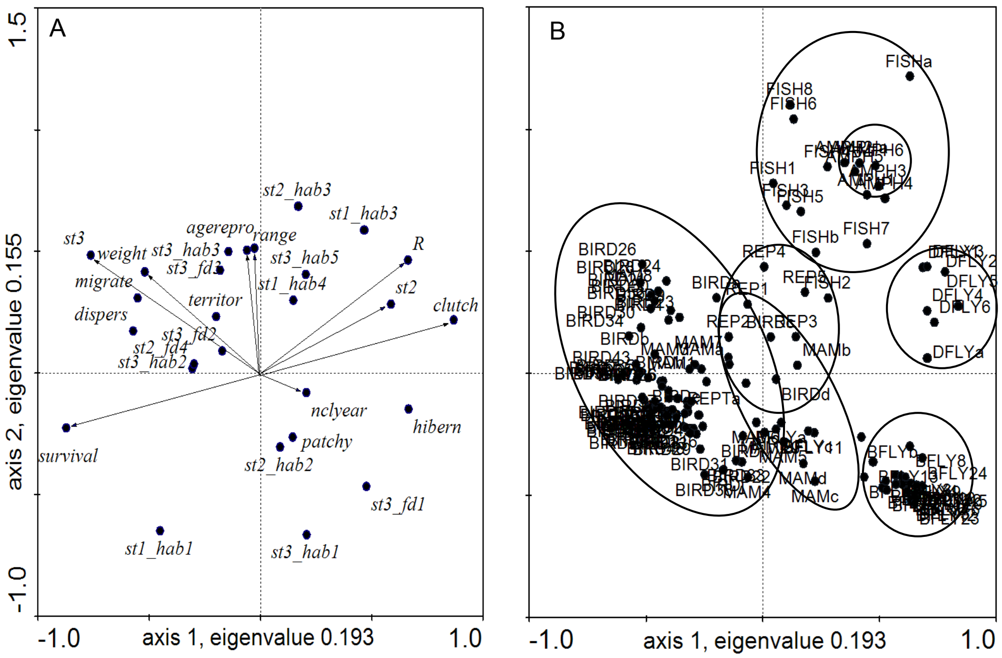

Figure 2. PCA ordination of characteristics (panel A) and species (panel B) using the total dataset. The position of variables in panel A is indicated with an arrow and bullet, position of factors is indicated with a bullet. The circles in panel B indicate the species clusters of taxonomic groups.

Birds

The ordination of the birds species (Figure 3) showed that the common species were separated from the nature target species and were all positioned in the upper right quadrant, except for Buzzard (*Buteo buteo*, BIRDb). This segregation of the common species coincides with r-strategy traits such as number of clutches per year, reproductive effort and clutch size.

The first axis in the PCA ordination of the subset birds is interpreted as representing r-strategy versus K-strategy. Characteristics related with r-strategy (high reproduction, high number of clutches per year, short adult stage) are roughly pointing to the right. Survival to first reproduction is pointing downwards. Characteristics related with adult body weight and maximum lifespan are pointing upwards. The third axis (not shown here) roughly represents food preference.

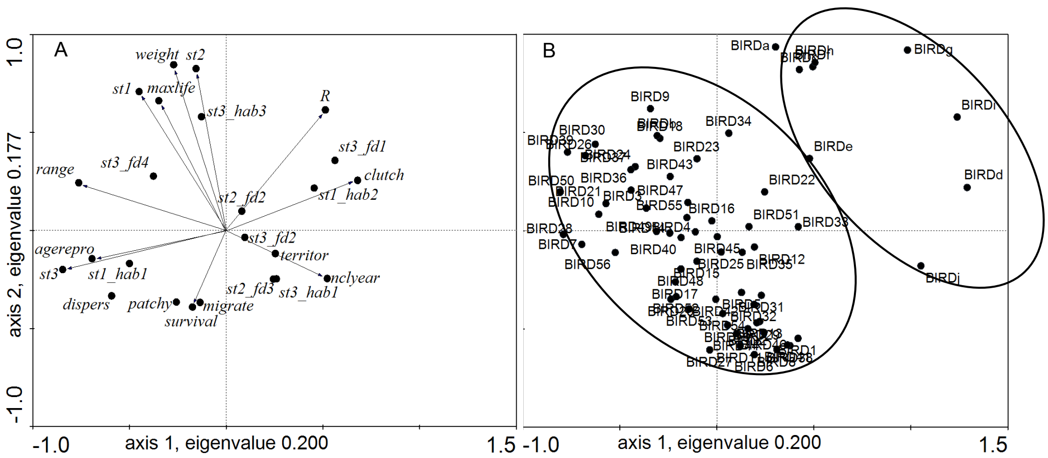

Figure 3. PCA ordination of characteristics (panel A) and species (panel B) for birds. The position of variables in panel A is indicated with an arrow and bullet, position of factors is indicated with a bullet. The circles in panel B indicate the separation of target species from common species.

Butterflies

Ordination of the butterfly species resulted in two distinct clusters (Figure 4). The first cluster was formed by Niobe Fritillary (*Argynnis niobe,* BFLY8), which is positioned in the upper half of the ordination plot. This species is the only butterfly species in the dataset to deposit eggs in the soil litter layer. Another distinctive characteristic in this species is the duration of the egg stage; this is 9 months, much longer than for the other butterflies in the dataset.

A second cluster is formed in the lower right quadrant by three common butterfly species Red Admiral (*Vanessa atalanta*, BFLYa), Large White (*Pieris brassicae*, BFLYb) and Brimstone (*Gonepteryx rhamni*, BFLYc); and two nature target species Large Tortoiseshell (*Nymphalis polychloros*, BFLY11) and Queen of Spain Fritillary (*Issoria lathonia*, BFLY13). Distinctive characteristics in these species are large home ranges, long duration of adult life, and dispersive and migratory behaviour.

The remaining species are all positioned around the origin, with no clear correlation with ecological characteristics.

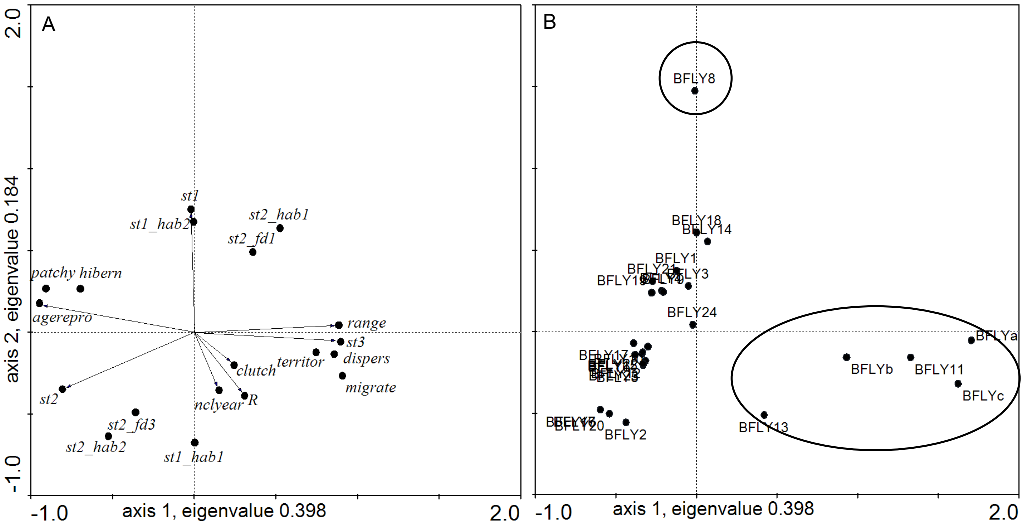

Figure 4. PCA ordination of characteristics (panel A) and species (panel B) for butterflies. Position of variables is indicated with an arrow and bullet, position of factors is indicated with a bullet. The circles in panel B indicate clusters of species.

2.2.2 Defining groups of ecological characteristics

The three ordination exercises resulted in comparable clusters of variables. We have mentioned earlier that significant correlations occur between variables (Appendix 3). If we combine the ordination results with the correlation results and interpret the clusters, we can distinguish the following sets (in brackets are the codes used in the ordination plots):

1) Lifetime reproduction (*R*), number of clutches per year (*nclyear*) and median clutch size (*clutch*).
2) Duration of stage 1, 2 or 3 (*st1, st2, st3*), adult body weight (*weight*)
3) Home range (*range*), median age at reproduction (*agerepro*)
4) Survival to first reproduction (*survival*)

Thus, ecological traits describing fast-reproducing species were segregated from ecological traits describing large-bodied and long-lived species. Generalizing: r-strategy can be separated from K-strategy.
On the other hand, the ordination of the factors describing food preference, habitat preference, and behavioural patterns differed between the three ordinations. It was therefore not possible to generalize the results and describe clusters within these factors.

2.2.3 Sensitivity analysis of ordination

We divided the ecological characteristics into several subsets that describe different aspects of the ecology:

- Reproduction: clutch size, number of clutches per year, lifetime reproduction, survival to first reproduction.
- Behaviour: dispersive capacity, patchy distribution, territorial behaviour, hibernation, migration.
- Size and lifespan: duration of juvenile stage, duration of adult stage, age at first reproduction, home range, adult body weight.
- Habitat preferences.
- Food preferences.

To assess which subset had the largest impact on the final ordination, using the total dataset, we calculated the PCA several times, each time omitting one of the subsets of characteristics. We then calculated the mean distance that characteristics had moved in the ordination plot, using the biplot scores as x,y-coordinates. This distance is on a relative scale, without units, and can be used to make comparisons within the same dataset. A longer distance indicates a greater influence of that set of characteristics on the ordination.

This analysis showed that the ordination was most sensitive to changes in reproduction traits, implicating that these had the largest effect on the final ordination (Table 2). The ordination was least sensitive to changes in habitat and food preferences, and intermediate sensitive to changes in size and lifespan and behaviour patterns.

Table 2. Sensitivity of PCA ordination for changes in traits, distance moved in ordination plots of characteristics compared with original plot (is Figure 2).

Cluster	Distance moved
Reproduction	0.72
Behaviour	0.32
Size and lifespan	0.25
Food	0.16
Habitat	0.16

3 Ecological vulnerability analysis

3.1 Assessing ecological vulnerability by multi-criteria analysis

We developed a novel method to assess the ecological vulnerability of selected fauna wildlife species to soil and sediment contamination using a multi-criteria analysis (MCA) approach. The research described here is an elaboration of a pilot study (Faber *et al.*, 2004a).
The MCA in brief: species traits and other autecological characteristics are used to rank a set of wildlife species by vulnerability for a certain chemical. Data are used that refer to life history, feeding biology, dispersal, physiology, histology, *etc.* The ranking is done by multi-criteria analysis, using weight factors assigned through expert judgment in order to weigh the relative contribution of each ecological characteristic to vulnerability given a particular environmental contaminant.

The vulnerability assessment is done for a set of species selected from nature target types as defined in the 'Handbook Nature Target Types' (Bal *et al.*, 1995), as already described in §2.1. For these species, specific ecological characteristics were obtained from literature or expert judgment. The characteristics were selected by experts in order to represent all important aspects covering exposure to effect at the population level, and are divided into four main categories (Table 3):

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 categories represent the pathway from exposure to population effects. First, the individual has to be exposed to a contaminant by various routes of contact in habitat and/or food. Second, internal mechanisms of metabolic regulation and compartmentation determine the body burden and internal exposure which may result in an adverse effect. The magnitude of this effect is determined by the third category: intrinsic toxicological sensitivity, which is dependent of the contaminant and may vary with species. Fourth, population dynamics determine the resilience (or lack of resilience) that species may be expected to have at the population level to overcome toxicity at the individual level. This population resilience is independent of contaminant type.

Table 3. Species characteristics considered in the vulnerability analysis and contribution to vulnerability. Weight factors for the test substances by main category (in bold) and for separate characteristics within a category. A full description is given in Appendix 4.

Characteristic	Effect on vulnerability	Range of values	Cu/Zn	Cd	DDT	Chlorpyrifos	Ivermectin
Main category A: External exposure			**0.333**	**0.333**	**0.333**	**0.333**	**0.333**
Habitat preference	increase	5 categories [a]	0.500	0.071	0.071	0.258	0.258
Maximum life-span	increase	Variable	0.000	0.214	0.214	0.032	0.032
Log home-range	decrease	Variable	0.250	0.143	0.143	0.129	0.194
Food preference	increase	4 categories [b]	0.000	0.286	0.286	0.129	0.129
Food needs	increase	Variable	0.000	0.143	0.143	0.065	0.065
Hibernation	decrease	3 categories	0.125	0.071	0.071	0.000	0.065
Season dependent presence	increase	4 categories	0.125	0.071	0.071	0.258	0.129
Home range < distribution contaminant	increase	yes/no	0.000	0.000	0.000	0.129	0.129
Main category B: Internal exposure			**0.333**	**0.333**	**0.333**	**0.333**	**0.333**
Log Field Metabolic Rate	decrease	Variable	0.200	0.125	0.133	0.364	0.364
Hibernation	increase	3 categories	0.000	0.125	0.200	0.000	0.000
Season dependent presence	decrease	4 categories	0.000	0.125	0.200	0.000	0.000
Storage organs	decrease	yes/no	0.000	0.375	0.200	0.091	0.091
Excretion organs	decrease	yes/no	0.800	0.125	0.133	0.182	0.182
Detoxification mechanisms	decrease	yes/no	0.000	0.125	0.133	0.364	0.364
Main category C: Effects on individual level			**0.000**	**0.000**	**0.000**	**0.000**	**0.000**
Toxicological sensitivity	increase	4 categories	1.000	1.000	1.000	1.000	1.000
Main category D: Effects on population level			**0.333**	**0.333**	**0.333**	**0.333**	**0.333**
Age at first reproduction	increase	Variable	0.176	0.176	0.176	0.176	0.176
Log number of offspring in life	decrease	Variable	0.176	0.176	0.176	0.176	0.176
Survival juveniles until first reproduction	decrease	Variable	0.176	0.176	0.176	0.176	0.176
Dispersal capacity	increase	5 categories	0.294	0.294	0.294	0.294	0.294
Living-area patchy or dense	increase	yes/no	0.118	0.118	0.118	0.118	0.118
Territorial behaviour	increase	3 categories	0.059	0.059	0.059	0.059	0.059

a) increasing vulnerability: habitat 1 = vegetation; habitat 2 = on soil; habitat 3 = in water; habitat 4 = in soil; habitat 5 = in sediment.

b) increasing vulnerability: food source 1 = vegetables, nectar, seeds, fruits; food source 2 = soil, detritus, waste material; food source 3 = insect, soil organisms, vertebrate herbivores; food source 4 = vertebrate carnivores.

Traditional ecotoxicological testing in the laboratory is strongly focussed on toxicological sensitivity of species to particular contaminants, as represented by main category C. The duration of standardised acute tests and of most chronic tests is not long enough to ensure that internal regulation mechanisms reach equilibrium during the test. The recommended test duration in EPA and OECD guidelines for acute toxicity is between 24 and 96 hours, which is only a fraction of maximum life span for most vertebrate species. Chronic toxicity tests are usually much less than half of the maximum life span of the tested animal (see also Luttik, 2003). Thus, main category B characteristics are likely to be misrepresented by traditional ecotoxicological laboratory tests. The multi-criteria vulnerability analysis therefore potentially has a wider scope.

The vulnerability analysis was developed for different types of contaminants, since contaminants may have different fates and behaviour in the environment, in biota, and in food webs. Therefore, the magnitude of each species characteristic contributing to ecological vulnerability may depend on the contaminant. This is incorporated in the MCA method by using different weight factors for each characteristic, depending on contaminant type.

We selected the contaminants for this study with consideration for differences in internal regulation potential, bioaccumulation potential, persistence in the environment, and toxicity. The following contaminants were selected, each representing a distinct scenario in contaminants and emission routes (Table 4):

- essential metals copper and zinc, with low to medium toxicity;
- non-essential metal cadmium, with high toxicity;
- persistent organic pesticide DDT, with high toxicity;
- persistent organophosphate insecticide chlorpyrifos, with medium toxicity;
- persistent veterinary pharmaceutical ivermectin, with low to medium toxicity.

The metals copper, zinc and cadmium and the pesticide DDT had previously been studied for a smaller set of species (Faber *et al.*, 2004a). These contaminants have a diffused distribution in the Netherlands, with local differences in concentration. Chlorpyrifos and ivermectin were considered appropriate additions, since these represent a previously used pesticide of wide application, and a widely used anthelmintic veterinary pharmaceutical. The field distribution of these two contaminants is more localised, and can be very different between plots. The latter two were chosen from the NOMIRACLE project test substances list.

Table 4. Matrix of chemicals and risk scenarios.

Contaminant type	Exposure site		
	in soil	in water	at soil surface
Essential metal	copper, zinc	copper, zinc	
Non-essential metal	cadmium	cadmium	
Persistent organic pollutant	DDT	DDT	
Degradable organic pollutant	chlorpyrifos, ivermectin	(chlorpyrifos)	chlorpyrifos, ivermectin

Calculation of vulnerability

Vulnerability scores were calculated per species using the multi-criteria analysis software program BOSdA (Janssen *et al.*, 2000). 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 135 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. This calculation was done for each characteristic; an example is given in Box 1.

Box 1. Calculation of vulnerability scores.

The characteristics used in the multi-criteria analysis have different scales and different ranges. A comparison of the characteristics can only be executed when all values are standardised to a single unit. After standardisation all values lose their dimension. Scale-types are ratio scale for variables (the relative meaning is proportional with the value), interval scale for categories (only differences between values have a meaning, there is no useful zero value for this aspect), and binary scale (yes/no) (see Table 2).

Values on a ratio scale are standardized to a maximum: the values are linearly related to a value between 0 and 1. For a characteristic with an increasing effect on vulnerability, the highest value in the range is equalled to 1, and all the other values are relatively scaled to this value. For a characteristic with a decreasing effect on vulnerability, the standardization is reversed. Maximum values are equalled to 0, and all other values are relatively scaled between 0 and 1.

Values on an interval scale are standardized by intervals with the highest value equalled to 1 and the lowest to 0, again for a characteristic with increasing effect on vulnerability.

Binary scale values do not need to be standardized, since they are already standardized to 0 or 1.

Example: calculation of scores for the characteristic maximum life span.

It is judged that vulnerability increases with longevity (see Table 3). This characteristic has a ratio scale and is therefore standardized against a maximum. The maximum value (600 months) is positioned on 1, and all other values are proportionally related to 1 by the following calculation:

Score = species value/maximum value.

For the bird species Common Tern (Sterna hirundo, BIRD50), with a maximum life span of 300 months, this results in the following score: 300/600 = 0.5. The fish species Bullhead (Cottus gobio, FISH7) has a maximum lifespan of 60 months, this results in a score of 60/600 = 0.1.

These calculations are repeated for all species and every characteristic. The contribution of each characteristic to vulnerability is expressed by a weight factor, which was estimated by experts. The scores per species are then multiplied by the respective weight factor and added to arrive to the final score for that species.

The next step is to determine the contribution of each characteristic to species vulnerability. This was expressed by a weight factor, which was estimated by experts. The calculated score for each characteristic (see example in Box 1) was multiplied by its weight factor (depending on contaminant, see Table 3). The weighed scores for each characteristic were then summed to obtain a final score. This final score was used to rank species by relative order of vulnerability.

The weight factors were determined relatively to a 100% within each category, and are dependent on the type of contaminant. For secondary poisoning substances food choice was considered important, while for metabolically well-regulated substances, habitat choice is more important. For example, external exposure to copper was judged to be related to habitat exposure only; habitat choice, size of home range,

hibernation, and season-dependent presence were therefore judged important characteristics. Other characteristics in this category describing food choice and life span were not considered important, since copper is an essential element with little bioaccumulating potential. The six tested chemicals have different internal regulation mechanisms and bioaccumulation potentials. Copper and zinc were thought to act similarly and the same weights were used (Faber *et al.*, 2004a). The weight factors are presented in Table 3, with detailed justification in Appendix 4. Since we used the same dataset for the vulnerability analysis for all test chemicals, the vulnerability assessment may be compared between scenarios.
Obviously, the availability of information on toxicological sensitivity is limited for the species in our dataset. Given this restriction we therefore chose to exclude main category C from our analysis (*i.e.* weight 0). We tentatively judged categories to be equally important, therefore the remaining categories were given a third of the total weight (0.333). If more toxicological data would become available, these may be easily incorporated and the weights for categories be adjusted accordingly. We have done so as a means to test the robustness of the method (Chapter 4).

3.2 Vulnerability ranking

The multi-criteria analysis (MCA) results in a score for each species, and these scores are used to rank the 135 species from most vulnerable (top rank, highest score) to least vulnerable (bottom rank, lowest score) for a particular 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', using the weights given in Table 3. Detailed results for each species and contaminant are given in Appendices 5-10.

3.2.1 Which species are vulnerable?

The ten most vulnerable and five least vulnerable species for each contaminant are presented in Table 5. Results for zinc and copper are combined, since the same weights were used in the MCA. The vulnerability scores and rankings are semi-quantitative, and should be interpreted as such. We arbitrarily chose to display the ten most vulnerable species and five least vulnerable species.

Zinc and copper
Within the database of 135 species Bullhead (*Cottus gobio*, FISH7) was amongst the species most vulnerable to zinc and copper. This is a small, sediment-dwelling fish which feeds on benthic invertebrates. Other top vulnerable species were found amongst fish, amphibians and dragonflies, and the European Mole (*Talpa europaea*, MAMa) (Table 5). In overview these species share habitat preferences for sediment, soil or water, exhibit a year-round residence, and do not hibernate. Further, they are characterized by a very low dispersive capacity and show territorial behaviour. As shown by ANOVA analysis compared over all groups, dragonflies and amphibians

were the taxonomic groups with on average a high vulnerability to zinc and copper; birds had on average a low vulnerability (Figure 5).

Cadmium
Common Tern (*Sterna hirundo*, BIRD50) was amongst the species most vulnerable to cadmium. This is a fish-eating, migrating bird with low reproduction traits. Other top vulnerable species were found amongst birds and mammals, and the Slow Worm (*Anguis fragilis*, REP3) (Table 5). All are predacious, preying on both herbivorous and carnivorous vertebrates, thus representing high trophic levels in the food web. They have in common a long lifespan, hibernation (except for the bird species), and a varying period of residence during the year.
As shown by ANOVA analysis compared over all taxonomic groups, reptiles, mammals and amphibians showed on average a high vulnerability to cadmium; butterflies on average had a low vulnerability (Figure 5).

DDT
Slow Worm (*Anguis fragilis*, REP3) was amongst the species most vulnerable to DDT. This is a long-lived reptile with a small home range and low dispersive capacity. Other top vulnerable species included reptiles and amphibians, Common Tern (*Sterna hirundo*, BIRD50) and Greater Mouse-eared Bat (*Myotis myotis*, MAM6) (Table 5). The top 10 species were characterized by a long lifespan, a year-round residence, hibernation (except Common Tern), and a low dispersive capacity. As was the case for cadmium, species vulnerable to DDT are all predators of herbivorous and carnivorous vertebrates, and represent high trophic levels in the food web. As shown by ANOVA analysis compared over all taxonomic groups, reptiles and amphibians showed on average a high vulnerability to DDT; birds, mammals, butterflies and fish appeared to have a low vulnerability (Figure 5).

Chlorpyrifos
Slow Worm (*Anguis fragilis*, REP3) was amongst the species most vulnerable to chlorpyrifos. Other vulnerable species were mostly reptiles and amphibians, but there was also a fish species, two mammals and a butterfly in the top 10 (Table 5). They all have habitat preferences for soil and vegetation, low food demands, a year-round residence, and low dispersive capacities. As shown by ANOVA analysis compared over all groups, reptiles and amphibians showed on average a high vulnerability to chlorpyrifos; birds on average had a low vulnerability (Figure 5).

Ivermectin
Slow Worm (*Anguis fragilis*, REP3) was amongst the species most vulnerable to ivermectin. Other vulnerable species belonged to various taxonomic groups, namely reptiles, mammals, butterflies, amphibians and fish (Table 5). They all have a habitat preference for soil, except for Bullhead (*Cottus gobio*, FISH7). Further, they have a year-round residence, low food demands, and low dispersive capacities. As shown by ANOVA analysis compared over all groups, reptiles showed on average a high vulnerability to ivermectin; birds and fish on average had a low vulnerability (Figure 5).

Summarizing results of the vulnerability ranking
The following generalizations can be made when the characteristics of the most vulnerable species of the different contaminants are compared:

- species vulnerable to cadmium or DDT had a longer maximum lifespan, and species vulnerable to copper or zinc had a shorter maximum lifespan;
- species vulnerable to cadmium had a lower life time reproduction, and species vulnerable to copper or zinc had a higher life time reproduction;
- species vulnerable to copper, zinc or ivermectin had a lower survival to first reproduction, and species vulnerable to cadmium had a higher survival to first reproduction;
- species vulnerable to cadmium had a higher Field Metabolic Rate.

These differences can be summarized as follows: species vulnerable to copper/zinc can be classified as r-strategists, and species vulnerable to cadmium and DDT can be classified as K-strategists; species vulnerable to ivermectin and chlorpyrifos are intermediate.

Table 5. Top 10 and bottom 5 species with MCA scores for zinc/copper, cadmium, DDT, chlorpyrifos and ivermectin. See Appendix 1 for scientific names.

Rank	Zinc/Copper			Cadmium			DDT			Chlorpyrifos			Ivermectin		
	Species	Code	Score	Species	Code	Score	Species	Code	Score	Species	Code	Score	Species	Code	Score
1	Bullhead	FISH7	0.58	Common Tern	BIRD50	0.56	Slow Worm	REP3	0.53	Slow Worm	REP3	0.58	Slow Worm	REP3	0.58
2	Stone Loach	FISH2	0.56	Great Reed Warbler	BIRD13	0.53	Viviparous Lizard	REPa	0.52	Viviparous Lizard	REPa	0.58	Viviparous Lizard	REPa	0.57
3	Alpine Newt	AMPH1	0.55	Greater Mouse-eared Bat	MAM6	0.52	Alpine Newt	AMPH1	0.52	Alpine Newt	AMPH1	0.55	European Mole	MAMa	0.55
4	Palmate Newt	AMPH6	0.54	Oystercatcher	BIRDh	0.52	Palmate Newt	AMPH6	0.51	Sand Lizard	REP5	0.54	Sand Lizard	REP5	0.54
5	Great Crested Newt	AMPH3	0.54	Geoffroy's Bat	MAM5	0.52	Great Crested Newt	AMPH3	0.51	Palmate Newt	AMPH6	0.54	Alcon Blue	BFLY2	0.53
6	Scarce Chaser	DFLY5	0.53	White Stork	BIRD30	0.52	Sand Lizard	REP5	0.49	Bullhead	FISH7	0.54	Alpine Newt	AMPH1	0.53
7	European Mole	MAMa	0.53	Badger	MAM1	0.51	Common Tern	BIRD50	0.49	Great Crested Newt	AMPH3	0.54	Bullhead	FISH7	0.52
8	Green Hawker	DFLY2	0.52	European Mole	MAMa	0.51	Common Adder	REP1	0.48	European Mole	MAMa	0.53	Palmate Newt	AMPH6	0.52
9	Norfolk Damselfly	DFLY4	0.51	Slow Worm	REP3	0.50	Poolfrog	AMPHa	0.48	Large Chequered Skipper	BFLY19	0.53	Great Crested Newt	AMPH3	0.51
10	Catfish	FISH4	0.51	Hen Harrier	BIRD3	0.50	Greater Mouse-eared Bat	MAM6	0.47	Geoffroy's Bat	MAM5	0.52	Dusky Large Blue	BFLY7	0.51
131	Large White	BFLYb	0.27	Large Tortoiseshell	BFLY11	0.28	Large White	BFLYb	0.27	Spoonbill	BIRD26	0.29	Greylag Goose	BIRD9	0.26
132	Ruff	BIRD17	0.26	Allis Shad	FISH3	0.25	Field Vole	MAMd	0.27	Pintail	BIRD34	0.27	Red Kite	BIRD39	0.26
133	Brimstone	BFLYc	0.26	Large White	BFLYb	0.24	Bank Vole	MAMc	0.26	Twaite Shad	FISH5	0.26	Brimstone	BFLYc	0.25
134	Red Admiral	BFLYa	0.24	Brimstone	BFLYc	0.23	Brimstone	BFLYc	0.25	Allis Shad	FISH3	0.23	Red Admiral	BFLYa	0.24
135	Red Kite	BIRD39	0.24	Red Admiral	BFLYa	0.22	Red Admiral	BFLYa	0.24	Greylag Goose	BIRD9	0.21	Allis Shad	FISH3	0.24

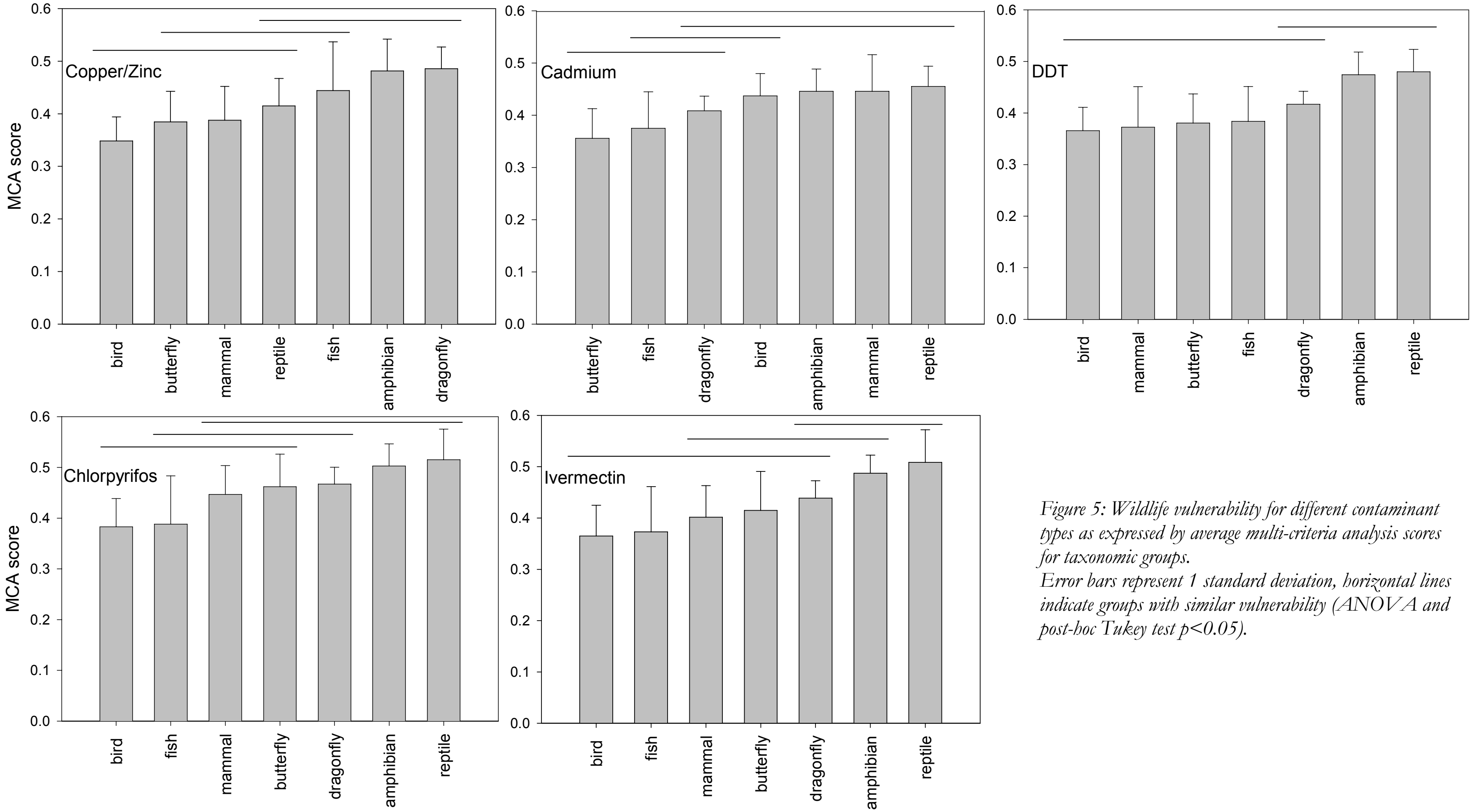

Figure 5: Wildlife vulnerability for different contaminant types as expressed by average multi-criteria analysis scores for taxonomic groups.
Error bars represent 1 standard deviation, horizontal lines indicate groups with similar vulnerability (ANOVA and post-hoc Tukey test p<0.05).

3.2.2 How important is population resilience?

Characteristics in main category D describe the population resilience or recovery potential after disturbance. The weights used within this main category to rank the species are independent of the contaminant of interest. The top 10 of most vulnerable species and bottom 5 least vulnerable species for main category D are given in Table 6. The most vulnerable species for main category D, in other words the species with the least population recovery potential, are a damselfly (Green Hawker, *Aeshna viridis*, rank 1), reptile species (Viviparous Lizard, *Lacerta vivipara*, rank 2, and Sand Lizard, *Lacerta agilis*, rank 5), an amphibian species (Alpine Newt, *Triturus alpestris*, rank 3), and a bird species (Great Reed Warbler, *Acrocephalus arundinaceus*, rank 4). Ranks 6 to 10 are all butterflies. The high scores mainly result from high age at first reproduction, low survival rates to first reproduction, low dispersive capacities and patchy distributions.

Table 6. Top 10 and bottom 5 species with vulnerability score for main category D; and portion of main category D in final score for each contaminant. See Appendix 1 for scientific names.

Rank	Species	Code	Score	Portion of final score (%)				
				zinc/ copper	cad- mium	DDT	chlor- pyrifos	iver- mectin
1	Green Hawker	DFLY2	0.79	51	61	61	55	56
2	Viviparous Lizard	REPa	0.78	54	53	50	45	45
3	Alpine Newt	AMPH1	0.76	46	52	49	46	48
4	Great Reed Warbler	BIRD13	0.74	59	47	53	47	52
5	Sand Lizard	REP5	0.74	55	53	50	45	46
6	Dusky Large Blue	BFLY7	0.74	56	57	53	47	49
7	Scarce Large Blue	BFLY16	0.74	56	57	53	47	49
8	Alcon Blue	BFLY2	0.74	51	58	58	47	47
9	Large Chequered Skipper	BFLY19	0.74	59	63	59	47	58
10	Brown Hairstreak	BFLY18	0.74	61	66	62	48	60
131	Red Admiral	BFLYa	0.31	43	47	43	34	43
132	Red Kite	BIRD39	0.29	40	23	27	31	38
133	Ruff	BIRD17	0.29	37	27	33	31	37
134	Shoveler	BIRD43	0.29	31	27	35	30	28
135	Brimstone	BFLYc	0.28	36	41	38	31	37

The average contribution of main category D in the final score is roughly 45% (Table 7). For species with high scores in main category D (Table 6), this portion is even larger and may range between 45 to 60%. When scores per main category are compared with total scores using Spearman's rank correlation, main category D has the strongest correlation with the overall integrated score. From this it can be concluded that main category D contributes more to vulnerability than external or internal exposure. However, for cadmium the strongest correlation with final score is for main category A.

Table 7. Average scores of main category D as percentage of total vulnerability scores, expressed per taxonomic group. Spearman's ϱ rank correlation coefficients between main category D scores and total scores are given.

Taxonomic group	Zinc/ Copper % total	Cadmium % total	DDT % total	Chlorpyrifos % total	Ivermectin % total
Birds	45	36	43	42	44
Butterflies	53	57	54	44	50
Mammals	45	39	47	39	43
Fish	43	49	49	49	49
Amphibians	46	49	46	42	44
Dragonflies	45	51	50	46	50
Reptiles	52	48	46	42	43
Overall average	47	44	47	43	46
Spearman's ϱ	0.83 P<0.001	0.35 P<0.001	0.80 P<0.001	0.81 P<0.001	0.79 P<0.001

3.2.3 Robustness of the MCA results

The weights given to each main category were determined by expert judgement. A sensitivity analysis was performed to test the sensitivity of the calculated vulnerability score for changes in weight between categories, using the Sensitivity routine in the BOSdA program (Janssen *et al.*, 2000). The change in weights for each main category that is needed to change the original ranking was calculated for:
1) displace the original number one in rank from the first place by any other species;
2) place the original number five in rank as new number one;
3) place the original number 10 in rank as new number one.

The sensitivity was calculated as the distance between the original weight vector and the new weight vector. The distance is expressed on a relative scale without units, and can only be used for comparison within the same dataset. A long distance indicates a low sensitivity to changes in weight; a short distance indicates a high sensitivity to changes in weight (Table 8).

Table 8. Results of sensitivity analysis MCA: distance between original weight vector and new weight vector to replace number 1, put number 5 on 1, or to put number 10 on 1; nv indicates no valid vector.

Contaminant	New number 1	Original number five on 1	Original number 10 on 1
Zinc/Copper	0.061	nv	nv
Cadmium	0.150	0.299	nv
DDT	0.021	nv	nv
Chlorpyrifos	0.034	nv	nv
Ivermectin	0.044	nv	nv

The rankings proved rather robust to changes in weights. It was relatively easy to replace the original number one, usually by the number 2 in rank. But in all but one case it was not possible to put the number 5 in rank on number 1, or to put the number 10 in rank on number 1.
The effect that changes in weight can have on species ranking is visualized by an example for cadmium (Figure 6). Main category C has only one characteristic, which

has four different scores. From Figure 6 it becomes clear that if main category C is given a weight of 1, the final score is fully determined by the score for this category, and the species lines diverge and form four groups. The species lines in main category D have a more scattered picture, with diverging, converging, and parallel patterns. A change in weight for this main category (as represented by the vertical line) will result in a different species ranking.

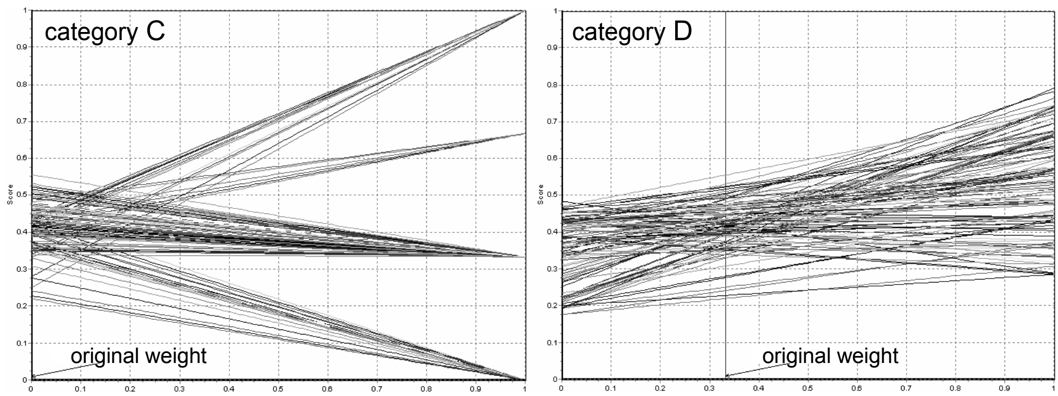

Figure 6. Effect of a change in weight (x-axis) on cadmium MCA scores (y-axis) for the 135 species in our dataset, each line represents a species. The vertical line indicates the original weight, 0 for main category C and 0.33 for main category D.

4 Vulnerability predictions using ecological characteristics

We have analysed our dataset of 135 species with ecological characteristics in two fundamentally different ways:

1. Grouping by principal component analysis using *mathematical relations* to calculate ordination diagrams of species and characteristics based on a *correlation* matrix of the characteristics; *i.e.* analyzing how the species and their traits cluster together.
2. Multi-criteria analysis of characteristics by different *weights* as assigned by *expert judgement*.

In this chapter the results of these analyses are combined to further identify major determinant traits for ecological vulnerability in view of selected chemicals scenarios. First we identify groups of species in the ordination diagram with similar vulnerabilities for a particular chemical. We then compare this with the ordination direction of characteristics, to identify characteristics that are associated with vulnerable species. Major determinant characteristics are indicated by agreement between ordination directions of characteristics and the vulnerability of species possessing such characteristics as obtained from MCA.

4.1 Ecological characteristics and vulnerability

4.1.1 Is vulnerability related to ecological characteristics?

The results from multi-criteria vulnerability analysis may be combined with the species ordination results to assess which traits correlate with vulnerability for specific contaminants. The species ordination plot (Figure 2B) was redrawn with colour markings to indicate categories in vulnerability; thus each symbol in the plot represents a species and the colour now indicates vulnerability (Figures 7-11). Note that the species ordination is similar to Figure 2. The only difference between the figures is the colour of each symbol, representing vulnerability to one of the six test chemicals. We then compared segregation of colours with the ordination of characteristics (Figure 2A). Characteristics that correspond with the vulnerability scores and strongly affect the ordination (*i.e.* furthest away from origin) are presented in the graphs as black diamonds (position in ordination) and arrows (direction of effect).

Copper and zinc

There was a diagonal segregation between high vulnerability (red symbols) and low vulnerability (open symbols) for copper and zinc, with the red symbols all located in the upper right half, and the white symbols in the lower left half (Figure 7). A high vulnerability score (red symbols) co-occurred with preference for aquatic habitat (habitat 5), large life time reproduction (R), and large clutch size. A low vulnerability score (green and open symbols) co-occurred with high survival to first reproduction, a preference for plant-derived food (food 1), and duration of adult stage (stage 3).

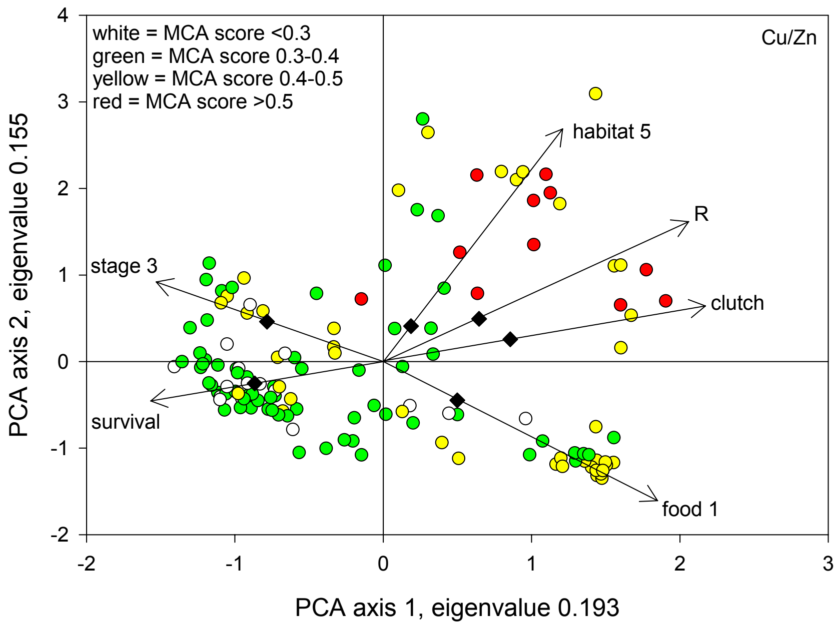

Figure 7. Species ordination of the total dataset, using a colour code for each species to indicate the vulnerability score for copper/zinc; ordination of selected characteristics is shown using black diamonds and arrows, where the distance of the diamond from the origin indicates the importance of the characteristic, the arrow indicating the direction.

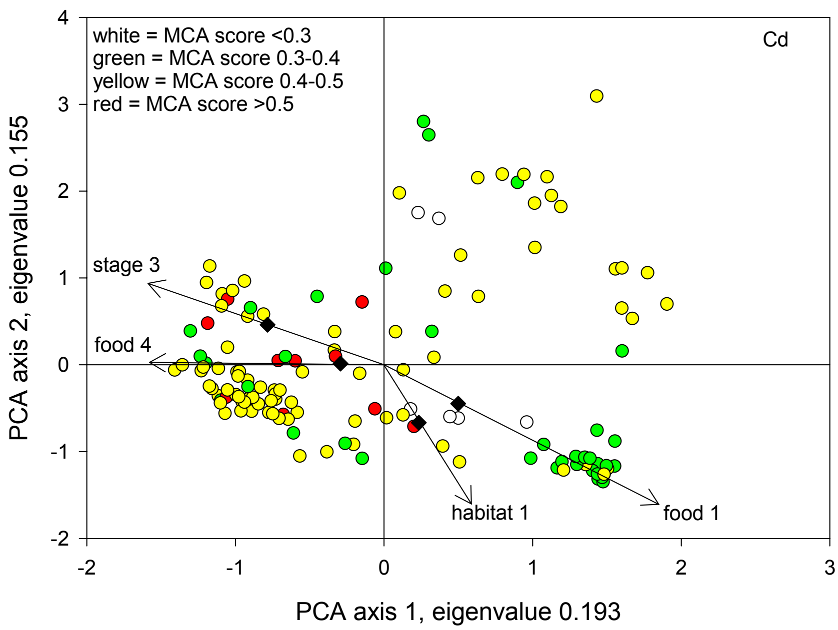

Figure 8. Species ordination of the total dataset, using a colour code for each species to indicate the vulnerability score for cadmium; ordination of selected characteristics is shown using black diamonds and arrows, where the distance of the diamond from the origin indicates the importance of the characteristic, the arrow indicating the direction.

Cadmium

There was a vertical segregation in high vulnerability (red symbols) and low vulnerability (open symbols), with the red symbols roughly located in the left half of the graph, and the white symbols located in the right half of the graph (Figure 8). This is roughly the r/K-strategy axis, indicating that K-strategic species on the left are more vulnerable to cadmium than r-strategic species on the right. A high vulnerability score for cadmium (red symbols) co-occurred with duration of adult stage (stage 3), and preference for carnivorous vertebrates as prey (food 4). A low vulnerability score (open symbols) co-occurred with preference for plant-derived food (food 1), and preference for vegetation as habitat (habitat 1).

DDT

There was no clear segregation between high and low vulnerability scores (red and white symbols); correlating characteristics with high or low vulnerability is therefore not possible (Figure 9). A high vulnerability score for DDT (red symbols) seemed to be associated with preference for sediment as habitat (habitat 5), a preference for carnivorous vertebrates as prey (food 4), and a long juvenile stage (stage 2). A low vulnerability score (green symbols) seemed to be associated with a preference for plant-derived food (food 1), high survival to first reproduction, high dispersive capacities, large home range and a preference for vegetation as habitat (habitat 1).

Chlorpyrifos

There was a diagonal segregation between high vulnerability (red symbols) and low vulnerability (open symbols), with the open symbols all located in the upper left half, and the red symbols roughly in the lower right half (Figure 10). This roughly corresponds with the r/K strategy axis; K-strategic species on the left are less vulnerable to chlorpyrifos than r-strategic species on the right. A high vulnerability score for chlorpyrifos (red symbols) co-occurred with a preference for vegetation as habitat (habitat 1) a preference for soil as habitat (habitat 4), a preference for plant-derived food (food 1), and a long juvenile stage (stage 2). A low vulnerability score (open and green symbols) co-occurred with a preference for aquatic habitat (habitat 3), large body weight and high dispersive capacities.

Ivermectin

There was no clear segregation between high and low vulnerability scores (red and open symbols), correlating characteristics with high or low vulnerability was therefore not possible (Figure 11). A high vulnerability score for ivermectin (red symbols) seemed to be associated with a preference for soil as habitat (habitat 2 and 4). A low vulnerability score (open symbols) seemed to be associated with high survival to first reproduction, high dispersive capacities, large adult body weight, and large home range.

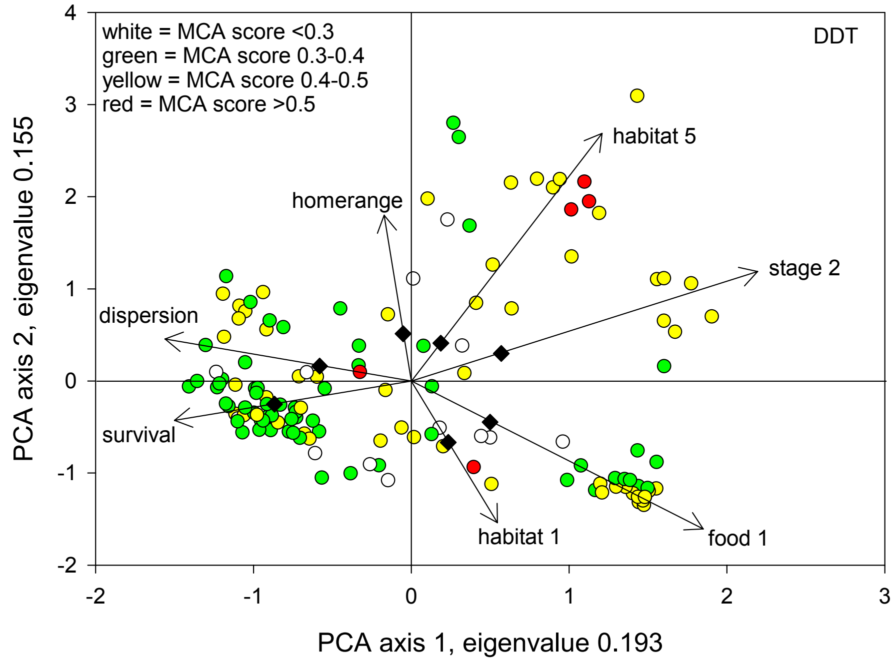

Figure 9. Species ordination of the total dataset, using a colour code for each species to indicate the vulnerability score for DDT; ordination of selected characteristics is shown using black diamonds and arrows, where the distance of the diamond from the origin indicates the importance of the characteristic, the arrow indicating the direction.

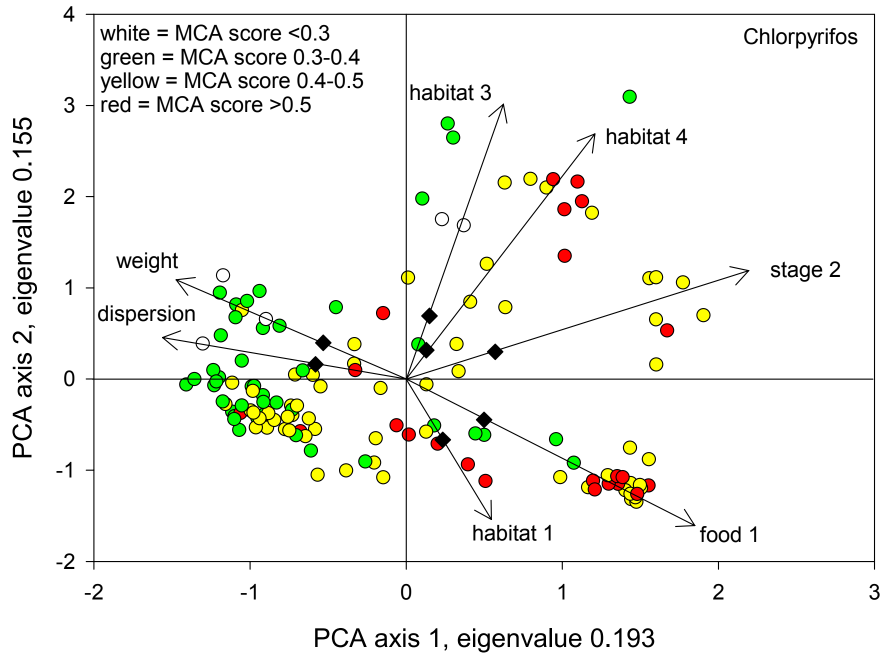

Figure 10. Species ordination of the total dataset, using a colour code for each species to indicate the vulnerability score for chlorpyrifos; ordination of selected characteristics is shown using black diamonds and arrows, where the distance of the diamond from the origin indicates the importance of the characteristic, the arrow indicating the direction

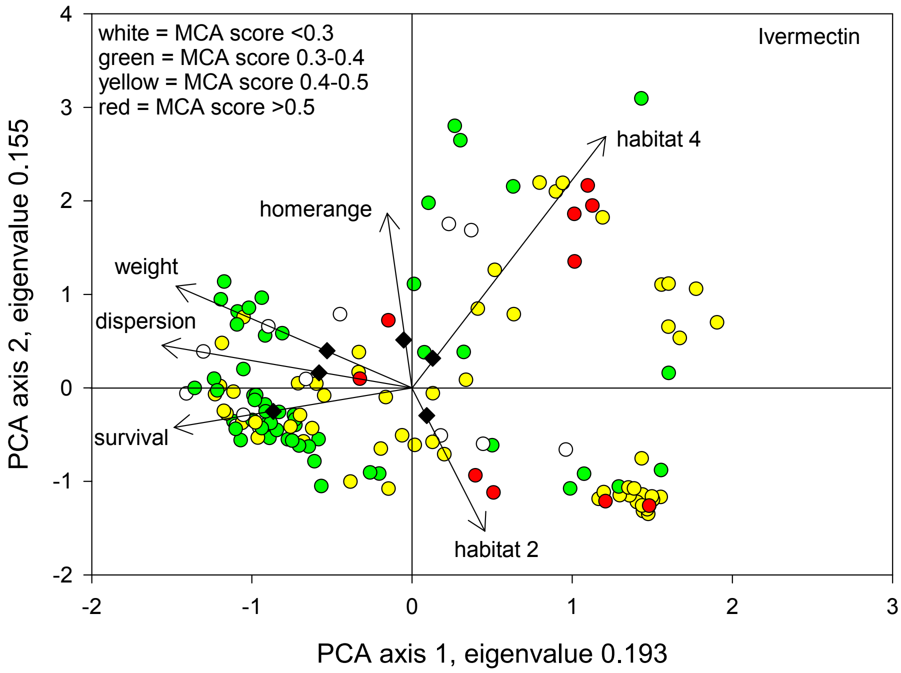

Figure 11. Species ordination of the total dataset, using a colour code for each species to indicate the vulnerability score for ivermectin; ordination of selected characteristics is shown using black diamonds and arrows, where the distance of the diamond from the origin indicates the importance of the characteristic, the arrow indicating the direction.

4.1.2 What characteristics predict vulnerability to contaminants?

The coupling between vulnerability scores and PCA ordination gave reasonable results for copper/zinc, cadmium and chlorpyrifos (Table 9). Ordination results corroborated the expert judgement: characteristics indicative of low or high vulnerability were given a large weight in the MCA. For essential metals, exposure through habitat is a risk factor. For non-essential metals (cadmium), separation of low *vs.* high vulnerability corresponds with the r *vs.* K-strategy, with K-strategists having a higher vulnerability than r-strategists. The separation of low *vs.* high vulnerability for chlorpyrifos was reversed: r-strategic species were more vulnerable than K-strategic species.
Comparing Figures 7 to 11 with each other it seems that species which are vulnerable to cadmium (vulnerable species are located in the left half of the ordination), are generally not vulnerable to the other scenario chemicals (vulnerable species are mostly located in the right half of the ordination), and *vice versa*.
The coupling between vulnerability scores and PCA ordination is less clear for DDT and ivermectin. For these two contaminants, factors correlated with low vulnerability are in main category D. This may indicate that population resilience gives a basic level of resistance against disturbances.

Table 9. Summary of indicative characteristics.

Contaminant	Main characteristic indicative for vulnerability
Copper/Zinc	habitat choice
Cadmium	r-strategy = low vulnerability, K-strategy = high vulnerability; higher trophic level = high vulnerability
DDT	population resilience reduces vulnerability
Chlorpyrifos	habitat choice; r-strategy = high vulnerability, K-strategy = low vulnerability
Ivermectin	population resilience reduces vulnerability

4.2 Ecological and toxicological significance of the vulnerability ranking

Are the results of the vulnerability analysis in line with current knowledge and risk assessment? Does our method truly identify the most vulnerable species? It is important to evaluate and validate the vulnerability ranking results to answer such questions. This is not easy, since results from vulnerability analysis and available toxicological sensitivity data are fundamentally different.
Below we compare the vulnerability results with known toxicological sensitivities, using two approaches:

1. Consistency with field observations
2. Comparison with (laboratory) toxicological sensitivity data

4.2.1 Consistency with field observations

Our approach for validation of results of vulnerability ranking is to compare with field observations. Alternative ways of validation (or falsification) seem unavailable. We checked for consistency with field data in two ways:

- *Consistency*
  Are there known examples of species that suffer effects from a known (single) contaminant in the field, and appear vulnerable from our analysis?
  This would corroborate the vulnerability analysis results.
- *Inconsistency*
  Are there effects in the field known for wildlife species that have low vulnerability in our analysis?
  This would at least falsify expert judgement at critical points in the MCA.

One must realize that there is a certain bias in field observations. Certain wildlife species are 'popular', such as (predatory) birds (Little Owl, Common Tern) and mammals (Badger, Otter); less often studied species may experience larger field effects. Thus, literature data may not reveal the most vulnerable species.

There is a certain degree of agreement amongst scientists which (type of) species are most vulnerable to certain contaminants. We make a comparison between these expert judgements and results of the MCA vulnerability analysis. One must keep in mind that input of our MCA was also based on expert judgement, in some cases the same expert judgement as used here to validate the results. Nevertheless, the comparison is worthwhile since it will give information on the performance of the method. We provide the results on a case by case evaluation.

Pesticides
Pesticide use has been hypothesized as one of the causes of observed amphibian and reptile decline (Gibbons *et al.*, 2000; Davidson, 2004). This is in agreement with our vulnerability ranking, where amphibians and reptiles are the most vulnerable groups for DDT and chlorpyrifos. However, it remains largely unknown to which degree contaminants may cause effects in amphibian and reptile populations (Gibbons *et al.*, 2000).
Bats are considered susceptible to pesticides, even though there has been very little research done, and effects other than mortality are not studied (Clark & Shore, 2001). Our vulnerability results indicate that the Greater Mouse-eared Bat (*Myotis myotis*, MAM6) is vulnerable to DDT, and Geoffroy's Bat (*Myotis emarginatus*, MAM5) is vulnerable to chlorpyrifos.

Bioaccumulating substances
Bioaccumulating substances, such as cadmium and DDT, are expected to cause effects especially in top predators, with long life spans, and K-strategy life history traits. This is very much in agreement with our vulnerability ranking; the most vulnerable species were all predators with a high trophic level in food web, and K-strategy characteristics.

Field data for mammals indicate that the Badger (*Meles meles*, MAM1) and the European Mole (*Talpa europaea*, MAMa) are sensitive to cadmium. It was shown that elevated cadmium concentrations in soil are associated with a reduced population recovery rate in Badger, as result of reduced reproduction (Van den Brink & Ma, 1998). The European Mole is also known to be affected by soil cadmium (Ma, 1987). Our results show that both species are ranked in the top10 of most vulnerable species to cadmium, which is in agreement with field data.

The limited information available on cadmium toxicity to bats in the field indicates that cadmium had a negative effect on population of the Alabama Grey Bat (*Myotis grisescens*) (Clark & Shore, 2001). This is in agreement with our vulnerability analysis, where two bat species, Greater Mouse-eared Bat (*Myotis myotis*, MAM6) and Geoffroy's Bat (*Myotis emarginatus*, MAM5), both also belonging to the *Myotis* genus, were ranked as vulnerable to cadmium.

A well-known effect of DDT is eggshell thinning in birds of prey, with disastrous effects on populations (Wienemeyer & Porter, 1970). However, our vulnerability ranking does not mirror this. Specific toxicity effects with such strong population impact as eggshell thinning are potentially overlooked, as toxicity data were not incorporated in the vulnerability analysis. While a single bird species occurred in the DDT vulnerability top 10, *viz*. Common Tern (*Sterna hirundo*, BIRD50), this particular result was based on other ecological characteristics, such as high position in food web, migratory activity, and low reproduction.

Essential metals
For essential metals exposure through habitat is estimated as the most important factor to determine vulnerability. This is in agreement with the vulnerability ranking for zinc and copper; the most vulnerable species were water, sediment or soil inhabiting species, thus with higher direct exposure to contaminants.

Pharmaceuticals
The hazard of pharmaceutical residues in the environment is an emerging area of concern. Presently there is only limited literature on the effects of pharmaceuticals on non-target organisms (for review see *e.g.* Boxall *et al.*, 2004; Lahr, 2004). For some substances, detailed information of detrimental effects is available. Residues of veterinary diclofenac in livestock are high enough to result in renal failure and mortality in vultures feeding on the carcasses, causing a decline in vulture population in Pakistan (Oaks *et al.*, 2004). The widely used anthelmintic ivermectin is recognized to affect non-target organisms; ivermectin residues in dung from treated livestock are detrimental to dung insects. This is expected to have indirect effects on vertebrate wildlife species that feed specifically on dung insects such as certain species of birds and bats (McCracken, 1993). This expectation could not be tested by our vulnerability analysis, since our method does not incorporate indirect effects such as decrease in food.

4.2.2 Comparison with toxicological sensitivity

The results of the vulnerability ranking were compared with incidental literature data on toxicological sensitivity. First we assessed whether the average vulnerability for each taxonomic group had the same direction as toxicological sensitivity per group. For this we ranked the average vulnerability score (as shown in Figure 5) for each taxonomic group and compared this with the toxicological sensitivity for each taxonomic group, using rank correlation analysis (Spearman's ϱ). Toxicological sensitivity was described with a score from 1 to 4, see § 4.3 for further description.
Toxicological sensitivity is one aspect of ecological vulnerability. It may have a different direction than the other aspects (exposure, toxicokinetics, and population resilience). In our vulnerability scores we did not yet incorporate toxicological sensitivity, for general lack of data.

A significant correlation between ecological vulnerability and toxicological sensitivity was observed for zinc and copper (Table 10). The correlation for ivermectin suggests a trend ($p<0.10$). This may indicate that for these substances toxicological sensitivity and ecological vulnerability are determined by (or at least correlated with) the same traits. It may also indicate that toxicological effects are not counteracted by limited exposure or potential population resilience.

By contrast, for DDT, cadmium and chlorpyrifos the correlation is not significant (Table 10). This could mean that negative toxicological effects can perhaps be mitigated in the field by limited exposure, efficient detoxification/excretion, and/or population resilience. It also indicates that for these contaminants the rankings may change considerably if the main main category C (Effects on individual level) should also be incorporated with an equal weight of 0.25 (see § 4.3 for further discussion).

Table 10. Comparison of rank of average vulnerability score for taxonomic groups and toxicological sensitivity (tox class), using Spearman's correlation coefficient ϱ with significance values, ns indicates not significant.

Taxonomic group	Rank MCA score	Tox class	Taxonomic group	Rank MCA score	Tox class	Taxonomic group	Rank MCA score	Tox class
Zinc			*Copper*			*Cadmium*		
Bird	1	1	bird	1	1	butterfly	1	1
butterfly	2	1	butterfly	2	1	fish	2	4
mammal	3	1	mammal	3	1	dragonfly	3	4
reptile	4	1	reptile	4	1	bird	4	2
Fish	5	2	fish	5	3	amphibian	5	3
amphibian	6	2	amphibian	6	3	mammal	6	2
dragonfly	7	3	dragonfly	7	3	reptile	7	2
Spearman's ϱ	**0.896 (P<0.05)**			**0.866 (P<0.05)**			-0.094 (ns)	
DDT			*Chlorpyrifos*			*Ivermectin*		
Bird	1	2	bird	1	3	bird	1	2
mammal	2	1	fish	2	4	fish	2	2
butterfly	3	2	mammal	3	2	mammal	3	1
Fish	4	4	butterfly	4	2	butterfly	4	2
dragonfly	5	4	dragonfly	5	4	dragonfly	5	2
amphibian	6	4	amphibian	6	4	amphibian	6	3
reptile	7	2	reptile	7	2	reptile	7	3
Spearman's ϱ	0.501 (ns)			-0.077 (ns)			**0.697 (P<0.10)**	

The available LC_{50} or NOEC values for species in our dataset were also compared with the rank in the vulnerability analysis (Table 11). There are more LC_{50} values available for aquatic species, mostly fish, than for terrestrial species. There are not enough LC_{50} values available for chlorpyrifos and ivermectin to be able to make a comparison with MCA ranking.

In general, the vulnerability rank of aquatic species corresponded well with the LC_{50} values. Carp (*Cyprinus carpio*, FISHa) is less sensitive for zinc or copper than Stone Loach (*Noemacheilus barbatulus*, FISH2) or Three Spined Stickleback (*Gasterosteus aculeatus*, FISHb), and has a lower vulnerability ranking. Also for cadmium the order for aquatic species in LC_{50} values is in good agreement with the vulnerability ranking. Carp is the most sensitive species, and has the highest vulnerability ranking. Stone Loach and the Common Blue Damselfly (*Enallagma cyathigerum*, DFLYa) have a lower sensitivity, and a lower vulnerability ranking. By contrast, for DDT there is no agreement between LC_{50} and vulnerability rank; Stone Loach is most sensitive according to LC_{50}, but Carp has a higher vulnerability ranking.

For terrestrial species, Mallard Duck (*Anas plathyrynchos*, BIRDa) and Common Rat (*Rattus norvegicus*, MAMb), the comparison can only be made for cadmium and DDT. By contrast with the aquatic species there is no agreement between LC_{50} and vulnerability rank. In both cases the LC_{50} values suggest a higher sensitivity of Mallard Duck, but Common Rat has the highest vulnerability ranking.

Table 11. Comparison of toxicity values for species in the dataset, and their ranking in vulnerability analysis. See Appendix 1 for scientific names and Appendix 11 for literature references.

Chemical Wildlife species	Rank	LC_{50} (µg/L)	NOEC (µg/L)	LC_{50} (mg/kg food)	NOEC (mg/kg food)
Zinc					
Stone Loach	2	2500			
Great Crested Newt	5	3000			
Carp	29	7800			
Mallard Duck	88			3000	
Copper					
Stone Loach	2	260	120		
Three Spined Stickleback	11	227			
Common Rat	25				265
Carp	29	661	50		
Cadmium					
Carp	48	240			
Common Rat	53				10
Stone Loach	79	2000			
Mallard Duck	97			3065	1.6
Common Blue Damselfly	121	650000			
DDT					
Carp	22	110			
Stone Loach	42	11.5			
Common Rat	97				20
Ide	107	200			
Mallard Duck	120			875	3.3
Chlorpyrifos					
Carp	94	1.3			
Mallard Duck	129			190	80
Ivermectin					
Mallard Duck	126			570	80

4.3 Toxicological sensitivity incorporated in ecological vulnerability analysis

The MCA methodology was designed to incorporate toxicity data. Unfortunately, the availability of such data is limited, and therefore this main main category of characteristics was not incorporated in the present analyses. In this section we present the results of a pilot test where we *did* use the limited available data on toxicity to calculate the MCA. For this purpose, toxicity was classified on a scale of 1 to 4, from very slightly toxic, to highly toxic (after Canton *et al.*, 1991). This approach was chosen to circumvent incomparability in routes of exposure (*e.g.* water, food, soil) and concentration units (*e.g.* mg/L, mg/kg food, mg/kg body weight) between toxicological tests. The assumption needed to be made that toxicity is comparable within taxonomic groups, and that thus a single score can be assigned per group (Table 12).

Table 12. Toxicity class used in multi-criteria analysis: 1 = very slightly toxic, 2 = slightly toxic, 3 = moderately toxic, 4 = highly toxic (Canton et al., 1991). See Appendix 11 for references.

	Copper	Zinc	Cadmium	DDT	Chlorpyrifos	Ivermectin
Amphibians	3	2	3	4	4	3
Dragonflies	3	3	4	4	4	2
Reptiles	1	1	2	2	2	3
Fish	3	2	4	4	4	2
Butterflies	1	1	1	2	2	2
Birds	1	1	2	2	3	2
Mammals	1	1	2	1	2	1

For each contaminant separately the toxicity class was represented as a colour code in the species ordination plot (Figure 12). This illustrates that:

- Copper, zinc and ivermectin are moderately toxic at most (no red symbols).
- The highest toxicological sensitivity is observed in taxonomic groups which are (part of their life) aquatic (fish, dragonflies and amphibians). These groups are located in the upper right quadrant.
- The highest toxicological sensitivity for ivermectin is ascribed to amphibians and reptiles. One must realize that there is very little toxicological data available for ivermectin (see Appendix 11).

The toxicity classes were used in the multi-criteria vulnerability analysis, as inputs for main category C. This main category was weighed 0.05, approximating the weight for equal representation, as toxicity was one of 21 aspects in total. The other three main categories were given equal weights (0.317). The sensitivity score was based on limited toxicological data, mostly for species that were not included in our dataset. We therefore considered it inappropriate to weigh main category C equally to the other three main categories.

The inclusion of main category C with limited weight did not change the rankings drastically. The general pattern is that taxonomic groups with high toxicological sensitivity increase in vulnerability (Table 13).

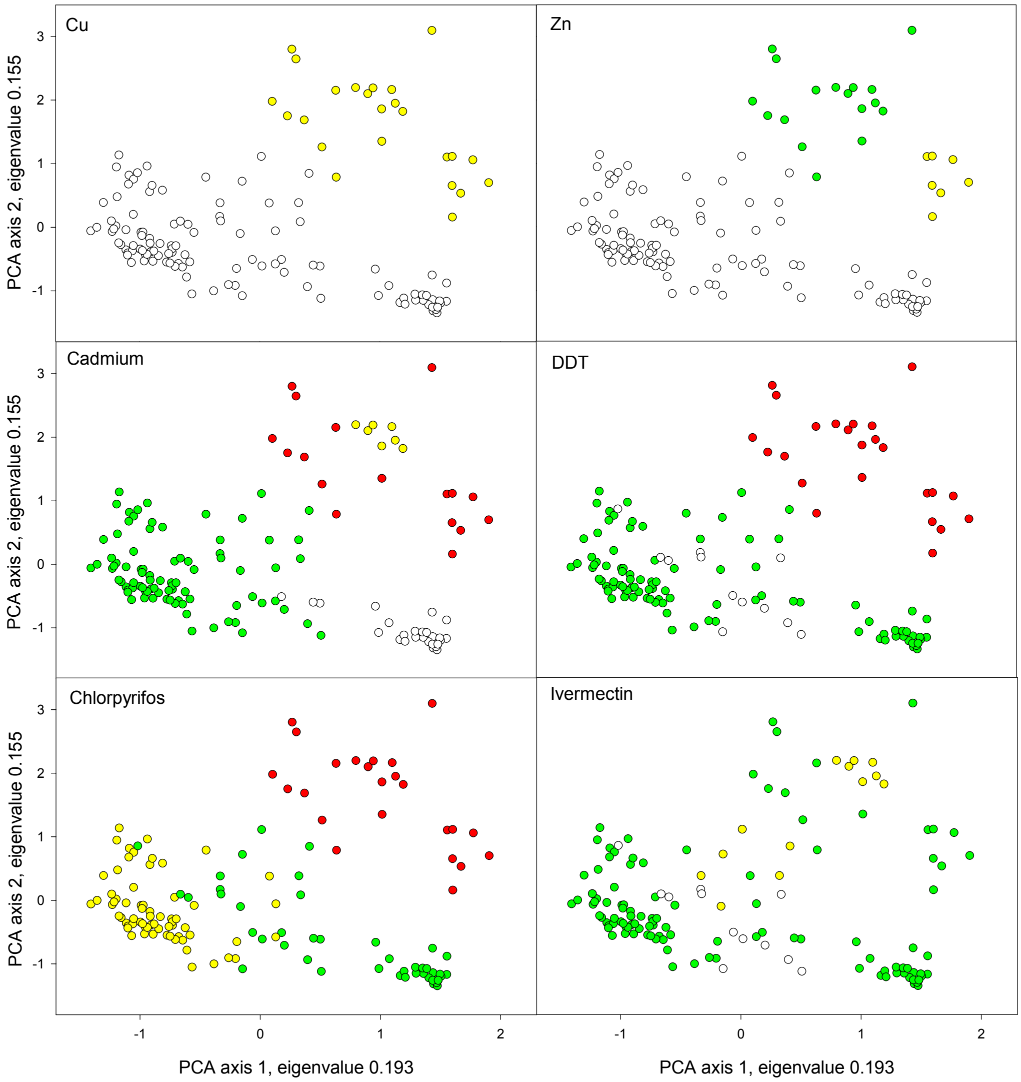

Figure 12. PCA species ordination plot with colour codes for toxicity class: open= very slightly toxic, green = slightly toxic, yellow = moderately toxic, red = highly toxic.

Table 13. Top five vulnerable species incorporating toxicity (main category C), compared with initial ranking as obtained without use of the toxicity data. See Appendix 1 for scientific names.

Rank	Species	Code	Score	Initial rank	Species	Code	Score	Initial rank	Species	Code	Score	Initial rank
	Zn				*Cu*				*Cd*			
1	Bullhead	FISH7	0.57	1	Bullhead	FISH7	0.59	1	Common Tern	BIRD50	0.54	1
2	Stone Loach	FISH2	0.57	2	Stone Loach	FISH2	0.57	2	Great Reed Warbler	BIRD13	0.52	2
3	Scarce Chaser	DFLY5	0.54	6	Alpine Newt	AMPH1	0.56	3	Gr. Mouse-eared Bat	MAM6	0.52	3
4	Alpine Newt	AMPH1	0.54	3	Palmate Newt	AMPH6	0.55	4	Oystercatcher	BIRDh	0.51	4
5	Palmate Newt	AMPH6	0.53	4	Great Crested Newt	AMPH3	0.54	5	Geoffroy's Bat	MAM5	0.51	5
	DDT				*Chlorpyrifos*				*Ivermectin*			
1	Alpine Newt	AMPH1	0.54	3	Alpine Newt	AMPH1	0.58	3	Slow Worm	REP3	0.59	1
2	Palmate Newt	AMPH6	0.53	4	Slow Worm	REP3	0.57	1	Viviparous Lizard	REPa	0.58	2
3	Great Crested Newt	AMPH3	0.53	5	Viviparous Lizard	REPa	0.57	2	Sand Lizard	REP5	0.54	4
4	Slow Worm	REP3	0.52	1	Palmate Newt	AMPH6	0.57	5	Alpine Newt	AMPH1	0.53	6
5	Viviparous Lizard	REPa	0.51	2	Bullhead	FISH7	0.56	6	Palmate Newt	AMPH6	0.52	8

5 Concluding remarks

5.1 Method evaluation

Ecological vulnerability analysis as a new method of (relative) risk assessment
The ecological vulnerability analysis results in a ranking of species by relative vulnerability for specifically tested contaminants. A comparison between the results of the vulnerability ranking with field data revealed that there are no large inconsistencies. Validation with laboratory data proved to be difficult, however, since the setup of most ecotoxicological studies implies that results can only be interpreted in terms of toxicological sensitivity of a species to a contaminant. By contrast, the results of the vulnerability analysis were based on exposure to contaminants and potential population recovery after exposure, and did not incorporate toxicological sensitivity.
Toxicological sensitivity is one aspect of ecological vulnerability. It may have a different direction than the other aspects (exposure, toxicokinetics, and population resilience). A comparison between the vulnerability scores for ecological vulnerability and literature toxicological sensitivity data reveals that these have the same direction for zinc and copper. This may indicate that for these substances toxicological sensitivity and ecological vulnerability are determined by (or at least correlated with) the same traits. For DDT, chlorpyrifos and cadmium the directions are different. This indicates that for these contaminants the rankings may change considerably when toxicity would also be incorporated. Further, it could also mean that negative toxicological effects can perhaps be mitigated in the field by limited exposure, efficient detoxification/excretion, and/or population resilience.

There are some indications that current risk assessments based on toxicological sensitivity are overestimating ecological risks to wildlife. For example, a critical review of cadmium effects in wildlife compared with soil risk assessment concludes that there is meagre evidence that wild animals have been seriously harmed by cadmium (Beyer, 2000). Beyer tries to explain this discrepancy in the derivation of No Observed Effect Levels from data available in literature. However, the discrepancy between field effects (= ecological vulnerability) and toxicological sensitivity (No Observed Effect Levels) may also be explained by a lesser ecological vulnerability as a consequence of limited exposure and/or population recovery potential.

Predicting vulnerability from ecological characteristics
Ordination analysis revealed that ecological traits describing fast-reproducing species can be separated from ecological traits describing large-bodied and long-lived species. In general r-strategies can be separated from K-strategies. This separation was the most important axis in the ordination. Sensitivity analyses confirmed that the ordination was most sensitive to changes in r-strategy traits, suggesting that these had the largest effect on the final ordination.

From the results of the ecological vulnerability analysis, the following generalizations can be made when the characteristics of the most vulnerable species of the different contaminants are compared:

- species vulnerable to copper/zinc can be classified as r-strategists;
- species vulnerable to cadmium and DDT can be classified as K-strategists;
- species vulnerable to ivermectin and chlorpyrifos are intermediate.

The interpretation of vulnerability scores and grouping of characteristics together gives the following additional information. For essential metals (copper and zinc), exposure through habitat (soil and sediment) is a risk factor. For non-essential metals (cadmium), K-strategists have a higher vulnerability than r-strategists. For chlorpyrifos the result is reversed: r-strategists have a higher vulnerability than K-strategists; in addition exposure through habitat (vegetation and soil) is also a risk factor for chlorpyrifos. The coupling between vulnerability scores and PCA ordination is less clear for DDT and ivermectin. For these two contaminants, factors correlated with low vulnerability are in main category D, especially dispersion and survival of offspring to first reproduction. This may indicate that population resilience gives a basic level of resistance to contaminants.

Summarizing:

- exposure through habitat is a key factor for vulnerability to copper, zinc and chlorpyrifos;
- K-strategy characteristics and trophic level are key factors for vulnerability to cadmium and DDT;
- r-strategy characteristics are key factors for vulnerability to chlorpyrifos;
- no specific characteristics could be identified that determine vulnerability to ivermectin;
- population resilience represents a basic level of resistance.

Extrapolation to other contaminants

We selected six contaminants for the multi-criteria analysis. These contaminants were chosen to represent different scenarios in terms of type of chemical and environmental fate (see Table 4, §3.1).

For essential metals exposure and internal regulation mechanisms will be comparable. The differentiating aspects between such metals would predominantly be in toxicity (main category C). The inclusion of this category in the analysis may result in different risk assessments. If excluded, the results for copper and zinc are therefore thought to be representative for all essential metals.

For non-essential metals extrapolation is more complicated. We chose cadmium as non-essential chemical, but if cadmium were compared for example with lead, several differences emerge: bioaccumulation is lower for lead and internal regulation mechanisms are specific. Thus, weight factors for main category A and B should be differently specified for cadmium and lead. Generalisation in this scenario is therefore limited.

Results obtained for DDT are expected to be comparable for other cyclodiene pesticides such as aldrin and dieldrins, as environmental fate, exposure and internal regulation mechanisms are quite similar between these pesticides. The differentiating aspect is toxicity (main category C). Under exclusion of these toxicity data the results may be extrapolated.

Results for chlorpyrifos are not readily compared with other organophosphate pesticides. Extrapolation is therefore not recommended.

Pharmaceuticals are designed to have biocidal effects, and have specific modes of action. The results for ivermectin may be extrapolated to other avermectins that are used as anthelmintic. However, further extrapolation to all veterinary pharmaceuticals does not seem legitimate in view of specific applications and effects.

Usefulness of ecological vulnerability analysis: pros and cons

There are several advantageous aspects of the vulnerability analysis:

- The input needed is ecological information of species, which is usually easily obtained from literature. Technically, toxicological data may be used as well, but while data is scarce this is restricted to a generalizing level.
- Results are ecologically meaningful: actual wildlife species are involved, not 'laboratory fauna' or statistical estimation of communities, and results from vulnerability analysis may be appreciated as hypotheses that can be assessed in the field.
- Vulnerability in aquatic and terrestrial species can be compared directly; with toxicity data this is hardly possible, since exposure routes are different.
- Species comparisons in risk assessments can be tailor-made to meet the specific questions in nature conservation, *e.g.* species may be compared for a particular area (site-specific risk assessment, monitoring), or target species may be compared between nature target types (spatial planning of nature development, feasibility studies).
- Results may be applied in monitoring. The most vulnerable species from our analysis can be considered as indicator species (Faber *et al.*, 2004b). The least vulnerable species in our analysis are usually robust species with high resistance to disturbances.
- Results may be applied in the management of soils, vegetation and wildlife in nature conservation areas, with focus on vulnerable wildlife species (Klok *et al.*, 2004).
- As results are aimed for application in risk assessment and risk management for wildlife, the method suffers little from uncertainty from 'lab to field' extrapolation as in 'traditional' risk assessment using laboratory toxicity data. Given a better relevancy in the risk assessment, the acceptance of the results by stakeholders and the readiness to include in decision making may be improved.

However, the method still has some shortcomings and limitations that require further development:

- While the MCA method is a suitable tool to make an unrestricted number of relative comparisons (and many more species and characteristics may be included), it is a complex technique which may not be easily comprehended by outsiders. The assessment of weight factors will remain a matter for experts, leaving a 'black box' component to the method if applied in decision making.

- Important steps in the MCA method are the selection of criteria and the weight that is given to criteria. These two steps control the outcome of the ranking. The selection of criteria was aimed to be complete within each category. Weight factors were determined by expert judgement, which is subjective. The outcome of the MCA is determined by the (factual) data for each characteristic, multiplied by the (subjective) weight factor. Despite this subjectivity in the approach, the sensitivity analysis (§3.2.3) showed that the ranking would only change significantly after considerable changes in weights. We defined the criteria and weights by expert judgement, ensuring that the outcome reflects the best possible state of knowledge. Future increasing insights can always be incorporated.
- The ecological vulnerability analysis is a conceptual, ordinal method; it gives a relative ranking of species, but as yet no actual risk levels can be derived from the ranking. The method is not yet ready for determining the actual risk at particular concentration levels.
- Specific (and often unexpected) toxic effects, such as eggshell thinning by DDT/DDE, and indirect effects, such as food depletion to higher animals by ivermectin, cannot yet be properly predicted by our method for lack of generic data.

Despite these shortcomings, and in view of the consistency of results, the method is useful in our opinion, and can be used as a welcome addition to existing practices.

5.2 Future research

Incorporation of toxicological sensitivity

Ecotoxicological data are scarce for the species present in our dataset (*viz.* Table 11). We therefore chose at this moment not to incorporate this aspect in our analysis. Incorporation of toxicological sensitivity can be done for each species, or by using an estimate for average sensitivity in each taxonomic group. The first option is practically impossible and unethical, since it implies an infinite number of laboratory tests to obtain LC_{50}/NOEC values for so many (target) species and contaminants.
The second option is the approach that we used in this report as a pilot. However, the use of a sensitivity estimate for entire taxonomic groups (mammals, birds, fish, etc.) has limitations as well. First, the sensitivity estimate is based on available data that were mostly for species that did not occur in our dataset, and that may differ from wildlife species sensitivities. Second, the approach only makes sense if the groups are different in their general sensitivity, that is: if sensitivity distributions are not entirely overlapping. This is difficult to ascertain, since there are so limited data available, and the exposure routes and units of LC_{50}/NOEC are different between aquatic and terrestrial species. The Dutch institute RIVM has done some investigations into this subject; their reports show that most distributions do overlap (Luttik *et al.*, 1997; Traas *et al.*, 1998). An exception is the NOEC distribution for cadmium, where birds have lower NOECs than mammals (Luttik *et al.*, 1997).

If this path of estimating sensitivity for taxonomic groups is followed, then a prerequisite is to obtain comparable LC_{50}/NOEC values. A 'golden standard' might be to express all effect concentrations in terms of (estimated) body burden (mg/kg body weight). Body burden may have more toxicological relevance than environmental concentration, since it is the result of both exposure and internal physiological mechanisms. It includes both oral and dermal exposure routes for aquatic and terrestrial species. With such standardisation toxicity data become better comparable, and classification can be made more precisely than currently practiced.

Further NOMIRACLE developments

We have presented a method to assess ecological vulnerability of fauna species. The results of the analyses are qualitative and should be interpreted on a relative scale.

The ecological vulnerability analysis approach has potential for further development, such as application in:

- risk mapping of contaminants and ecosystems;
- food web modelling;
- random walk modelling;
- risk scenario ranking.

Within the project framework, at Alterra we will focus on food web studies and risk mapping.

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Glossary

acute = of short duration, in relation to exposure or effect. In experimental toxicology, acute refers to studies where dosing is either single or limited to one day although the total study duration may extend to two weeks.

body burden = total amount of a substance present in an organism at a given time.

chronic = long-term, in relation to exposure or effect. In experimental toxicology, chronic refers to studies occupying a large part of the lifetime of an organism.

detoxification = process(es) of chemical modification which make a toxic molecule less toxic.

ecological vulnerability = the extent to which species experience effects in the field of contamination (at population level), as a result of their species-specific ecological traits, and toxicological sensitivity.

excretion = discharge or elimination of an absorbed or endogenous substance, or of a waste product, and/or its metabolites, through some tissue of the body and its appearance in urine, faeces, or other products normally leaving the body.

exposure = 1. concentration, amount or intensity of a particular physical or chemical agent or environmental agent that reaches the target population, organism, organ, tissue or cell, usually expressed in numerical terms of substance concentration, duration, and frequency or intensity. 2. process by which a substance becomes available for absorption by the target population, organ, tissue or cell by any route.

hazard = a threatening event, or the probability of the occurrence of a potentially damaging phenomenon within a given time period and area.

lethal concentration = concentration of a substance in an environmental medium that causes death following a certain period of exposure. *E.g.* LC_{50} is the median concentration lethal to 50 % of a test population.

multi-criteria analysis = MCA = methodology which compares multiple aspects of multiple alternatives on a relative scale. Here MCA is used to rank species ('alternatives') on a vulnerability scale.

no observed effect level/concentration (NOEL or NOEC) = greatest concentration or amount of a substance found by experiment or observation, that causes no alterations of morphology, functional capacity, growth, development, or life span of target organisms distinguishable from those observed in normal (control) organisms of the same species and strain under the same defined conditions of exposure.

principal component analysis = PCA = multivariate analysis method calculated using CANOCO. PCA is an indirect ordination based on a linear model.

resilience = the capacity of a population/community/ecosystem to maintain or regain normal function and development following disturbance.

resistance = the ability of a population/community/ecosystem to withstand disturbances.

risk = expected losses due to a particular hazard for a given area and reference period. Based on mathematical calculations, risk is the product of hazard and vulnerability.

threshold = dose or exposure concentration below which an effect will not occur.

toxicity = adverse effects of a substance on a living organism defined with reference to the quantity of substance administered or absorbed, the route of absorption, the distribution in time, and the specific effects produced.

toxicokinetics = process of the uptake of potentially toxic substances by the body, the biotransformations they undergo, the distribution of the substances and their metabolites in the tissues, and the elimination of the substances and their metabolites from the body.

toxicological sensitivity = the extent to which species (or processes) experience the effect of substances, expressed as a toxicity threshold or toxicity value for a standard effect parameter (*e.g.* growth, survival, reproduction). This is usually measured under laboratory conditions on individuals. Toxicological sensitivity is expressed as a concentration or dose, and is an absolute species-specific characteristic.

Appendix 1 – List of species names and codes

English name	Dutch name	Latin name	Code
Amphibians			
Alpine Newt	Alpenwatersalamander	*Triturus alpestris*	AMPH1
Green Treefrog	Boomkikker	*Hyla arborea*	AMPH2
Great Crested Newt	Kamsalamander	*Triturus cristatus*	AMPH3
Common Spadefoot	Knoflookpad	*Pelobates fuscus*	AMPH4
Natterjack Toad	Rugstreeppad	*Bufo calamita*	AMPH5
Palmate Newt	Vinpootsalamander	*Triturus helveticus*	AMPH6
Poolfrog	Kleine Groene Kikker	*Rana lessonae*	AMPHa
Dragonflies			
Norfolk Hawker	Vroege Glazenmaker	*Aeshna isosceles*	DFLY1
Green Hawker	Groene Glazenmaker	*Aeshna viridis*	DFLY2
Hairy Dragonfly	Glassnijder	*Brachytron pratense*	DFLY3
Norfolk Damselfly	Donkere Waterjuffer	*Coenagrion armatum*	DFLY4
Scarce chaser	Bruine Korenbout	*Libellula fulva*	DFLY5
Siberian Winter Damselfly	Noordse Winterjuffer	*Sympecma paedisca*	DFLY6
Common Blue Damselfly	Watersnuffel	*Enallagma cyathigerum*	DFLYa
Reptiles			
Common Adder	Adder	*Vipera berus*	REP1
Smooth Snake	Gladde Slang	*Coronella austriaca*	REP2
Slow Worm	Hazelworm	*Anguis fragilis*	REP3
Grass Snake	Ringslang	*Natrix natrix*	REP4
Sand Lizard	Zandhagedis	*Lacerta agilis*	REP5
Viviparous Lizard	Levendbarende hagedis	*Lacerta/Zootoca vivipara*	REPa
Fish			
Barbel	Barbeel	*Barbus barbus*	FISH1
Stone Loach	Bermpje	*Noemacheilus barbatulus*	FISH2
Allis Shad	Elft	*Alosa alosa*	FISH3
Catfish	Europese Meerval	*Silurus glanis*	FISH4
Twaite Shad	Fint	*Alosa fallax*	FISH5
White Bream	Kolblei	*Abramis bjoerkna*	FISH6
Bullhead	Rivierdonderpad	*Cottus gobio*	FISH7
Ide	Winde	*Leuciscus idus*	FISH8
Carp	Karper	*Cyprinus carpio*	FISHa
Three Spined Stickleback	Driedoornig Stekelbaarsje	*Gasterosteus aculeatus*	FISHb
Butterflies			
Grizzled skipper	Aardbeivlinder	*Pyrgus malvae*	BFLY1
Alcon Blue	(Heide)gentiaan blauwtje	*Maculinea alcon*	BFLY2
Pearl-Bordered Fritillary	Zilvervlek	*Boloria euphrosyne*	BFLY3
Chequered Skipper	Bont dikkopje	*Carterophalus palaemon*	BFLY4
Brown Argus	Bruin blauwtje	*Aricia agestis*	BFLY5
Scooty Copper	Bruine vuurvlinder	*Lycaena tityrus*	BFLY6
Dusky Large Blue	Donker pimpernelblauwtje	*Maculinea nausithous*	BFLY7
Niobe Fritillary	Duinparelmoervlinder	*Argynnis niobe*	BFLY8

List of species names and codes (continued)

English name	Dutch name	Latin name	Code
Small Skipper	Geelsprietdikkopje	*Thymelicus sylvestris*	BFLY9
Dark Green Fritillary	Grote Parelmoervlinder	*Argynnis aglaja*	BFLY10
Large Tortoiseshell	Grote Vos	*Nymphalis polychloros*	BFLY11
Mazarine Blue	Klaverblauwtje	*Polyommatus semiargus*	BFLY12
Queen of Spain Fritillary	Kleine Parelmoervlinder	*Issoria lathonia*	BFLY13
Silver-spotted Skipper	Kommavlinder	*Hesperia comma*	BFLY14
Marsh Fritillary	Moerasparelmoervlinder	*Euphydryas aurinia*	BFLY15
Scarce Large Blue	Pimpernelblauwtje	*Maculinea teleius*	BFLY16
Purple-edged Copper	Rode Vuurvlinder	*Lycaena hippothoe*	BFLY17
Brown Hairstreak	Sleedoornpage	*Thecla betulae*	BFLY18
Large Chequered Skipper	Spiegeldikkopje	*Heteropterus morpheus*	BFLY19
Large Blue	Tijmblauwtje	*Maculinea arion*	BFLY20
Pearly Heath	Tweekleurig Hooibeestje	*Coenonympha arcania*	BFLY21
Glanville Fritillary	Veldparelmoervlinder	*Melitaea cinxia*	BFLY22
Small Pearl-Bordered Fritillary	Zilveren maan	*Clossiana selene*	BFLY23
Large Copper	Grote Vuurvlinder	*Lycaena dispar*	BFLY24
Red Admiral	Atalanta	*Vanessa atalanta*	BFLYa
Large White	Groot Koolwitje	*Pieris brassicae*	BFLYb
Brimstone	Citroentje	*Gonepteryx rhamni*	BFLYc
Birds			
Bearded Tit	Baardmannetje	*Panurus biarmicus*	BIRD1
Bluethroat	Blauwborst	*Luscinia svecica*	BIRD2
Hen Harrier	Blauwe kiekendief	*Circus cyaneus*	BIRD3
Little Grebe	Dodaars	*Tachybaptus ruficollis*	BIRD4
Wryneck	Draaihals	*Jynx torquilla*	BIRD5
Tawny Pipit	Duinpieper	*Anthus campestris*	BIRD6
Little Tern	Dwergstern	*Sterna albifrous*	BIRD7
Yellowhammer	Geelgors	*Emberiza citrinella*	BIRD8
Greylag Goose	Grauwe Gans	*Anser anser*	BIRD9
Montagu's Harrier	Grauwe kiekendief	*Circus pygargus*	BIRD10
Red-backed Shrike	Grauwe Klauwier	*Lanius collurio*	BIRD11
Green Woodpecker	Groene Specht	*Picus viridis*	BIRD12
Great Reed Warbler	Grote Karekiet	*Acrocephalus arundinaceus*	BIRD13
Black-tailed Godwit	Grutto	*Limosa limosa*	BIRD14
Hoopoe	Hop	*Upapa epops*	BIRD15
Kingfisher	Ijsvogel	*Alcedo atthis*	BIRD16
Ruff	Kemphaan	*Philomachus pugnax*	BIRD17
Barn Owl	Kerkuil	*Tyto alba*	BIRD18
Great Grey Shrike	Klapekster	*Lanius excubitor*	BIRD19
Little Ringed Plover	Kleine Plevier	*Charadrius dubius*	BIRD20
Avocet	Kluut	*Recurvirostra avosetta*	BIRD21
Black Grouse	Korhoen	*Tetrao tetrix*	BIRD22
Red-crested Pochard	Krooneend	*Netta rufina*	BIRD23
Night Heron	Kwak	*Nycticorax nycticorax*	BIRD24
Corncrake	Kwartelkoning	*Crex crex*	BIRD25
Spoonbill	Lepelaar	*Platalea leucorodia*	BIRD26
Nightjar	Nachtzwaluw	*Caprimulgus europaeus*	BIRD27
Arctic Tern	Noordse Stern	*Sterna paradisaea*	BIRD28

List of species names and codes (continued)

English name	Dutch name	Latin name	Code
Sand Martin	Oeverzwaluw	*Riparia riparia*	BIRD29
White Stork	Ooievaar	*Ciconia ciconia*	BIRD30
Ortolan Bunting	Ortolaan	*Emberiza hotulana*	BIRD31
Whinchat	Paapje	*Saxicola rubreta*	BIRD32
Partridge	Patrijs	*Perdix perdix*	BIRD33
Pintail	Pijlstaart	*Anas acuta*	BIRD34
Spotted Crake	Porseleinhoen	*Porzana porzana*	BIRD35
Purple Heron	Purperreiger	*Ardea purpurea*	BIRD36
Raven	Raaf	*Corvus corax*	BIRD37
Sedge Warbler	Rietzanger	*Acrocephalus schoenobaenus*	BIRD38
Red Kite	Rode Wouw	*Milvus milvus*	BIRD39
Bittern	Roerdomp	*Botarus stellaris*	BIRD40
Stonechat	Roodborsttapuit	*Saxicola troquata*	BIRD41
Woodchat Shrike	Roodkopklauwier	*Lanius senator*	BIRD42
Shoveler	Slobeend	*Anas clypeata*	BIRD43
Savi's Warbler	Snor	*Locustella luscinioides*	BIRD44
Little Owl	Steenuil	*Athene noctua*	BIRD45
Northern Wheatear	Tapuit	*Oenanthe oenanthe*	BIRD46
Kestrel	Torenvalk	*Falco tinnunculus*	BIRD47
Redshank	Tureluur	*Tringa totanus*	BIRD48
Short-eared Owl	Velduil	*Asio flammeus*	BIRD49
Common Tern	Visdief	*Sterna hirundo*	BIRD50
Water Rail	Waterral	*Rallus aquaticus*	BIRD51
Snipe	Watersnip	*Gallinago gallinago*	BIRD52
Golden Oriole	Wielewaal	*Oriolus oriolus*	BIRD53
Little Bittern	Woudaapje	*Ixobrychus minutis*	BIRD54
Garganey	Zomertaling	*Anas querquedula*	BIRD55
Black Tern	Zwarte Stern	*Chlidonias niger*	BIRD56
Mallard	Wilde eend	*Anas platyrhynchos*	BIRDa
Buzzard	Buizerd	*Buteo buteo*	BIRDb
Tufted Duck	Kuifeend	*Aythya fuligula*	BIRDc
Blackbird	Merel	*Turdus merula*	BIRDd
Hooded Crow	Kraai	*Corvus corone*	BIRDe
Grey Heron	Blauwe Reiger	*Ardea cinerea*	BIRDf
Coot	Meerkoet	*Fulica atra*	BIRDg
Oystercatcher	Scholekster	*Haematopus ostralegus*	BIRDh
Lapwing	Kievit	*Vanellus vanellus*	BIRDi
Whitethroat	Grasmus	*Sylvia communis*	BIRDj
Mammals			
Badger	Das	*Meles meles*	MAM1
Natterer's Bat	Franjestaart	*Myotis nattereri*	MAM2
Pine Marten	Boommarter	*Martes martes*	MAM3
Northern Vole	Noordse woelmuis	*Microtus oeconomus*	MAM4
Geoffroy's Bat	Ingekorven Vleermuis	*Myotis emarginatus*	MAM5
Greater Mouse-eared Bat	Vale Vleermuis	*Myotis myotis*	MAM6
Northern Water Shrew	Waterspitsmuis	*Neomys fodiens*	MAM7
Otter	Otter	*Lutra lutra*	MAM8

List of species names and codes (continued)

English name	Dutch name	Latin name	Code
Mole	Mol	*Talpa europaea*	MAMa
Common Rat	Bruine rat	*Rattus norvegicus*	MAMb
Bank Vole	Rosse woelmuis	*Clethrionomys glareolus*	MAMc
Field Vole	Aardmuis	*Microtus agrestis*	MAMd

Appendix 2 – Details of ordination analysis

The following dataset of ecological characteristics was used in the ordination analysis, with 12 variables and 28 factors. An indication for each characteristic is given in which analysis it was used.

Methods: Total set of characteristics used in principal component analysis

Characteristic	Unit	Abbr.	Min. value	Max. value	Used in total	Used in birds	Used in butterflies
Duration egg stage	month	st1	0	9.5	x	x	x
Duration juvenile stage	month	st2	0.4	66	x	x	x
Duration adult stage	month	st3	0.3	465	x	x	x
Maximum life span	month	maxlife	9.9	600		x	
Median age at first reproduction	month	agerepro	1.5	60	x	x	x
Median clutch size	number	clutch	0.6	1000000	x	x	x
Number of clutches/year	number	nclyear	0.5	5	x	x	x
Life time reproduction	number	R	9.2	46000000	x	x	x
Survival to first reproduction	%	survival	2.0	90	x	x	
Home range	M	range	30.0	3000000	x	x	x
Body weight	Gram	weight	0.4	37000	x	x	
Daily energy requirement	gram/day	energy	0.1	3700			
Stage 1 preference habitat 1 [a]		st1_hab1	0	1	x	x	x
Stage 1 preference habitat 2 [a]		st1_hab2	0	1		x	x
Stage 1 preference habitat 3 [a]		st1_hab3	0	1	x		
Stage 1 preference habitat 4 [a]		st1_hab4	0	1	x		
Stage 1 preference habitat 5 [a]		st1_hab5	0	1			
Stage 2 preference habitat 1		st2_hab1	0	1			x
Stage 2 preference habitat 2		st2_hab2	0	1	x		x
Stage 2 preference habitat 3		st2_hab3	0	1	x		
Stage 2 preference habitat 4		st2_hab4	0	1			
Stage 2 preference habitat 5		st2_hab5	0	1			
Stage 3 preference habitat 1		st3_hab1	0	1	x	x	
Stage 3 preference habitat 2		st3_hab2	0	1	x		
Stage 3 preference habitat 3		st3_hab3	0	1	x	x	
Stage 3 preference habitat 4		st3_hab4	0	1			
Stage 3 preference habitat 5		st3_hab5	0	1	x		
Stage 2 preference food 1 [b]		st2_fd1	0	1			x
Stage 2 preference food 2 [b]		st2_fd2	0	1	x	x	
Stage 2 preference food 3 [b]		st2_fd3	0	1		x	x
Stage 2 preference food 4 [b]		st2_fd4	0	1	x		
Stage 3 preference food 1		st3_fd1	0	1	x	x	
Stage 3 preference food 2		st3_fd2	0	1	x	x	
Stage 3 preference food 3		st3_fd3	0	1	x		
Stage 3 preference food 4		st3_fd4	0	1		x	
Hibernation		hibern	0	1	x		x
Migration		migrate	0	1	x	x	x
Dispersion		dispers	0	1	x	x	x
Patchy distribution		patchy	0	1	x	x	x
Territorial behaviour		territor	0	1	x	x	x

[a] habitat 1 = vegetation/other; habitat 2 = on soil; habitat 3 = in water; habitat 4 = in soil; habitat 5 = in sediment

[b] food source 1 = vegetables, nectar, seeds, fruits; food source 2 = soil, detritus, waste material; food source 3 = insect, soil organisms, vertebrate herbivores; food source 4 = vertebrate carnivores

The following comments can be made about the dataset:

- Lifespan was divided into three stages: egg, juvenile, and adult stage, respectively. This meant for butterflies a simplification, by omitting the pupae stage.
- Habitat preference and food preference were described as a factor for each life stage. This resulted in 15 habitat factors: 5 different habitats x 3 life stages.
- Food preference for life stage 1 (egg) was omitted; in total 8 food factors were used: 4 different food types x 2 life stages.
- Behavioural aspects such as dispersal capacity, hibernation, migration, patchy distribution, and territory behaviour, were all described as a factor.

Results of the ordination analysis: Number of species and characteristics, and eigenvalues of axes 1-4, used in each PCA analysis.

	Total dataset	Birds	Butterflies
No. species	135	66	27
No. characteristics used	29	24	19
Eigenvalue axis 1	0.193	0.200	0.398
Eigenvalue axis 2	0.155	0.178	0.184
Eigenvalue axis 3	0.084	0.103	0.117
Eigenvalue axis 4	0.079	0.082	0.093

Appendix 3 – Correlation matrix ecological variables

	stage1	stage2	stage3	maxlife	agerepro	clutch	nclyear	R	survival	range	weight	daily intake
stage2	0.12											
stage3	-0.13	-0.04										
maxlife	-0.11	-0.01	**0.79**									
agerepro	0.11	**0.58**	**0.47**	**0.45**								
clutch	-0.05	-0.05	0.09	**0.35**	0.20							
nclyear	-0.02	-0.04	**-0.30**	-0.28	-0.20	-0.04						
R	-0.05	-0.05	0.09	**0.35**	0.20	**0.75**	-0.04					
survival	-0.07	**-0.39**	**0.44**	**0.35**	-0.09	-0.10	-0.18	-0.10				
range	-0.06	0.15	-0.02	-0.02	0.10	-0.01	-0.06	-0.01	-0.13			
weight	-0.01	0.20	0.21	**0.44**	**0.37**	**0.84**	-0.12	**0.84**	-0.10	0.08		
daily intake	-0.01	0.16	0.25	**0.46**	**0.37**	**0.81**	-0.14	**0.81**	-0.05	0.07	**0.97**	
FMR	-0.08	-0.02	-0.07	-0.04	-0.20	-0.03	-0.10	-0.03	0.03	0.00	-0.03	-0.03

Bold values indicate a significant Pearson correlation coefficient, after Bonferroni correction.
FMR = Field Metabolic Rate (kJ/day); other abbreviations as in Appendix 2.

Appendix 4 – Explanation of multi-criteria analysis with BOSdA software program

The vulnerability analysis is developed for fauna species belonging to nature-target-types (defined in Handbook Nature Target types, Bal *et al.*, 1995). For these species, available knowledge was collected of characteristics describing autecology, ecophysiology, population-ecology and ecotoxicology. These data form the basis of the vulnerability analysis.
In a multi-criteria analysis (MCA) all these relevant characteristics are weighed and directed towards the soil-pollution in four groups of characteristics (external exposure, internal exposure, effects on individual level, and effects on population level). After that, in the MCA, all characteristics of all relevant species are compared and the species are ranked on a vulnerability axis.

Description of the characteristics
There are a large number of different factors that will influence the vulnerability of fauna. A subdivision is made into four categories of characteristics based on ecological and ecotoxicological knowledge of these factors. For each of these categories questions were formulated aimed to improve the understanding of the vulnerability of fauna species. The questions also clarify what is meant with each main category. The four main categories are:

A. External exposure
This main category deals with species characteristics that determine the availability and assimilation of substances from the environment.
- Does the species come into contact with the substance (time, substrate, avoidance behaviour)?
- In which life-stage of the species does this contact occur (juvenile, adult, ….)?
- What is the duration and intensity of this contact?
- What is the exposure route (dermal uptake, food intake, inhalation)?
- If exposure is through food, what is the diet?

B. Internal exposure
This main category deals with species characteristics that determine the internal concentration, the internal activity and the internal relocation of substances.
- In what way can the substance be regulated and to what amount? (detoxification, excretion, storage)?
- Are there periods in life-history when the substance becomes available (during migration, hibernation)?

C. Effects on individual level
This main category deals with species characteristics that determine the toxicological sensitivity (of individuals) for substances.
- What kind of (eco)toxicological effect is caused by the substance to the species (mortality, chronic, sub chronic)?
- How large is the effect (LC_{50}, NOEC)?

D. Effects on population level
This main category deals with characteristics that determine the functioning of the population in relation to the presence of a substance, in terms of population recovery or resilience.
- What type of effect is caused by the substance on the population (density, demography)?
- Are there any mechanisms that hide the effects (territoriality)?
- Are there recovery-mechanisms related to population survival (population growth rate, dispersal behaviour)?

The questions of each main category clarify the meaning of each category. For example: The chance that a species gets into contact with a substance is determined by its choice of habitat, migratory behaviour and whether the species hibernates. A species that lives in the soil has a higher chance of contact with a substance that is bound to soil-particles (direct contact) than a species that lives in the vegetation (indirect contact). The behavioural characteristics determine the duration that a species is in contact with the substance.

Within each category, characteristics (related to the questions asked) are defined and quantified for each species by use of scientific literature and reports. The quantification of characteristics is necessary to be able to perform multi-criteria analysis (MCA). This will be explained in the following paragraphs.

Multi-criteria analysis using BOSdA

For performing the MCA the computer-program BOSdA is used (Janssen *et al.*, 2000). This program was developed by IVM (Institute for Environmental Studies, Free University Amsterdam) and the Dutch Financial Department. The program was originally designed for making decisions in the spatial planning process in the Netherlands. In this process, alternative locations and alternative arrangements of large building-projects have to be compared (according to the Dutch laws) on economic, ecological, ergonomic etc. characteristics. These characteristics use very different quantities and units. Some of the characteristics can be put into an economic value, but others are more intuitive values (like influence on the surrounding landscape). Comparison between these characteristics is therefore very difficult. BOSdA is able to compare different characteristics in a relative way. For our research goal, BOSdA is suitable because, as in spatial planning, alternatives (here: different species) have to be compared on a lot of different aspects (here: ecological and ecotoxicological characteristics of species). For example, characteristics that are difficult to compare are life-span and habitat-choice. In the vulnerability analysis these characteristics have to be compared to result in a ranking of vulnerability of species. BOSdA is used to perform the comparison of all characteristics in an unambiguous way. In a non-automated surrounding, it is hardly possible to perform this comparison. BOSdA has the advantage that key-characteristics can easily be traced after the comparison.

Methodical

The characteristics used in the analysis have to be quantified, weighed, scaled and their mutual relationship has to be described before they can be used in BOSdA. The direction of its effect on the vulnerability has to be determined for each characteristic. All characteristics are summarised with their direction with respect to vulnerability, the scale that is used and the standardisation method.

Determination of the direction of the used characteristics:

For each characteristic we determined the direction of the correlation with vulnerability, *e.g.* positive (↑) or negative (↓) The terms used in BOSdA are either a benefit-aspect (positive contribution to vulnerability; the higher the value for the characteristic, the more vulnerable the species is) or a cost-aspect (negative contribution to vulnerability; the lower the value for the aspect, the more vulnerable the species is). Since we wanted to avoid the strong economic connotation related with 'costs' and 'benefits', we use arrows to indicate the direction of the correlation. An upward arrow describes a benefit-aspect (↑ = raising vulnerability), a downward arrow describes a cost-aspect (↓ = decreasing vulnerability).

Determination of the scale of the used characteristic:

For each characteristic it is necessary to know the scale of the values. In BOSdA scales have to be standardised to make comparisons possible. BOSdA makes use of different scale-types like a binary scale (yes or no), a ratio-scale (the relative meaning of the aspect is proportional with the value of the aspect), an interval scale (only differences between values have a meaning, there is no useful zero value for this aspect).

Standardisation of the values of characteristics:

The values of characteristics have to be compared in the vulnerability analysis. This can only be executed when all values are standardised to the same unit. After standardisation all values lose their dimension. BOSdA uses different standardisations, like the maximum standardisation (the values of the aspect are linearly related to a value between 0 and 1; the highest value in the range of the aspect will be equalled to 1 and all the other values are relatively scaled to this value) and the interval standardisation (in which the highest value is equalled to 1 and the lowest to 0 in case of a benefit-aspect).

Characteristic	Category	Direction	Scale	Standardisation
Habitat- / substrate choice	A	↑	Ratio-scale	Maximum
Maximum life-span	A	↑	Ratio-scale	Maximum
Log home-range	A	↓	Ratio-scale	Maximum
Food preference	A	↑	Ratio-scale	Maximum
Food needs	A	↑	Ratio-scale	Maximum
Hibernation	A	↓	Interval-scale	Interval
Season dependent presence	A	↑	Interval-scale	Interval
Home range < distribution cont.	A	↑	Interval-scale	Interval
Log Field Metabolic Rate	B	↓	Ratio-scale	Maximum
Hibernation	B	↑	Interval-scale	Interval
Season dependent presence	B	↓	Interval-scale	Interval
Storage organs	B	↓	Binary	-
Excretion organs	B	↓	Binary	-
Detoxification mechanisms	B	↓	Binary	-
Toxicological sensitivity	C	↑	Interval-scale	Interval
Age at first reproduction	D	↑	Ratio-scale	Maximum
Log number of offspring in life	D	↓	Ratio-scale	Maximum
Survival juveniles until first reproduction	D	↓	Ratio-scale	Maximum
Dispersal capacity	D	↑	Interval-scale	Interval
Living-area patchy or dense	D	↑	Binary	-
Territory behaviour	D	↑	Interval-scale	Interval

Characteristics in main category A: external exposure

Habitat-/substrate choice

This characteristic indicates in which habitat or on which substrate the species lives. Five habitats/substrates are distinguished and defined as classes:

Habitat/substrate	Zn, Cu, Cd, DDT	Chlorpyrifos	Ivermectin
Vegetation/others	1	5	1
On soil	2	3.5	5
In water	3	1	1
In soil	4	3.5	5
In sediment	5	2	1

For 'classic' soil contaminants (Zn, Cu, Cd, DDT) this classification is based on the fact that species that live on the vegetation are physically less exposed to substances in the soil, and therefore are less vulnerable for these substances. Most vulnerable are species that live in the sediment, because they are continuously exposed to the substances. The other habitats or substrates are scaled in between. For chlorpyrifos and ivermectin, the ranking of the five different habitat types is different. Chlorpyrifos is applied on vegetation; therefore this habitat type has the highest rank. Environmental fate of ivermectin is mostly soil; therefore the two soil habitat types have the highest rank.

The choice of habitat of a species is not necessarily the same throughout life but can differ per life-stage. For the taxonomic groups in this vulnerability analyses the following life-stages will be distinguished. If for certain species another division is more appropriate, this will be mentioned in the fact-sheet concerning the species

The score for this characteristic for a species (that lives in different habitats or substrates) is calculated by multiplying the duration (months) with the class-number. This is done for each habitat/substrate class and these scores are then added up and divided by the total life-span (months) according to the formula:

$$\text{Score} = \frac{((L1*H1) + (L2*H2) + (L3*H3) + (L4*H4))}{(L1 + L2 + L3 + L4)}$$

in which: L = Duration of a life-stage

H = Habitat/substrate choice of the life-stage.

This characteristic is a ↑ characteristic. This means that the higher the value of this characteristic, the higher the chance of the organism to be exposed and the more vulnerable it will be. The scale is the ratio-scale because the calculation of a weighed average habitat choice depending on duration of life-stages makes it possible to create a continuous scale between 0 and the maximum. The standardisation is the maximum standardisation.

Taxonomic group	Life stages			
	1	2	3	4
Amphibians	Egg	Larvae	Adult	-
Dragonflies	Egg	Larvae	Adult	-
Reptiles	Egg	Larvae	Adult	-
Fish	Egg	Juvenile	Adult	-
Butterflies	Egg	Caterpillar	Pupae	Butterfly
Birds	Egg	Juvenile (until fledging)	Juvenile (after fledging)/Adult	-
Mammals	Nursed Juvenile	Independent Juvenile	Adult	-

Maximum life-span
This characteristic is expressed in months. It is a ↑ characteristic (benefit) which means that the higher the maximum life-span, the longer a species can be exposed to substances, the more vulnerable a species will be. The life-span is expressed as a ratio-scale and will be standardised according to the maximum standardisation.

Home-range
This characteristic expresses the size of the biotope of a species, expressed as the diameter of the biotope in meters. Because the differences between species are enormous, this characteristic is log-transformed. The variation of the home-range of species varies from 30 meters (Bullhead, *Cottus gobio*) to 3000000 meters (Allis Shad, *Alosa alosa*). The values of this characteristic lay on a ratio-scale, but when these values are used as they are, BOSdA will assign an unproportional importance to the highest values, while average values cannot be distinguished by BOSdA. The final ranking of the species will mainly be determined by this one characteristic only. Therefore a logarithmic transformation is performed on the values. With this transformation the characteristic is levelled, but the differences are still present.
Home-range is a ↓ characteristic. It is supposed that the larger the home-range of a species (and the larger its biotope), the smaller the chance of exposure to a substance in soil on a certain location is and the less vulnerable the species will be. This characteristic is also expressed in a ratio-scale and maximum standardised.

Food preference
This characteristic expresses the exposure to substances because of food preference. Four food types were distinguished. This division is based on the fact that some substances accumulate in the food chain. Predators will then be exposed to higher concentrations of substances.

Food	Class
Plants/nectar/seeds/fruit	1
Soil/detritus/litter	2
Insects/soil organisms/vertebrate herbivorous organisms	3
Vertebrate carnivore organisms	4

Like the characteristic habitat/substrate, food choice is not always the same in all life-stages. The duration of the different life-stages is taken into account with the calculation of the value for this characteristic. This calculation is performed with a similar formula as for habitat/substrate characteristic:

$$\text{Score} = \frac{((L1*F1) + (L2*F2) + (L3*F3) + (L4*F4))}{(L1 + L2 + L3 + L4)}$$

in which: L = duration of the life-stage (months)
F = food choice in the life-stage

This characteristic is a ↑ characteristic. This means that the higher the value for this characteristic for a species, the higher the exposure of a species to substances through the food will be, the more vulnerable a species is supposed to be. The value is expressed as on a ratio-scale and maximum-standardised.

Food needs
This characteristic expresses the amount of food ingested by an organism daily, expressed as gr/day. This characteristic is a ↑ characteristic which means that the more food a species ingests, the higher the exposure

to substances will be and the more vulnerable a species is supposed to be. It is difficult to find data on this characteristic for the species in this vulnerability analysis. For the taxonomic groups amphibians, dragonflies, reptiles and fish, food needs are estimated by an expert. For the taxonomic group butterflies food needs are estimated as 3 gr/day. For the taxonomic group of birds the food needs are dependent of body weight and of type of food. A general formula for birds is:

food need (gr/day) = 3,4*($BW^{(0,68)}$) (food choice 1)
food need (gr/day) = 1,7*($BW^{(0,68)}$) (food choice 2, 3, and 4)
in which BW = bodyweight in grams (based on Daan *et al.*, 1991).

For mammals the following formulas are used:

food need (gr/day) = 0,3*BW (if BW <100 gr)
food need (gr/day) = 0,1*BW (if BW >100 gr)
in which BW = bodyweight in grams (based on Daan *et al.*, 1991).

This characteristic is expressed on a ratio-scale and maximum standardised.

Characteristic hibernation
This characteristic expresses whether a species hibernates or not. The following division is used:

Hibernation	Class
Never	1
Not always	2
Always	3

It is supposed that a species that always hibernates has a smaller chance to be exposed to substances based on the fact that exposure during hibernation is nil. This characteristic is a ↓ characteristic. The higher the value for this characteristic, the smaller the chance of exposure, and the less vulnerable the species is. This characteristic is expressed on an interval-scale and is interval-standardised.

Characteristic season dependent presence
This characteristic expresses what part of the year a species is present, due to migrating for climatic reasons. The following classes are used for this characteristic:

Season dependent presence	Class
Sometimes or always present in winter, never in summer	1
Never present in winter, always present in summer	2
Sometimes present in winter, always present in summer	3
Always present, winter and summer	4

A species is supposed to be less exposed to substances when it migrates to another location. It is assumed that the substance is not present in the hibernating area. This characteristic is a ↑ characteristic, which means that if a species scores higher on this value, the higher the chance on exposure, the more vulnerable it will be. This characteristic is expressed on an interval-scale with an interval-standardisation.

Characteristic home range < distribution of contaminant
This is a contaminant specific characteristic, and is important for contaminants with a local distribution such as insecticides applied on a field, and veterinary pharmaceuticals distributed by cattle. In our study, chlorpyrifos and ivermectin are supposed to have a more patchy distribution. This increases the hazard for species with a small home range, for species with a large home range the patchy distribution of the contaminant reduces the vulnerability. The characteristic is scored on a yes/no binary scale for each species as home range < 1 hectare, with 1 hectare being arbitrarily defined as the average distribution of chlorpyrifos and ivermectin. This characteristic is therefore a ↑ characteristic.

Characteristics in main category B: internal exposure
Field Metabolic Rate
The higher the metabolism, the higher the chance that the species is able to excrete or detoxificate substances, the lower the internal exposure and also the vulnerability will be. The direction of this characteristic is a ↓ characteristic.

Field Metabolic Rate is calculated based on body weight, using the following formulas:

Rodent mammals:	$FMR = 10.52 * BW^{0.507}$ (Nagy, 1987)
Non-rodent mammals:	$FMR = 3.35 * BW^{0.813}$ (Nagy, 1987)
Passerine birds:	$FMR = 8.892 * BW^{0.749}$ (Nagy, 1987)
Sea birds	$FMR = 8.017 * BW^{0.704}$ (Nagy, 1987)
All other birds:	$FMR = 4.797 * BW^{0.749}$ (Nagy, 1987)
Butterflies:	$FMR = 15.212 * BW^{0.757}$ (Waser, 1982)
Dragonflies:	$FMR = 41.472 * BW$ (May, 1995)
Fish:	$FMR = 0.196 * BW^{0.889}$ (Nagy, 2005)
Amphibians:	$FMR = 0.196 * BW^{0.889}$ (Nagy, 2005)
Reptiles:	$FMR = 0.196 * BW^{0.889}$ (Nagy, 2005)

in which BW = bodyweight in grams, and FMR = Field Metabolic Rate in kJ/day.

To reduce impact of outliers, the values were log-transformed before used in the MCA. This characteristic is expressed on a ratio-scale and maximum standardised.

Hibernation
This characteristic is the same as treated under main category A. In this main category the characteristic deals with the use of the fat storage in the body during hibernation. A species that hibernates, uses its fat storage during winter to survive, the substances that are stored in the fat become available in the blood, through which exposure to substances takes place. Thus, in contrary to main category A, for internal exposure hibernation is a ↑ characteristic. The higher the score on this characteristic (more hibernation), the higher the chance of exposure to substances, the more vulnerable a species will be. Scale and standardisation are the same.

Season dependent presence
This also was treated in main category A. In main category B this characteristic means that if a species shows migratory behaviour, it will use its fat storage to travel, like in hibernation. Substances that are stored in the fat will become available in the blood, and the species is internally exposed. This is a ↓ characteristic. The lower the score on this characteristic (see table in main category A, more migration behaviour), the higher the chance that it will be exposed, and the higher the vulnerability of the species is supposed to be. Scale and standardisation are the same.

Storage organs
This characteristic expresses whether a species has organs to store substances. It is a ↓ characteristic on a binary scale (yes/no). If a species has storage organs this characteristic scores 'yes', otherwise it scores 'no'. A species that uses storage organs is supposed to be less vulnerable, because through internal storage of substances, exposure will be lower. For this vulnerability analysis, too few literature data were found to determine the presence of storage organs for each species. The choice has been made to score species within taxonomical groups the same. There is a difference for substances, because many species can store the substances cadmium and DDT, but can't store copper and zinc. Insufficient data is available for Chlorpyrifos and Ivermectin, a 'yes' was scored for all groups. This characteristic has a binary scale, which does not need to be standardised.

Taxonomic group	Copper	Zinc	Cadmium	DDT	Chlorpyrifos	Ivermectin
Amphibians	yes	yes	yes	yes	yes	yes
Dragonflies	yes	yes	yes	yes	yes	yes
Reptiles	yes	yes	yes	yes	yes	yes
Fish	yes	yes	yes	yes	yes	yes
Butterflies	yes	yes	yes	yes	yes	yes
Birds	no	no	yes	yes	yes	yes
Mammals	no	no	yes	yes	yes	yes

Excretion mechanisms
This characteristic expresses whether a species uses excretion mechanisms for excreting substances from its body. If a species uses such mechanisms the characteristic is scored with 'yes', otherwise with 'no'. The use of such mechanisms means that substances can be excreted and that exposure is smaller. This means that a species is less vulnerable. As for storage organs (see previous paragraph), data were insufficient to determine to the species level whether excretion mechanisms occur, a score is assigned on taxonomic group level.

Insufficient data is available for Chlorpyrifos and Ivermectin, a 'yes' was scored for all groups. This characteristic has a binary scale, which does not need to be standardised.

Taxonomic group	Copper	Zinc	Cadmium	DDT	Chlorpyrifos	Ivermectin
Amphibians	yes	yes	yes	yes	yes	yes
Dragonflies	yes	yes	yes	yes	yes	yes
Reptiles	yes	yes	yes	yes	yes	yes
Fish	yes	yes	yes	yes	yes	yes
Butterflies	yes	yes	yes	yes	yes	yes
Birds	yes	yes	no	yes	yes	yes
Mammals	yes	yes	no	yes	yes	yes

Detoxification mechanisms

This characteristic expresses whether a species uses detoxification mechanisms to make substances harmless. If a species uses such mechanisms the characteristic is scored with 'yes' otherwise with 'no'. The use of such mechanisms means that substances can be detoxified to be harmless for the species and that internal exposure is smaller. This means that a species is less vulnerable. As for storage organs and excretion mechanisms (see previous paragraphs), data were insufficient to determine to the species level whether detoxification mechanisms occur. Insufficient data is available for Chlorpyrifos and Ivermectin, a 'yes' was scored for all groups. This characteristic has a binary scale, which does not need to be standardised.

Taxonomic group	Copper	Zinc	Cadmium	DDT	Chlorpyrifos	Ivermectin
Amphibians	yes	yes	yes	yes	yes	yes
Dragonflies	yes	yes	yes	yes	yes	yes
Reptiles	yes	yes	yes	yes	yes	yes
Fish	yes	yes	yes	yes	yes	yes
Butterflies	yes	yes	yes	yes	yes	yes
Birds	no	no	no	yes	yes	yes
Mammals	no	no	no	yes	yes	yes

Characteristics in main category C: Effects on individual level

Intrinsic toxicological sensitivity

This means the sensitivity of a species for a contaminant. Unfortunately, very few ecotoxicological data are available for our specific target species. For the common species, very limited ecotoxicological data are available. It was therefore decided to estimate ecotoxicological sensitivity not on species level but on taxonomic group level, as a score from 1 to 4, in which 1 = very slightly toxic, 2 = slightly toxic, 3 = moderately toxic, and 4 = toxic.

Taxonomic group	Copper	Zinc	Cadmium	DDT	Chlorpyrifos	Ivermectin
Amphibians	3	2	3	4	4	3
Dragonflies	3	3	4	4	4	2
Reptiles	1	1	2	2	2	3
Fish	3	2	4	4	4	2
Butterflies	1	1	1	2	2	2
Birds	1	1	2	2	3	2
Mammals	1	1	2	1	2	1

Characteristics in main category D: Effects on population level

Age at first reproduction

This characteristic expresses at what age (in months) species reproduce for the first time in life. It is supposed that species that reproduce later in life are more vulnerable for substances. This is based on the assumption that due to effects of substances these species could possibly not reach the age of reproduction because they are longer exposed to the substance. This characteristic is a ↑characteristic, which means that the older at first reproduction the more vulnerable the species is. The characteristic is expressed on a ratio-scale and maximum standardised.

Number of produced offspring in life
This characteristic expresses the number of offspring that maximally could be produced by an organism in its whole life. This characteristic often has to be calculated from other data according to the following formula:

$$N = ((L_{max} - L_{1e})*A_1*R_j/12))$$

in which: N = the maximum number of offspring produced in life
L_{max} = maximum life-span
L_{1e} = age at first reproduction
A_1 = clutch size
R_j = number of clutches per year

Because the maximum number of offspring differs enormously between species (due to different strategies) this characteristic is log-transformed. This characteristic is a ↓ characteristic, which means that the less offspring produced in life, the more vulnerable the population of the species is supposed to be. The characteristic is expressed on a ratio-scale and is maximum standardised.

Survival of offspring until first reproduction
In the previous characteristic the theoretical total number of offspring was calculated. In reality only a part of the juveniles survives before the reproductive age is reached. Species that produce enormous numbers of offspring often have a high mortality-rate, because they put most energy in reproduction (r-strategists). This characteristic is an expression of the survival until first reproduction. This characteristic is a ↓ characteristic which means, the lower the percentage of survival until first reproduction, the more vulnerable the population of species is supposed to be. This characteristic is expressed on a ratio-scale and is maximum standardised.

Dispersal capacity
This characteristic expresses the ability of species to disperse over the available space. Populations of species with a low dispersal capacity have a higher risk of (local) extinction due to the presence of substances then species with a high dispersal capacity, which can easily colonise new habitats. Five classes of dispersal capacity are defined. For a few taxonomic groups, dispersal is well described (butterflies). For the other species estimation was made on the basis of known dispersal of the species in the Netherlands, faithfulness to location and migration behaviour. This division is:

Dispersal capacity	Class
Very small dispersal capacity	5
…	4
…	3
…	2
Free distribution	1

This characteristic is a ↑ characteristic. The higher the score for this characteristic, the smaller the dispersal capacity is and the more difficult a species can disperse to other areas. This means that the species is vulnerable for substances. This characteristic is expressed on an interval-scale, and is interval-standardised.

Characteristic distribution patchy or dense
This characteristic is an expression of the distribution of species and populations in their biotope. It is a binary characteristic, which means that the score is either 'patchy' or 'dense'. This characteristic is a ↑ characteristic. It is supposed that a population of species with a patchy distribution has a smaller ability for colonisation in other areas or spreading in their biotope than other species with a dense distribution. The first species or population is supposed to be more vulnerable. This means that suitable patches in their biotope will longer be empty. The characteristic is expressed on a binary scale.

Characteristic territory behaviour
This characteristic is an expression whether protection by species of their biotope is occurring. The following sub-division is made:

Territory behaviour	Class
Always	3
Not always	2
Never	1

If a species only shows territory behaviour in breeding time or only near the nest, it is placed in class 2. This characteristic is a ↑ characteristic. A species that shows territory behaviour is not able to move free in the available space. A species that does not show this behaviour, on the contrary, can settle down wherever it is able to because it is not threatened by conspecifics. This last species is able to colonise new habitats or places in its biotope more easily. A species that shows territory behaviour is supposed to be more vulnerable because the chance that this species cannot use all of its biotope is higher. This characteristic is expressed on an interval-scale and is interval standardised.

Weight factors
With the definition of the aspect and the score for each species (on the datasheets) it is possible to run the MCA resulting in a ranking of species on a vulnerability-axis. By the use of weighing factors, for aspects as well as for categories, BOSdA offers the possibility to judge the aspects to their relative contribution to vulnerability. This contribution is substance dependent. For substances that accumulate in the food-chain, food-choice is of high importance, while for a substance that is regulated inside the body, this aspect is of less relevance. Weighing-factors determine the importance of the different aspects. The weighing-factors are determined (for this vulnerability analysis) by expert-judgement. The six tested chemicals have different internal exposure routes. These routes have influence on the weights given to each characteristic. Copper and zinc are (regulated) essential metals, cadmium is a non-essential metal. DDT is a non essential organic substance. Chlorpyrifos and Ivermectin are both persistent lipophilic substances, which can be detoxified within organisms. The weighing factors are presented in the following table; a further explanation is given below the table.

	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
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
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, and as explained before, 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.

Weights within main category A: External Exposure

For the non-accumulating substances copper and zinc three characteristics are not relevant: maximum life-span, food choice and food needs; and thus are given weight = 0. For these two metals exposure of species via the substrate in which they live is the most important characteristic. With this, 'home-range' is more important than 'hibernation' and 'season dependent presence'. It is not duration of exposure that is important for these two metals, but concentration.

By contrast, because of the accumulation potency of cadmium and DDT exposure through food is more important (characteristics food choice and food needs). Duration of exposure is a very important factor with accumulating substances. Therefore the characteristic maximum life-span is given a larger weight. Exposure through the substrate in which species live is for these substances less important.

Chlorpyrifos and Ivermectin have an intermediate position. Exposure through habitat choice, presence and home range is given the largest weight, but exposure does also take place through food choice and food needs.

Weights within main category B: Internal exposure

For DDT and cadmium the characteristics that deal with processes that make them unavailable (detoxification, storage and excretion) are important characteristics and have a high weight. Together with these characteristics, habits of species that can make substances internally available (like hibernation and migration, use of fat-reserves) are important as well for DDT. For cadmium these two characteristics are relatively less important because this metal is stored in kidney and liver and does not become available when fat-reserves are used.

For Chlorpyrifos and Ivermectin detoxification processes are considered important, as well as metabolic rate. Storage and excretion are less important. Hibernation and migration are supposed not to increase internal concentrations, since detoxification processes occur faster than release of substance from fat reserve.

For the essential metals copper and zinc it is supposed that detoxification mechanisms play no important role at all, because these substances are internally regulated. Storage-organs are not present for these metals and they do not become extra available during hibernation or migration.

Weights within main category D: Effects on population level

In this main category mechanisms that support population recovery from effects are important. These characteristics are independent of contaminant, and therefore are given the same weighing factors. The largest weight is attributed to dispersal capacity because species that have a low dispersal capacity have a high chance to become locally extinct because of the presence of substances. The chance to re-colonise the lost territory is small with these species. Characteristics that deal with spreading within the biotope of species (patchiness and territory behaviour) are of less importance because they only have influence on re-colonisation but not on becoming locally extinct. Characteristics that are involved in the population recovery and maintenance through reproduction and (population) growth (characteristics number of juveniles, time until first reproduction, survival of juveniles to first reproduction, *etc.*) are less important, but play a role.

Appendix 5 – MCA results Zinc

Zinc results: rank for scenario 1, species name and code, scores for each category, and final scores using two scenarios: scenario 1: weights A = 0.333, B = 0.333 and D = 0.333; scenario 2: weights A = 0.317, B = 0.317, C = 0.05, D = 0.317.

Rank	Species name	Code	Main category A	Main category B	Main category C	Main category D	Scenario 1	Scenario 2
1	Bullhead	FISH7	0.94	0.15	0.33	0.65	0.58	0.57
2	Stone Loach	FISH2	0.90	0.17	0.33	0.61	0.56	0.55
3	Alpine Newt	AMPH1	0.71	0.18	0.33	0.76	0.55	0.54
4	Palmate Newt	AMPH6	0.71	0.18	0.33	0.73	0.54	0.53
5	Great Crested Newt	AMPH3	0.71	0.17	0.33	0.73	0.54	0.53
6	Scarce chaser	DFLY5	0.84	0.11	0.67	0.64	0.53	0.54
7	Mole	MAMa	0.83	0.09	0	0.67	0.53	0.50
8	Green Hawker	DFLY2	0.66	0.11	0.67	0.79	0.52	0.53
9	Norfolk Damselfly	DFLY4	0.67	0.13	0.67	0.71	0.50	0.51
10	Catfish	FISH4	0.90	0.05	0.33	0.56	0.50	0.50
11	Three Spined Stickleback	FISHb	0.63	0.2	0.33	0.66	0.50	0.49
12	Hairy Dragonfly	DFLY3	0.67	0.11	0.67	0.71	0.50	0.51
13	Norfolk Hawker	DFLY1	0.66	0.11	0.67	0.70	0.49	0.50
14	Alcon Blue	BFLY2	0.61	0.11	0	0.74	0.49	0.46
15	Viviparous Lizard	REPa	0.48	0.18	0	0.78	0.48	0.46
16	Common Spadefoot	AMPH4	0.66	0.15	0.33	0.57	0.46	0.45
17	Northern Water Shrew	MAM7	0.74	0.11	0	0.53	0.46	0.44
18	Common Tern	BIRD50	0.57	0.08	0	0.73	0.46	0.44
19	Slow Worm	REP3	0.51	0.13	0	0.72	0.45	0.43
20	Sand Lizard	REP5	0.46	0.15	0	0.74	0.45	0.43
21	Poolfrog	AMPHa	0.50	0.17	0.33	0.67	0.45	0.44
22	Dusky Large Blue	BFLY7	0.48	0.11	0	0.74	0.44	0.42
23	Scarce Large Blue	BFLY16	0.48	0.11	0	0.74	0.44	0.42
24	Common Blue Damselfly	DFLYa	0.79	0.18	0.67	0.36	0.44	0.46
25	Common Rat	MAMb	0.69	0.08	0	0.55	0.44	0.42
26	Little Grebe	BIRD4	0.68	0.08	0	0.55	0.44	0.42
27	Marsh Fritillary	BFLY15	0.47	0.11	0	0.73	0.44	0.42
28	White Bream	FISH6	0.63	0.10	0.33	0.57	0.43	0.43
29	Carp	FISHa	0.65	0.02	0.33	0.61	0.43	0.42
30	Green Treefrog	AMPH2	0.47	0.17	0.33	0.62	0.42	0.42
31	Great Reed Warbler	BIRD13	0.43	0.09	0	0.74	0.42	0.40
32	Siberian Winter Damselfly	DFLY6	0.43	0.13	0.67	0.70	0.42	0.43
33	Barbel	FISH1	0.66	0.04	0.33	0.55	0.42	0.41
34	Large Chequered Skipper	BFLY19	0.40	0.11	0	0.74	0.42	0.40
35	Brown Argus	BFLY5	0.47	0.11	0	0.66	0.41	0.39
36	Scooty Copper	BFLY6	0.46	0.11	0	0.67	0.41	0.39
37	Purple-edged Copper	BFLY17	0.46	0.11	0	0.67	0.41	0.39
38	Oystercatcher	BIRDh	0.55	0.06	0	0.63	0.41	0.39
39	Large Blue	BFLY20	0.47	0.11	0	0.66	0.41	0.39
40	Small Pearl-Bordered Fritillary	BFLY23	0.47	0.11	0	0.66	0.41	0.39
41	Grizzled skipper	BFLY1	0.45	0.11	0	0.67	0.41	0.39

Table MCA results Zinc (continued)

Rank	Species name	Code	Main category A	Main category B	Main category C	Main category D	Scenario 1	Scenario 2
42	Grey Heron	BIRDf	0.62	0.04	0	0.57	0.41	0.39
43	Mazarine Blue	BFLY12	0.46	0.11	0	0.66	0.41	0.39
44	Natterjack Toad	AMPH5	0.67	0.15	0.33	0.41	0.41	0.41
45	Glanville Fritillary	BFLY22	0.46	0.11	0	0.66	0.41	0.39
46	Dark Green Fritillary	BFLY10	0.45	0.11	0	0.66	0.41	0.39
47	Red-crested Pochard	BIRD23	0.60	0.04	0	0.58	0.41	0.39
48	Brown Hairstreak	BFLY18	0.37	0.11	0	0.74	0.41	0.39
49	Niobe Fritillary	BFLY8	0.44	0.11	0	0.66	0.40	0.38
50	Coot	BIRDg	0.59	0.05	0	0.57	0.40	0.38
51	Common Adder	REP1	0.44	0.11	0	0.64	0.40	0.38
52	Tawny Pipit	BIRD6	0.51	0.10	0	0.58	0.40	0.38
53	Little Owl	BIRD45	0.49	0.08	0	0.62	0.40	0.38
54	Black Tern	BIRD56	0.58	0.09	0	0.52	0.40	0.38
55	Night Heron	BIRD24	0.58	0.05	0	0.55	0.39	0.37
56	Avocet	BIRD21	0.59	0.07	0	0.52	0.39	0.37
57	Tufted Duck	BIRDc	0.69	0.05	0	0.44	0.39	0.37
58	Otter	MAM8	0.59	0.01	0	0.58	0.39	0.37
59	Badger	MAM1	0.48	0	0	0.68	0.39	0.37
60	Blackbird	BIRDd	0.56	0.07	0	0.53	0.39	0.37
61	Pearly Heath	BFLY21	0.38	0.11	0	0.67	0.39	0.37
62	Geoffroy's Bat	MAM5	0.40	0.13	0	0.63	0.39	0.37
63	Chequered Skipper	BFLY4	0.37	0.11	0	0.67	0.38	0.36
64	Small Skipper	BFLY9	0.38	0.11	0	0.66	0.38	0.36
65	Water Rail	BIRD51	0.58	0.08	0	0.49	0.38	0.36
66	Lapwing	BIRDi	0.53	0.07	0	0.54	0.38	0.36
67	Savi's Warbler	BIRD44	0.56	0.1	0	0.48	0.38	0.36
68	Greater Mouse-eared Bat	MAM6	0.37	0.11	0	0.66	0.38	0.36
69	Hen Harrier	BIRD3	0.48	0.06	0	0.60	0.38	0.36
70	Northern Vole	MAM4	0.60	0.10	0	0.44	0.38	0.36
71	White Stork	BIRD30	0.48	0.03	0	0.63	0.38	0.36
72	Hooded Crow	BIRDe	0.55	0.04	0	0.54	0.38	0.36
73	Snipe	BIRD52	0.52	0.09	0	0.52	0.38	0.36
74	Pearl-Bordered Fritillary	BFLY3	0.36	0.11	0	0.66	0.38	0.36
75	Large Copper	BFLY24	0.36	0.11	0	0.65	0.37	0.36
76	Black-tailed Godwit	BIRD14	0.48	0.07	0	0.57	0.37	0.36
77	Black Grouse	BIRD22	0.47	0.05	0	0.60	0.37	0.36
78	Arctic Tern	BIRD28	0.55	0.08	0	0.48	0.37	0.35
79	Ide	FISH8	0.59	0.06	0.33	0.46	0.37	0.37
80	Smooth Snake	REP2	0.44	0.10	0	0.56	0.37	0.35
81	Whitethroat	BIRDj	0.50	0.10	0	0.50	0.37	0.35
82	Sand Martin	BIRD29	0.44	0.11	0	0.54	0.36	0.35
83	Bluethroat	BIRD2	0.42	0.10	0	0.56	0.36	0.34
84	Natterer's Bat	MAM2	0.40	0.13	0	0.55	0.36	0.34
85	Bittern	BIRD40	0.54	0.05	0	0.49	0.36	0.34
86	Silver-spotted Skipper	BFLY14	0.37	0.11	0	0.59	0.36	0.34
87	Spoonbill	BIRD26	0.54	0.04	0	0.49	0.36	0.34
88	Mallard	BIRDa	0.66	0.05	0	0.36	0.36	0.34

Table MCA results Zinc (continued)

Rank	Species name	Code	Main category A	Main category B	Main category C	Main category D	Scenario 1	Scenario 2
89	Yellowhammer	BIRD8	0.43	0.10	0	0.53	0.35	0.34
90	Kingfisher	BIRD16	0.48	0.10	0	0.48	0.35	0.34
91	Sedge Warbler	BIRD38	0.45	0.11	0	0.50	0.35	0.34
92	Grass Snake	REP4	0.45	0.10	0	0.51	0.35	0.34
93	Little Ringed Plover	BIRD20	0.51	0.10	0	0.43	0.35	0.33
94	Pintail	BIRD34	0.68	0.05	0	0.31	0.35	0.33
95	Bearded Tit	BIRD1	0.49	0.11	0	0.43	0.34	0.33
96	Corncrake	BIRD25	0.51	0.08	0	0.44	0.34	0.33
97	Spotted Crake	BIRD35	0.58	0.09	0	0.36	0.34	0.33
98	Field Vole	MAMd	0.54	0.11	0	0.37	0.34	0.32
99	Twaite Shad	FISH5	0.51	0.08	0.33	0.43	0.34	0.34
100	Little Bittern	BIRD54	0.41	0.08	0	0.52	0.34	0.32
101	Little Tern	BIRD7	0.46	0.10	0	0.44	0.33	0.32
102	Red-backed Shrike	BIRD11	0.43	0.09	0	0.48	0.33	0.32
103	Partridge	BIRD33	0.52	0.06	0	0.42	0.33	0.32
104	Stonechat	BIRD41	0.45	0.10	0	0.45	0.33	0.32
105	Northern Wheatear	BIRD46	0.43	0.10	0	0.47	0.33	0.32
106	Garganey	BIRD55	0.50	0.06	0	0.43	0.33	0.31
107	Montagu's Harrier	BIRD10	0.39	0.07	0	0.52	0.33	0.31
108	Green Woodpecker	BIRD12	0.48	0.06	0	0.44	0.33	0.31
109	Redshank	BIRD48	0.42	0.08	0	0.48	0.33	0.31
110	Hoopoe	BIRD15	0.39	0.09	0	0.49	0.32	0.31
111	Raven	BIRD37	0.46	0.03	0	0.48	0.32	0.31
112	Bank Vole	MAMc	0.54	0.11	0	0.31	0.32	0.30
113	Large Tortoiseshell	BFLY11	0.38	0.11	0	0.44	0.31	0.29
114	Shoveler	BIRD43	0.58	0.06	0	0.29	0.31	0.29
115	Great Grey Shrike	BIRD19	0.40	0.08	0	0.44	0.31	0.29
116	Queen of Spain Fritillary	BFLY13	0.35	0.11	0	0.46	0.31	0.29
117	Nightjar	BIRD27	0.43	0.08	0	0.41	0.31	0.29
118	Allis Shad	FISH3	0.47	0.08	0.33	0.36	0.30	0.30
119	Whinchat	BIRD32	0.42	0.10	0	0.39	0.30	0.29
120	Barn Owl	BIRD18	0.48	0.07	0	0.33	0.29	0.28
121	Kestrel	BIRD47	0.44	0.08	0	0.36	0.29	0.28
122	Pine Marten	MAM3	0.45	0.04	0	0.38	0.29	0.28
123	Greylag Goose	BIRD9	0.51	0.03	0	0.33	0.29	0.28
124	Short-eared Owl	BIRD49	0.40	0.07	0	0.40	0.29	0.28
125	Golden Oriole	BIRD53	0.40	0.08	0	0.38	0.29	0.27
126	Buzzard	BIRDb	0.38	0.05	0	0.42	0.28	0.27
127	Wryneck	BIRD5	0.41	0.10	0	0.34	0.28	0.27
128	Purple Heron	BIRD36	0.36	0.05	0	0.44	0.28	0.27
129	Ortolan Bunting	BIRD31	0.41	0.10	0	0.33	0.28	0.27
130	Woodchat Shrike	BIRD42	0.43	0.09	0	0.32	0.28	0.27
131	Large White	BFLYb	0.33	0.11	0	0.37	0.27	0.26
132	Ruff	BIRD17	0.42	0.08	0	0.29	0.26	0.25
133	Brimstone	BFLYc	0.38	0.11	0	0.28	0.26	0.24
134	Red Admiral	BFLYa	0.30	0.11	0	0.31	0.24	0.23
135	Red Kite	BIRD39	0.38	0.05	0	0.29	0.24	0.23

Appendix 6 – MCA results Copper

Copper results: rank for scenario 1, species name and code, scores for each category, and final scores using two scenarios: scenario 1: weights A = 0.333, B = 0.333 and D = 0.333; scenario 2: weights A = 0.317, B = 0.317, C = 0.05, D = 0.317.

Rank	Species	Code	Main category A	Main category B	Main category C	Main category D	Scenario 1	Scenario 2
1	Bullhead	FISH7	0.94	0.15	0.67	0.65	0.58	0.59
2	Stone Loach	FISH2	0.90	0.17	0.67	0.61	0.56	0.57
3	Alpine Newt	AMPH1	0.71	0.18	0.67	0.76	0.55	0.56
4	Palmate Newt	AMPH6	0.71	0.18	0.67	0.73	0.54	0.55
5	Great Crested Newt	AMPH3	0.71	0.17	0.67	0.73	0.54	0.54
6	Scarce chaser	DFLY5	0.84	0.11	0.67	0.64	0.53	0.54
7	Mole	MAMa	0.83	0.09	0	0.67	0.53	0.50
8	Green Hawker	DFLY2	0.66	0.11	0.67	0.79	0.52	0.53
9	Norfolk Damselfly	DFLY4	0.67	0.13	0.67	0.71	0.50	0.51
10	Catfish	FISH4	0.90	0.05	0.67	0.56	0.50	0.51
11	Three-spined Stickleback	FISHb	0.63	0.20	0.67	0.66	0.50	0.51
12	Hairy Dragonfly	DFLY3	0.67	0.11	0.67	0.71	0.50	0.51
13	Norfolk Hawker	DFLY1	0.66	0.11	0.67	0.70	0.49	0.50
14	Alcon Blue	BFLY2	0.61	0.11	0	0.74	0.49	0.46
15	Viviparous Lizard	REPa	0.48	0.18	0	0.78	0.48	0.46
16	Common Spadefoot	AMPH4	0.66	0.15	0.67	0.57	0.46	0.47
17	Northern Water Shrew	MAM7	0.74	0.11	0	0.53	0.46	0.44
18	Common Tern	BIRD50	0.57	0.08	0	0.73	0.46	0.44
19	Slow Worm	REP3	0.51	0.13	0	0.72	0.45	0.43
20	Sand Lizard	REP5	0.46	0.15	0	0.74	0.45	0.43
21	Poolfrog	AMPHa	0.50	0.17	0.67	0.67	0.45	0.46
22	Dusky Large Blue	BFLY7	0.48	0.11	0	0.74	0.44	0.42
23	Scarce Large Blue	BFLY16	0.48	0.11	0	0.74	0.44	0.42
24	Common Blue Damselfly	DFLYa	0.79	0.18	0.67	0.36	0.44	0.46
25	Common Rat	MAMb	0.69	0.08	0	0.55	0.44	0.42
26	Little Grebe	BIRD4	0.68	0.08	0	0.55	0.44	0.42
27	Marsh Fritillary	BFLY15	0.47	0.11	0	0.73	0.44	0.42
28	White Bream	FISH6	0.63	0.10	0.67	0.57	0.43	0.45
29	Carp	FISHa	0.65	0.02	0.67	0.61	0.43	0.44
30	Green Treefrog	AMPH2	0.47	0.17	0.67	0.62	0.42	0.43
31	Great Reed Warbler	BIRD13	0.43	0.09	0	0.74	0.42	0.40
32	Siberian Winter Damselfly	DFLY6	0.43	0.13	0.67	0.70	0.42	0.43
33	Barbel	FISH1	0.66	0.04	0.67	0.55	0.42	0.43
34	Large Chequered Skipper	BFLY19	0.40	0.11	0	0.74	0.42	0.40
35	Brown Argus	BFLY5	0.47	0.11	0	0.66	0.41	0.39
36	Scooty Copper	BFLY6	0.46	0.11	0	0.67	0.41	0.39
37	Purple-edged Copper	BFLY17	0.46	0.11	0	0.67	0.41	0.39
38	Oystercatcher	BIRDh	0.55	0.06	0	0.63	0.41	0.39
39	Large Blue	BFLY20	0.47	0.11	0	0.66	0.41	0.39
40	Small Pearl-Bordered Fritillary	BFLY23	0.47	0.11	0	0.66	0.41	0.39
41	Grizzled skipper	BFLY1	0.45	0.11	0	0.67	0.41	0.39
42	Grey Heron	BIRDf	0.62	0.04	0	0.57	0.41	0.39

Table MCA results Copper (continued)

Rank	Species	Code	Main category A	Main category B	Main category C	Main category D	Scenario 1	Scenario 2
43	Mazarine Blue	BFLY12	0.46	0.11	0	0.66	0.41	0.39
44	Natterjack Toad	AMPH5	0.67	0.15	0.67	0.41	0.41	0.42
45	Glanville Fritillary	BFLY22	0.46	0.11	0	0.66	0.41	0.39
46	Dark Green Fritillary	BFLY10	0.45	0.11	0	0.66	0.41	0.39
47	Red-crested Pochard	BIRD23	0.60	0.04	0	0.58	0.41	0.39
48	Brown Hairstreak	BFLY18	0.37	0.11	0	0.74	0.41	0.39
49	Niobe Fritillary	BFLY8	0.44	0.11	0	0.66	0.40	0.38
50	Coot	BIRDg	0.59	0.05	0	0.57	0.40	0.38
51	Common Adder	REP1	0.44	0.11	0	0.64	0.40	0.38
52	Tawny Pipit	BIRD6	0.51	0.10	0	0.58	0.40	0.38
53	Little Owl	BIRD45	0.49	0.08	0	0.62	0.40	0.38
54	Black Tern	BIRD56	0.58	0.09	0	0.52	0.40	0.38
55	Night Heron	BIRD24	0.58	0.05	0	0.55	0.39	0.37
56	Avocet	BIRD21	0.59	0.07	0	0.52	0.39	0.37
57	Tufted Duck	BIRDc	0.69	0.05	0	0.44	0.39	0.37
58	Otter	MAM8	0.59	0.01	0	0.58	0.39	0.37
59	Badger	MAM1	0.48	0.00	0	0.68	0.39	0.37
60	Blackbird	BIRDd	0.56	0.07	0	0.53	0.39	0.37
61	Pearly Heath	BFLY21	0.38	0.11	0	0.67	0.39	0.37
62	Geoffroy's Bat	MAM5	0.40	0.13	0	0.63	0.39	0.37
63	Chequered Skipper	BFLY4	0.37	0.11	0	0.67	0.38	0.36
64	Small Skipper	BFLY9	0.38	0.11	0	0.66	0.38	0.36
65	Water Rail	BIRD51	0.58	0.08	0	0.49	0.38	0.36
66	Lapwing	BIRDi	0.53	0.07	0	0.54	0.38	0.36
67	Savi's Warbler	BIRD44	0.56	0.10	0	0.48	0.38	0.36
68	Greater Mouse-eared Bat	MAM6	0.37	0.11	0	0.66	0.38	0.36
69	Hen Harrier	BIRD3	0.48	0.06	0	0.60	0.38	0.36
70	Northern Vole	MAM4	0.60	0.10	0	0.44	0.38	0.36
71	White Stork	BIRD30	0.48	0.03	0	0.63	0.38	0.36
72	Hooded Crow	BIRDe	0.55	0.04	0	0.54	0.38	0.36
73	Snipe	BIRD52	0.52	0.09	0	0.52	0.38	0.36
74	Pearl-Bordered Fritillary	BFLY3	0.36	0.11	0	0.66	0.38	0.36
75	Large Copper	BFLY24	0.36	0.11	0	0.65	0.37	0.36
76	Black-tailed Godwit	BIRD14	0.48	0.07	0	0.57	0.37	0.36
77	Black Grouse	BIRD22	0.47	0.05	0	0.60	0.37	0.36
78	Arctic Tern	BIRD28	0.55	0.08	0	0.48	0.37	0.35
79	Ide	FISH8	0.59	0.06	0.67	0.46	0.37	0.39
80	Smooth Snake	REP2	0.44	0.10	0	0.56	0.37	0.35
81	Whitethroat	BIRDj	0.50	0.10	0	0.50	0.37	0.35
82	Sand Martin	BIRD29	0.44	0.11	0	0.54	0.36	0.35
83	Bluethroat	BIRD2	0.42	0.10	0	0.56	0.36	0.34
84	Natterer's Bat	MAM2	0.40	0.13	0	0.55	0.36	0.34
85	Bittern	BIRD40	0.54	0.05	0	0.49	0.36	0.34
86	Silver-spotted Skipper	BFLY14	0.37	0.11	0	0.59	0.36	0.34
87	Spoonbill	BIRD26	0.54	0.04	0	0.49	0.36	0.34
88	Mallard	BIRDa	0.66	0.05	0	0.36	0.36	0.34
89	Yellowhammer	BIRD8	0.43	0.10	0	0.53	0.35	0.34
90	Kingfisher	BIRD16	0.48	0.10	0	0.48	0.35	0.34

Table MCA results Copper (continued)

Rank	Species	Code	Main category A	Main category B	Main category C	Main category D	Scenario 1	Scenario 2
91	Sedge Warbler	BIRD38	0.45	0.11	0	0.50	0.35	0.34
92	Grass Snake	REP4	0.45	0.10	0	0.51	0.35	0.34
93	Little Ringed Plover	BIRD20	0.51	0.10	0	0.43	0.35	0.33
94	Pintail	BIRD34	0.68	0.05	0	0.31	0.35	0.33
95	Bearded Tit	BIRD1	0.49	0.11	0	0.43	0.34	0.33
96	Corncrake	BIRD25	0.51	0.08	0	0.44	0.34	0.33
97	Spotted Crake	BIRD35	0.58	0.09	0	0.36	0.34	0.33
98	Field Vole	MAMd	0.54	0.11	0	0.37	0.34	0.32
99	Twaite Shad	FISH5	0.51	0.08	0.67	0.43	0.34	0.36
100	Little Bittern	BIRD54	0.41	0.08	0	0.52	0.34	0.32
101	Little Tern	BIRD7	0.46	0.10	0	0.44	0.33	0.32
102	Red-backed Shrike	BIRD11	0.43	0.09	0	0.48	0.33	0.32
103	Partridge	BIRD33	0.52	0.06	0	0.42	0.33	0.32
104	Stonechat	BIRD41	0.45	0.10	0	0.45	0.33	0.32
105	Northern Wheatear	BIRD46	0.43	0.10	0	0.47	0.33	0.32
106	Garganey	BIRD55	0.50	0.06	0	0.43	0.33	0.31
107	Montagu's Harrier	BIRD10	0.39	0.07	0	0.52	0.33	0.31
108	Green Woodpecker	BIRD12	0.48	0.06	0	0.44	0.33	0.31
109	Redshank	BIRD48	0.42	0.08	0	0.48	0.33	0.31
110	Hoopoe	BIRD15	0.39	0.09	0	0.49	0.32	0.31
111	Raven	BIRD37	0.46	0.03	0	0.48	0.32	0.31
112	Bank Vole	MAMc	0.54	0.11	0	0.31	0.32	0.30
113	Large Tortoiseshell	BFLY11	0.38	0.11	0	0.44	0.31	0.29
114	Shoveler	BIRD43	0.58	0.06	0	0.29	0.31	0.29
115	Great Grey Shrike	BIRD19	0.40	0.08	0	0.44	0.31	0.29
116	Queen of Spain Fritillary	BFLY13	0.35	0.11	0	0.46	0.31	0.29
117	Nightjar	BIRD27	0.43	0.08	0	0.41	0.31	0.29
118	Allis Shad	FISH3	0.47	0.08	0.67	0.36	0.30	0.32
119	Whinchat	BIRD32	0.42	0.10	0	0.39	0.30	0.29
120	Barn Owl	BIRD18	0.48	0.07	0	0.33	0.29	0.28
121	Kestrel	BIRD47	0.44	0.08	0	0.36	0.29	0.28
122	Pine Marten	MAM3	0.45	0.04	0	0.38	0.29	0.28
123	Greylag Goose	BIRD9	0.51	0.03	0	0.33	0.29	0.28
124	Short-eared Owl	BIRD49	0.40	0.07	0	0.40	0.29	0.28
125	Golden Oriole	BIRD53	0.40	0.08	0	0.38	0.29	0.27
126	Buzzard	BIRDb	0.38	0.05	0	0.42	0.28	0.27
127	Wryneck	BIRD5	0.41	0.10	0	0.34	0.28	0.27
128	Purple Heron	BIRD36	0.36	0.05	0	0.44	0.28	0.27
129	Ortolan Bunting	BIRD31	0.41	0.10	0	0.33	0.28	0.27
130	Woodchat Shrike	BIRD42	0.43	0.09	0	0.32	0.28	0.27
131	Large White	BFLYb	0.33	0.11	0	0.37	0.27	0.26
132	Ruff	BIRD17	0.42	0.08	0	0.29	0.26	0.25
133	Brimstone	BFLYc	0.38	0.11	0	0.28	0.26	0.24
134	Red Admiral	BFLYa	0.30	0.11	0	0.31	0.24	0.23
135	Red Kite	BIRD39	0.38	0.05	0	0.29	0.24	0.23

Appendix 7 – MCA results Cadmium

Cadmium results: rank for scenario 1, species name and code, scores for each category, and final scores using two scenarios: scenario 1: weights A = 0.333, B = 0.333 and D = 0.333; scenario 2: weights A = 0.317, B = 0.317, C = 0.05, D = 0.317.

Rank	Species	Code	Main category A	Main category B	Main category C	Main category D	Scenario 1	Scenario 2
1	Common Tern	BIRD50	0.56	0.38	0.33	0.73	0.56	0.55
2	Great Reed Warbler	BIRD13	0.46	0.39	0.33	0.74	0.53	0.52
3	Greater Mouse-eared Bat	MAM6	0.47	0.44	0.33	0.66	0.52	0.51
4	Oystercatcher	BIRDh	0.61	0.33	0.33	0.63	0.52	0.51
5	Geoffroy's Bat	MAM5	0.47	0.45	0.33	0.63	0.52	0.51
6	White Stork	BIRD30	0.57	0.35	0.33	0.63	0.52	0.51
7	Badger	MAM1	0.50	0.35	0.33	0.68	0.51	0.50
8	Mole	MAMa	0.54	0.30	0.33	0.67	0.50	0.50
9	Slow Worm	REP3	0.58	0.21	0.33	0.72	0.50	0.50
10	Hen Harrier	BIRD3	0.56	0.33	0.33	0.60	0.50	0.49
11	Grey Heron	BIRDf	0.63	0.28	0.33	0.57	0.49	0.49
12	Natterer's Bat	MAM2	0.47	0.46	0.33	0.55	0.49	0.49
13	Alpine Newt	AMPH1	0.47	0.24	0.67	0.76	0.49	0.50
14	Viviparous Lizard	REPa	0.45	0.24	0.33	0.78	0.49	0.48
15	Palmate Newt	AMPH6	0.48	0.24	0.67	0.73	0.48	0.49
16	Night Heron	BIRD24	0.52	0.37	0.33	0.55	0.48	0.47
17	Great Crested Newt	AMPH3	0.47	0.23	0.67	0.73	0.48	0.49
18	Avocet	BIRD21	0.53	0.38	0.33	0.52	0.48	0.47
19	Arctic Tern	BIRD28	0.57	0.38	0.33	0.48	0.48	0.47
20	Lapwing	BIRDi	0.54	0.34	0.33	0.54	0.47	0.47
21	Little Grebe	BIRD4	0.53	0.34	0.33	0.55	0.47	0.47
22	Otter	MAM8	0.59	0.25	0.33	0.58	0.47	0.47
23	Little Owl	BIRD45	0.50	0.30	0.33	0.62	0.47	0.47
24	Black Tern	BIRD56	0.51	0.39	0.33	0.52	0.47	0.47
25	Bluethroat	BIRD2	0.45	0.40	0.33	0.56	0.47	0.46
26	Tawny Pipit	BIRD6	0.44	0.39	0.33	0.58	0.47	0.46
27	Black-tailed Godwit	BIRD14	0.45	0.38	0.33	0.57	0.47	0.46
28	Sand Martin	BIRD29	0.46	0.40	0.33	0.54	0.47	0.46
29	Montagu's Harrier	BIRD10	0.50	0.37	0.33	0.52	0.46	0.46
30	Snipe	BIRD52	0.48	0.39	0.33	0.52	0.46	0.46
31	Sand Lizard	REP5	0.43	0.22	0.33	0.74	0.46	0.46
32	Hoopoe	BIRD15	0.50	0.39	0.33	0.49	0.46	0.45
33	Spoonbill	BIRD26	0.53	0.36	0.33	0.49	0.46	0.45
34	Savi's Warbler	BIRD44	0.50	0.40	0.33	0.48	0.46	0.45
35	Northern Water Shrew	MAM7	0.53	0.32	0.33	0.53	0.46	0.45
36	Common Adder	REP1	0.54	0.19	0.33	0.64	0.46	0.45
37	Blackbird	BIRDd	0.49	0.34	0.33	0.53	0.45	0.45
38	Little Tern	BIRD7	0.52	0.39	0.33	0.44	0.45	0.44
39	Whitethroat	BIRDj	0.45	0.40	0.33	0.50	0.45	0.44
40	Redshank	BIRD48	0.48	0.39	0.33	0.48	0.45	0.44
41	Little Bittern	BIRD54	0.45	0.38	0.33	0.52	0.45	0.44
42	Red-backed Shrike	BIRD11	0.47	0.39	0.33	0.48	0.45	0.44
43	Kingfisher	BIRD16	0.55	0.31	0.33	0.48	0.45	0.44

Table MCA results Cadmium (continued)

Rank	Species	Code	Main category A	Main category B	Main category C	Main category D	Scenario 1	Scenario 2
44	Poolfrog	AMPHa	0.44	0.23	0.67	0.67	0.45	0.46
45	Bittern	BIRD40	0.53	0.32	0.33	0.49	0.45	0.44
46	Carp	FISHa	0.71	0.02	1	0.61	0.45	0.47
47	Coot	BIRDg	0.44	0.32	0.33	0.57	0.44	0.44
48	Buzzard	BIRDb	0.54	0.36	0.33	0.42	0.44	0.43
49	Common Rat	MAMb	0.46	0.30	0.33	0.55	0.44	0.43
50	Bullhead	FISH7	0.56	0.10	1	0.65	0.44	0.47
51	Dusky Large Blue	BFLY7	0.38	0.19	0	0.74	0.44	0.42
52	Yellowhammer	BIRD8	0.39	0.39	0.33	0.53	0.44	0.43
53	Scarce Large Blue	BFLY16	0.38	0.19	0	0.74	0.44	0.42
54	Purple Heron	BIRD36	0.50	0.37	0.33	0.44	0.44	0.43
55	Catfish	FISH4	0.71	0.03	1	0.56	0.43	0.46
56	Green Hawker	DFLY2	0.44	0.07	1	0.79	0.43	0.46
57	Raven	BIRD37	0.55	0.27	0.33	0.48	0.43	0.43
58	Water Rail	BIRD51	0.47	0.34	0.33	0.49	0.43	0.43
59	Green Treefrog	AMPH2	0.44	0.23	0.67	0.62	0.43	0.44
60	Little Ringed Plover	BIRD20	0.46	0.40	0.33	0.43	0.43	0.43
61	Red-crested Pochard	BIRD23	0.35	0.36	0.33	0.58	0.43	0.43
62	Corncrake	BIRD25	0.47	0.38	0.33	0.44	0.43	0.43
63	Siberian Winter Damselfly	DFLY6	0.38	0.21	1	0.70	0.43	0.46
64	Northern Wheatear	BIRD46	0.43	0.39	0.33	0.47	0.43	0.43
65	Hooded Crow	BIRDe	0.46	0.28	0.33	0.54	0.43	0.42
66	Alcon Blue	BFLY2	0.46	0.07	0	0.74	0.42	0.40
67	Short-eared Owl	BIRD49	0.50	0.37	0.33	0.40	0.42	0.42
68	Barbel	FISH1	0.56	0.15	1	0.55	0.42	0.45
69	Great Grey Shrike	BIRD19	0.44	0.38	0.33	0.44	0.42	0.42
70	Norfolk Damselfly	DFLY4	0.47	0.08	1	0.71	0.42	0.45
71	Hairy Dragonfly	DFLY3	0.48	0.07	1	0.71	0.42	0.45
72	Red Kite	BIRD39	0.61	0.36	0.33	0.29	0.42	0.42
73	Common Spadefoot	AMPH4	0.46	0.22	0.67	0.57	0.42	0.43
74	Smooth Snake	REP2	0.49	0.19	0.33	0.56	0.41	0.41
75	Nightjar	BIRD27	0.45	0.38	0.33	0.41	0.41	0.41
76	Norfolk Hawker	DFLY1	0.47	0.07	1	0.70	0.41	0.44
77	Large Blue	BFLY20	0.38	0.19	0	0.66	0.41	0.39
78	Stone Loach	FISH2	0.51	0.11	1	0.61	0.41	0.44
79	Black Grouse	BIRD22	0.34	0.28	0.33	0.60	0.41	0.40
80	Whinchat	BIRD32	0.43	0.40	0.33	0.39	0.41	0.40
81	Sedge Warbler	BIRD38	0.32	0.40	0.33	0.50	0.41	0.40
82	Three-spined Stickleback	FISHb	0.39	0.16	1	0.66	0.40	0.43
83	Green Woodpecker	BIRD12	0.48	0.29	0.33	0.44	0.40	0.40
84	Woodchat Shrike	BIRD42	0.50	0.39	0.33	0.32	0.40	0.40
85	Kestrel	BIRD47	0.51	0.34	0.33	0.36	0.40	0.40
86	Barn Owl	BIRD18	0.58	0.29	0.33	0.33	0.40	0.40
87	Tufted Duck	BIRDc	0.48	0.28	0.33	0.44	0.40	0.40
88	Scarce chaser	DFLY5	0.49	0.07	1	0.64	0.40	0.43
89	Bearded Tit	BIRD1	0.40	0.36	0.33	0.43	0.40	0.39
90	Wryneck	BIRD5	0.45	0.40	0.33	0.34	0.40	0.39
91	Grass Snake	REP4	0.49	0.19	0.33	0.51	0.40	0.39

Table MCA results Cadmium (continued)

Rank	Species	Code	Main category A	Main category B	Main category C	Main category D	Scenario 1	Scenario 2
92	Stonechat	BIRD41	0.38	0.36	0.33	0.45	0.40	0.39
93	Golden Oriole	BIRD53	0.43	0.38	0.33	0.38	0.40	0.39
94	Garganey	BIRD55	0.39	0.37	0.33	0.43	0.40	0.39
95	Marsh Fritillary	BFLY15	0.26	0.19	0	0.73	0.39	0.37
96	Large Chequered Skipper	BFLY19	0.25	0.19	0	0.74	0.39	0.37
97	Mallard	BIRDa	0.53	0.28	0.33	0.36	0.39	0.39
98	Pintail	BIRD34	0.53	0.32	0.33	0.31	0.39	0.38
99	Spotted Crake	BIRD35	0.42	0.35	0.33	0.36	0.38	0.37
100	Natterjack Toad	AMPH5	0.50	0.22	0.67	0.41	0.38	0.39
101	Scooty Copper	BFLY6	0.26	0.19	0	0.67	0.37	0.36
102	Brown Hairstreak	BFLY18	0.19	0.19	0	0.74	0.37	0.36
103	Pine Marten	MAM3	0.45	0.28	0.33	0.38	0.37	0.37
104	Brown Argus	BFLY5	0.26	0.19	0	0.66	0.37	0.35
105	Greylag Goose	BIRD9	0.39	0.39	0.33	0.33	0.37	0.37
106	Purple-edged Copper	BFLY17	0.25	0.19	0	0.67	0.37	0.35
107	Pearly Heath	BFLY21	0.25	0.19	0	0.67	0.37	0.35
108	Small Pearl-Bordered Fritillary	BFLY23	0.26	0.19	0	0.66	0.37	0.35
109	Chequered Skipper	BFLY4	0.24	0.19	0	0.67	0.37	0.35
110	Small Skipper	BFLY9	0.25	0.19	0	0.66	0.37	0.35
111	Dark Green Fritillary	BFLY10	0.25	0.19	0	0.66	0.37	0.35
112	Mazarine Blue	BFLY12	0.25	0.19	0	0.66	0.37	0.35
113	Glanville Fritillary	BFLY22	0.25	0.19	0	0.66	0.37	0.35
114	Northern Vole	MAM4	0.34	0.31	0.33	0.44	0.36	0.36
115	Pearl-Bordered Fritillary	BFLY3	0.23	0.19	0	0.66	0.36	0.34
116	Large Copper	BFLY24	0.23	0.19	0	0.65	0.36	0.34
117	Ortolan Bunting	BIRD31	0.35	0.39	0.33	0.33	0.36	0.36
118	Partridge	BIRD33	0.36	0.29	0.33	0.42	0.36	0.36
119	Grizzled skipper	BFLY1	0.20	0.19	0	0.67	0.35	0.34
120	Ruff	BIRD17	0.39	0.38	0.33	0.29	0.35	0.35
121	Shoveler	BIRD43	0.49	0.28	0.33	0.29	0.35	0.35
122	Common Blue Damselfly	DFLYa	0.46	0.24	1	0.36	0.35	0.39
123	Field Vole	MAMd	0.36	0.32	0.33	0.37	0.35	0.35
124	Niobe Fritillary	BFLY8	0.19	0.19	0	0.66	0.35	0.33
125	White Bream	FISH6	0.39	0.06	1	0.57	0.34	0.37
126	Bank Vole	MAMc	0.38	0.32	0.33	0.31	0.34	0.34
127	Ide	FISH8	0.50	0.04	1	0.46	0.33	0.37
128	Silver-spotted Skipper	BFLY14	0.20	0.19	0	0.59	0.33	0.31
129	Queen of Spain Fritillary	BFLY13	0.19	0.28	0	0.46	0.31	0.29
130	Twaite Shad	FISH5	0.28	0.14	1	0.43	0.28	0.32
131	Large Tortoiseshell	BFLY11	0.24	0.15	0	0.44	0.28	0.26
132	Allis Shad	FISH3	0.25	0.13	1	0.36	0.25	0.28
133	Large White	BFLYb	0.16	0.19	0	0.37	0.24	0.23
134	Brimstone	BFLYc	0.25	0.15	0	0.28	0.23	0.22
135	Red Admiral	BFLYa	0.20	0.15	0	0.31	0.22	0.21

Appendix 8 – MCA results DDT

DDT results: rank for scenario 1, species name and code, scores for each category, and final scores using two scenarios: scenario 1: weights A = 0.333, B = 0.333 and D = 0.333; scenario 2: weights A = 0.317, B = 0.317, C = 0.05, D = 0.317.

Rank	Species	Code	Main category A	Main category B	Main category C	Main category D	Scenario 1	Scenario 2
1	Slow Worm	REP3	0.58	0.29	0.33	0.72	0.53	0.52
2	Viviparous Lizard	REPa	0.45	0.32	0.33	0.78	0.52	0.51
3	Alpine Newt	AMPH1	0.47	0.32	1	0.76	0.52	0.54
4	Palmate Newt	AMPH6	0.48	0.32	1	0.73	0.51	0.54
5	Great Crested Newt	AMPH3	0.47	0.31	1	0.73	0.50	0.53
6	Sand Lizard	REP5	0.43	0.30	0.33	0.74	0.49	0.48
7	Common Tern	BIRD50	0.56	0.19	0.33	0.73	0.49	0.49
8	Common Adder	REP1	0.54	0.27	0.33	0.64	0.48	0.48
9	Poolfrog	AMPHa	0.44	0.31	1	0.67	0.47	0.50
10	Greater Mouse-eared Bat	MAM6	0.47	0.27	0	0.66	0.47	0.44
11	Great Reed Warbler	BIRD13	0.46	0.20	0.33	0.74	0.47	0.46
12	Dusky Large Blue	BFLY7	0.38	0.27	0.33	0.74	0.46	0.46
13	Geoffroy's Bat	MAM5	0.47	0.29	0	0.63	0.46	0.44
14	Scarce Large Blue	BFLY16	0.38	0.27	0.33	0.74	0.46	0.46
15	Green Treefrog	AMPH2	0.44	0.31	1	0.62	0.46	0.48
16	Siberian Winter Damselfly	DFLY6	0.38	0.29	1	0.70	0.46	0.48
17	Badger	MAM1	0.50	0.17	0	0.68	0.45	0.43
18	White Stork	BIRD30	0.57	0.15	0.33	0.63	0.45	0.44
19	Barbel	FISH1	0.56	0.23	1	0.55	0.45	0.47
20	Carp	FISHa	0.71	0.02	1	0.61	0.45	0.47
21	Oystercatcher	BIRDh	0.61	0.10	0.33	0.63	0.45	0.44
22	Common Spadefoot	AMPH4	0.46	0.30	1	0.57	0.44	0.47
23	Smooth Snake	REP2	0.49	0.27	0.33	0.56	0.44	0.43
24	Natterer's Bat	MAM2	0.47	0.29	0	0.55	0.44	0.42
25	Bullhead	FISH7	0.56	0.10	1	0.65	0.44	0.47
26	Large Blue	BFLY20	0.38	0.27	0.33	0.66	0.44	0.43
27	Catfish	FISH4	0.71	0.03	1	0.56	0.43	0.46
28	Green Hawker	DFLY2	0.44	0.07	1	0.79	0.43	0.46
29	Mole	MAMa	0.54	0.06	0	0.67	0.42	0.40
30	Alcon Blue	BFLY2	0.46	0.07	0.33	0.74	0.42	0.42
31	Hen Harrier	BIRD3	0.56	0.11	0.33	0.60	0.42	0.42
32	Norfolk Damselfly	DFLY4	0.47	0.09	1	0.71	0.42	0.45
33	Grass Snake	REP4	0.49	0.27	0.33	0.51	0.42	0.42
34	Marsh Fritillary	BFLY15	0.26	0.27	0.33	0.73	0.42	0.42
35	Large Chequered Skipper	BFLY19	0.25	0.27	0.33	0.74	0.42	0.42
36	Hairy Dragonfly	DFLY3	0.48	0.07	1	0.71	0.42	0.45
37	Three-spined Stickleback	FISHb	0.39	0.20	1	0.66	0.42	0.45
38	Night Heron	BIRD24	0.52	0.17	0.33	0.55	0.41	0.41
39	Arctic Tern	BIRD28	0.57	0.19	0.33	0.48	0.41	0.41
40	Stone Loach	FISH2	0.51	0.12	1	0.61	0.41	0.44
41	Norfolk Hawker	DFLY1	0.47	0.07	1	0.70	0.41	0.44
42	Grey Heron	BIRDf	0.63	0.03	0.33	0.57	0.41	0.41
43	Avocet	BIRD21	0.53	0.18	0.33	0.52	0.41	0.41

Table MCA results DDT (continued)

Rank	Species	Code	Main category A	Main category B	Main category C	Main category D	Scenario 1	Scenario 2
44	Tawny Pipit	BIRD6	0.44	0.20	0.33	0.58	0.41	0.40
45	Black Tern	BIRD56	0.51	0.19	0.33	0.52	0.41	0.40
46	Bluethroat	BIRD2	0.45	0.20	0.33	0.56	0.40	0.40
47	Scarce chaser	DFLY5	0.49	0.08	1	0.64	0.40	0.43
48	Natterjack Toad	AMPH5	0.50	0.30	1	0.41	0.40	0.43
49	Scooty Copper	BFLY6	0.26	0.27	0.33	0.67	0.40	0.40
50	Little Grebe	BIRD4	0.53	0.12	0.33	0.55	0.40	0.40
51	Lapwing	BIRDi	0.54	0.12	0.33	0.54	0.40	0.40
52	Sand Martin	BIRD29	0.46	0.20	0.33	0.54	0.40	0.40
53	Brown Hairstreak	BFLY18	0.19	0.27	0.33	0.74	0.40	0.40
54	Montagu's Harrier	BIRD10	0.50	0.18	0.33	0.52	0.40	0.40
55	Black-tailed Godwit	BIRD14	0.45	0.18	0.33	0.57	0.40	0.40
56	Brown Argus	BFLY5	0.26	0.27	0.33	0.66	0.40	0.39
57	Purple-edged Copper	BFLY17	0.25	0.27	0.33	0.67	0.40	0.39
58	Pearly Heath	BFLY21	0.25	0.27	0.33	0.67	0.40	0.39
59	Small Pearl-Bordered Fritillary	BFLY23	0.26	0.27	0.33	0.66	0.40	0.39
60	Hoopoe	BIRD15	0.50	0.20	0.33	0.49	0.40	0.39
61	Snipe	BIRD52	0.48	0.19	0.33	0.52	0.40	0.39
62	Chequered Skipper	BFLY4	0.24	0.27	0.33	0.67	0.39	0.39
63	Small Skipper	BFLY9	0.25	0.27	0.33	0.66	0.39	0.39
64	Dark Green Fritillary	BFLY10	0.25	0.27	0.33	0.66	0.39	0.39
65	Mazarine Blue	BFLY12	0.25	0.27	0.33	0.66	0.39	0.39
66	Savi's Warbler	BIRD44	0.50	0.20	0.33	0.48	0.39	0.39
67	Glanville Fritillary	BFLY22	0.25	0.27	0.33	0.66	0.39	0.39
68	Spoonbill	BIRD26	0.53	0.16	0.33	0.49	0.39	0.39
69	Otter	MAM8	0.59	0.00	0	0.58	0.39	0.37
70	Little Owl	BIRD45	0.50	0.05	0.33	0.62	0.39	0.39
71	Little Tern	BIRD7	0.52	0.20	0.33	0.44	0.39	0.38
72	Little Bittern	BIRD54	0.45	0.19	0.33	0.52	0.39	0.38
73	Pearl-Bordered Fritillary	BFLY3	0.23	0.27	0.33	0.66	0.39	0.38
74	Large Copper	BFLY24	0.23	0.27	0.33	0.65	0.38	0.38
75	Whitethroat	BIRDj	0.45	0.20	0.33	0.50	0.38	0.38
76	Red-backed Shrike	BIRD11	0.47	0.20	0.33	0.48	0.38	0.38
77	Redshank	BIRD48	0.48	0.19	0.33	0.48	0.38	0.38
78	Grizzled skipper	BFLY1	0.20	0.27	0.33	0.67	0.38	0.38
79	Common Blue Damselfly	DFLYa	0.46	0.32	1	0.36	0.38	0.41
80	Northern Water Shrew	MAM7	0.53	0.08	0	0.53	0.38	0.36
81	Buzzard	BIRDb	0.54	0.17	0.33	0.42	0.38	0.37
82	Blackbird	BIRDd	0.49	0.11	0.33	0.53	0.38	0.37
83	Niobe Fritillary	BFLY8	0.19	0.27	0.33	0.66	0.37	0.37
84	Yellowhammer	BIRD8	0.39	0.20	0.33	0.53	0.37	0.37
85	Bittern	BIRD40	0.53	0.10	0.33	0.49	0.37	0.37
86	Coot	BIRDg	0.44	0.10	0.33	0.57	0.37	0.37
87	Purple Heron	BIRD36	0.50	0.17	0.33	0.44	0.37	0.37
88	Kingfisher	BIRD16	0.55	0.07	0.33	0.48	0.37	0.37
89	Corncrake	BIRD25	0.47	0.19	0.33	0.44	0.37	0.37
90	Northern Wheatear	BIRD46	0.43	0.20	0.33	0.47	0.37	0.37

Table MCA results DDT (continued)

Rank	Species	Code	Main category A	Main category B	Main category C	Main category D	Scenario 1	Scenario 2
91	Little Ringed Plover	BIRD20	0.46	0.20	0.33	0.43	0.36	0.36
92	Red-crested Pochard	BIRD23	0.35	0.16	0.33	0.58	0.36	0.36
93	Short-eared Owl	BIRD49	0.50	0.18	0.33	0.40	0.36	0.36
94	Water Rail	BIRD51	0.47	0.12	0.33	0.49	0.36	0.36
95	Great Grey Shrike	BIRD19	0.44	0.19	0.33	0.44	0.36	0.36
96	Common Rat	MAMb	0.46	0.05	0	0.55	0.35	0.34
97	Queen of Spain Fritillary	BFLY13	0.19	0.41	0.33	0.46	0.35	0.35
98	Silver-spotted Skipper	BFLY14	0.20	0.27	0.33	0.59	0.35	0.35
99	Red Kite	BIRD39	0.61	0.16	0.33	0.29	0.35	0.35
100	Raven	BIRD37	0.55	0.02	0.33	0.48	0.35	0.35
101	Nightjar	BIRD27	0.45	0.18	0.33	0.41	0.35	0.35
102	Hooded Crow	BIRDe	0.46	0.03	0.33	0.54	0.34	0.34
103	Sedge Warbler	BIRD38	0.32	0.21	0.33	0.50	0.34	0.34
104	Whinchat	BIRD32	0.43	0.20	0.33	0.39	0.34	0.34
105	White Bream	FISH6	0.39	0.06	1	0.57	0.34	0.37
106	Woodchat Shrike	BIRD42	0.50	0.19	0.33	0.32	0.34	0.34
107	Golden Oriole	BIRD53	0.43	0.19	0.33	0.38	0.33	0.33
108	Ide	FISH8	0.50	0.04	1	0.46	0.33	0.37
109	Garganey	BIRD55	0.39	0.18	0.33	0.43	0.33	0.33
110	Wryneck	BIRD5	0.45	0.20	0.33	0.34	0.33	0.33
111	Kestrel	BIRD47	0.51	0.12	0.33	0.36	0.33	0.33
112	Bearded Tit	BIRD1	0.40	0.14	0.33	0.43	0.32	0.32
113	Black Grouse	BIRD22	0.34	0.03	0.33	0.60	0.32	0.32
114	Stonechat	BIRD41	0.38	0.14	0.33	0.45	0.32	0.32
115	Green Woodpecker	BIRD12	0.48	0.04	0.33	0.44	0.32	0.32
116	Barn Owl	BIRD18	0.58	0.04	0.33	0.33	0.32	0.32
117	Tufted Duck	BIRDc	0.48	0.03	0.33	0.44	0.32	0.32
118	Greylag Goose	BIRD9	0.39	0.22	0.33	0.33	0.31	0.31
119	Pintail	BIRD34	0.53	0.10	0.33	0.31	0.31	0.31
120	Mallard	BIRDa	0.53	0.03	0.33	0.36	0.31	0.31
121	Spotted Crake	BIRD35	0.42	0.13	0.33	0.36	0.30	0.30
122	Twaite Shad	FISH5	0.28	0.19	1	0.43	0.30	0.34
123	Large Tortoiseshell	BFLY11	0.24	0.21	0.33	0.44	0.30	0.30
124	Ortolan Bunting	BIRD31	0.35	0.20	0.33	0.33	0.29	0.30
125	Ruff	BIRD17	0.39	0.19	0.33	0.29	0.29	0.29
126	Pine Marten	MAM3	0.45	0.03	0	0.38	0.29	0.27
127	Northern Vole	MAM4	0.34	0.07	0	0.44	0.28	0.27
128	Partridge	BIRD33	0.36	0.04	0.33	0.42	0.27	0.28
129	Shoveler	BIRD43	0.49	0.04	0.33	0.29	0.27	0.28
130	Field Vole	MAMd	0.36	0.07	0	0.37	0.27	0.25
131	Allis Shad	FISH3	0.25	0.19	1	0.36	0.27	0.30
132	Large White	BFLYb	0.16	0.27	0.33	0.37	0.27	0.27
133	Bank Vole	MAMc	0.38	0.07	0	0.31	0.25	0.24
134	Brimstone	BFLYc	0.25	0.21	0.33	0.28	0.25	0.25
135	Red Admiral	BFLYa	0.20	0.21	0.33	0.31	0.24	0.24

Appendix 9 – MCA results Chlorpyrifos

Chlorpyrifos results: rank for scenario 1, species name and code, scores for each category, and final scores using two scenarios: scenario 1: weights A = 0.333, B = 0.333 and D = 0.333; scenario 2: weights A = 0.317, B = 0.317, C = 0.05, D = 0.317.

Rank	Species	Code	Main category A	Main category B	Main category C	Main category D	Scenario 1	Scenario 2
1	Slow Worm	REP3	0.79	0.23	0.33	0.72	0.58	0.57
2	Viviparous Lizard	REPa	0.62	0.33	0.33	0.78	0.58	0.56
3	Alpine Newt	AMPH1	0.57	0.33	1	0.76	0.55	0.58
4	Sand Lizard	REP5	0.61	0.28	0.33	0.74	0.54	0.53
5	Palmate Newt	AMPH6	0.57	0.33	1	0.73	0.54	0.57
6	Bullhead	FISH7	0.69	0.28	1	0.65	0.54	0.56
7	Great Crested Newt	AMPH3	0.57	0.31	1	0.73	0.54	0.56
8	Mole	MAMa	0.76	0.16	0.33	0.67	0.53	0.52
9	Large Chequered Skipper	BFLY19	0.64	0.20	0.33	0.74	0.53	0.52
10	Geoffroy's Bat	MAM5	0.71	0.23	0.33	0.63	0.52	0.51
11	Great Reed Warbler	BIRD13	0.66	0.17	0.67	0.74	0.52	0.53
12	Alcon Blue	BFLY2	0.62	0.20	0.33	0.74	0.52	0.51
13	Dusky Large Blue	BFLY7	0.62	0.20	0.33	0.74	0.52	0.51
14	Scarce Large Blue	BFLY16	0.62	0.20	0.33	0.74	0.52	0.51
15	Greater Mouse-eared Bat	MAM6	0.70	0.20	0.33	0.66	0.52	0.51
16	Siberian Winter Damselfly	DFLY6	0.61	0.24	1	0.70	0.52	0.54
17	Brown Hairstreak	BFLY18	0.60	0.20	0.33	0.74	0.51	0.50
18	Natterer's Bat	MAM2	0.71	0.24	0.33	0.55	0.50	0.49
19	Poolfrog	AMPHa	0.53	0.30	1	0.67	0.50	0.53
20	Pearly Heath	BFLY21	0.63	0.20	0.33	0.67	0.50	0.49
21	Chequered Skipper	BFLY4	0.62	0.20	0.33	0.67	0.50	0.49
22	Small Skipper	BFLY9	0.63	0.20	0.33	0.66	0.50	0.49
23	Hen Harrier	BIRD3	0.78	0.11	0.67	0.60	0.50	0.51
24	Marsh Fritillary	BFLY15	0.56	0.20	0.33	0.73	0.50	0.49
25	Common Adder	REP1	0.64	0.20	0.33	0.64	0.49	0.49
26	Large Copper	BFLY24	0.62	0.20	0.33	0.65	0.49	0.48
27	Large Blue	BFLY20	0.61	0.20	0.33	0.66	0.49	0.48
28	Pearl-Bordered Fritillary	BFLY3	0.61	0.20	0.33	0.66	0.49	0.48
29	Stone Loach	FISH2	0.53	0.32	1	0.61	0.49	0.51
30	Common Spadefoot	AMPH4	0.61	0.28	1	0.57	0.49	0.51
31	Little Owl	BIRD45	0.70	0.14	0.67	0.62	0.49	0.50
32	Green Treefrog	AMPH2	0.53	0.30	1	0.62	0.48	0.51
33	Green Hawker	DFLY2	0.46	0.19	1	0.79	0.48	0.51
34	Norfolk Damselfly	DFLY4	0.48	0.24	1	0.71	0.48	0.50
35	Brown Argus	BFLY5	0.56	0.20	0.33	0.66	0.47	0.47
36	Scooty Copper	BFLY6	0.55	0.20	0.33	0.67	0.47	0.47
37	Purple-edged Copper	BFLY17	0.55	0.20	0.33	0.67	0.47	0.47
38	Glanville Fritillary	BFLY22	0.56	0.20	0.33	0.66	0.47	0.47
39	Small Pearl-Bordered Fritillary	BFLY23	0.56	0.20	0.33	0.66	0.47	0.47
40	Grizzled skipper	BFLY1	0.54	0.20	0.33	0.67	0.47	0.46
41	Dark Green Fritillary	BFLY10	0.55	0.20	0.33	0.66	0.47	0.46
42	Mazarine Blue	BFLY12	0.55	0.20	0.33	0.66	0.47	0.46

Table MCA results Chlorpyrifos (continued)

Rank	Species	Code	Main category A	Main category B	Main category C	Main category D	Scenario 1	Scenario 2
43	Niobe Fritillary	BFLY8	0.53	0.20	0.33	0.66	0.46	0.46
44	Lapwing	BIRDi	0.72	0.13	0.67	0.54	0.46	0.47
45	Silver-spotted Skipper	BFLY14	0.60	0.20	0.33	0.59	0.46	0.46
46	Smooth Snake	REP2	0.63	0.19	0.33	0.56	0.46	0.45
47	Kingfisher	BIRD16	0.71	0.19	0.67	0.48	0.46	0.47
48	Scarce chaser	DFLY5	0.52	0.21	1	0.64	0.46	0.48
49	Three-spined Stickleback	FISHb	0.35	0.36	1	0.66	0.46	0.48
50	Hairy Dragonfly	DFLY3	0.47	0.19	1	0.71	0.46	0.48
51	Norfolk Hawker	DFLY1	0.48	0.19	1	0.70	0.46	0.48
52	Blackbird	BIRDd	0.70	0.13	0.67	0.53	0.45	0.46
53	Field Vole	MAMd	0.79	0.19	0.33	0.37	0.45	0.44
54	Grass Snake	REP4	0.64	0.18	0.33	0.51	0.44	0.44
55	Whitethroat	BIRDj	0.62	0.19	0.67	0.50	0.44	0.45
56	Black Grouse	BIRD22	0.63	0.08	0.67	0.60	0.44	0.45
57	Sedge Warbler	BIRD38	0.61	0.20	0.67	0.50	0.44	0.45
58	Water Rail	BIRD51	0.67	0.15	0.67	0.49	0.44	0.45
59	Grey Heron	BIRDf	0.66	0.07	0.67	0.57	0.43	0.45
60	Natterjack Toad	AMPH5	0.62	0.27	1	0.41	0.43	0.46
61	Coot	BIRDg	0.64	0.09	0.67	0.57	0.43	0.45
62	Bank Vole	MAMc	0.79	0.20	0.33	0.31	0.43	0.43
63	Redshank	BIRD48	0.66	0.15	0.67	0.48	0.43	0.44
64	Common Rat	MAMb	0.59	0.14	0.33	0.55	0.43	0.42
65	Oystercatcher	BIRDh	0.55	0.10	0.67	0.63	0.43	0.44
66	Sand Martin	BIRD29	0.54	0.19	0.67	0.54	0.42	0.44
67	Bluethroat	BIRD2	0.53	0.18	0.67	0.56	0.42	0.44
68	Savi's Warbler	BIRD44	0.60	0.19	0.67	0.48	0.42	0.44
69	Northern Water Shrew	MAM7	0.52	0.21	0.33	0.53	0.42	0.42
70	Black-tailed Godwit	BIRD14	0.55	0.13	0.67	0.57	0.42	0.43
71	Catfish	FISH4	0.59	0.09	1	0.56	0.41	0.44
72	Green Woodpecker	BIRD12	0.69	0.11	0.67	0.44	0.41	0.43
73	Common Blue Damselfly	DFLYa	0.55	0.33	1	0.36	0.41	0.44
74	Badger	MAM1	0.55	0.00	0.33	0.68	0.41	0.41
75	Whinchat	BIRD32	0.65	0.19	0.67	0.39	0.41	0.42
76	Raven	BIRD37	0.70	0.05	0.67	0.48	0.41	0.42
77	Bearded Tit	BIRD1	0.59	0.20	0.67	0.43	0.41	0.42
78	Stonechat	BIRD41	0.57	0.19	0.67	0.45	0.40	0.42
79	Yellowhammer	BIRD8	0.50	0.17	0.67	0.53	0.40	0.41
80	Common Tern	BIRD50	0.32	0.15	0.67	0.73	0.40	0.41
81	Little Bittern	BIRD54	0.53	0.15	0.67	0.52	0.40	0.41
82	Tawny Pipit	BIRD6	0.44	0.17	0.67	0.58	0.40	0.41
83	Red-backed Shrike	BIRD11	0.54	0.17	0.67	0.48	0.40	0.41
84	Hooded Crow	BIRDe	0.57	0.08	0.67	0.54	0.40	0.41
85	Northern Vole	MAM4	0.56	0.19	0.33	0.44	0.40	0.39
86	Hoopoe	BIRD15	0.52	0.17	0.67	0.49	0.39	0.41
87	Partridge	BIRD33	0.64	0.12	0.67	0.42	0.39	0.41
88	Little Ringed Plover	BIRD20	0.57	0.18	0.67	0.43	0.39	0.41
89	Montagu's Harrier	BIRD10	0.53	0.12	0.67	0.52	0.39	0.40
90	Carp	FISHa	0.51	0.05	1	0.61	0.39	0.42

Table MCA results Chlorpyrifos (continued)

Rank	Species	Code	Main category A	Main category B	Main category C	Main category D	Scenario 1	Scenario 2
91	Northern Wheatear	BIRD46	0.52	0.18	0.67	0.47	0.39	0.40
92	Barbel	FISH1	0.53	0.08	1	0.55	0.39	0.42
93	Barn Owl	BIRD18	0.71	0.12	0.67	0.33	0.39	0.40
94	White Bream	FISH6	0.41	0.18	1	0.57	0.39	0.42
95	Spotted Crake	BIRD35	0.64	0.16	0.67	0.36	0.39	0.40
96	Otter	MAM8	0.56	0.01	0.33	0.58	0.38	0.38
97	Large White	BFLYb	0.57	0.20	0.33	0.37	0.38	0.38
98	White Stork	BIRD30	0.46	0.05	0.67	0.63	0.38	0.39
99	Bittern	BIRD40	0.55	0.09	0.67	0.49	0.38	0.39
100	Snipe	BIRD52	0.45	0.16	0.67	0.52	0.38	0.39
101	Pine Marten	MAM3	0.67	0.07	0.33	0.38	0.37	0.37
102	Little Grebe	BIRD4	0.42	0.14	0.67	0.55	0.37	0.39
103	Kestrel	BIRD47	0.61	0.14	0.67	0.36	0.37	0.39
104	Great Grey Shrike	BIRD19	0.52	0.14	0.67	0.44	0.37	0.38
105	Ortolan Bunting	BIRD31	0.60	0.17	0.67	0.33	0.37	0.38
106	Avocet	BIRD21	0.45	0.13	0.67	0.52	0.37	0.38
107	Nightjar	BIRD27	0.53	0.14	0.67	0.41	0.36	0.38
108	Large Tortoiseshell	BFLY11	0.43	0.20	0.33	0.44	0.36	0.36
109	Short-eared Owl	BIRD49	0.54	0.12	0.67	0.40	0.35	0.37
110	Buzzard	BIRDb	0.54	0.09	0.67	0.42	0.35	0.37
111	Wryneck	BIRD5	0.52	0.19	0.67	0.34	0.35	0.37
112	Little Tern	BIRD7	0.44	0.17	0.67	0.44	0.35	0.37
113	Purple Heron	BIRD36	0.51	0.09	0.67	0.44	0.35	0.36
114	Queen of Spain Fritillary	BFLY13	0.37	0.20	0.33	0.46	0.34	0.34
115	Corncrake	BIRD25	0.45	0.14	0.67	0.44	0.34	0.36
116	Golden Oriole	BIRD53	0.50	0.14	0.67	0.38	0.34	0.36
117	Woodchat Shrike	BIRD42	0.54	0.16	0.67	0.32	0.34	0.36
118	Tufted Duck	BIRDc	0.46	0.10	0.67	0.44	0.33	0.35
119	Ide	FISH8	0.43	0.11	1	0.46	0.33	0.37
120	Black Tern	BIRD56	0.31	0.17	0.67	0.52	0.33	0.35
121	Shoveler	BIRD43	0.59	0.10	0.67	0.29	0.33	0.34
122	Night Heron	BIRD24	0.31	0.10	0.67	0.55	0.32	0.34
123	Garganey	BIRD55	0.41	0.12	0.67	0.43	0.32	0.34
124	Ruff	BIRD17	0.50	0.15	0.67	0.29	0.31	0.33
125	Arctic Tern	BIRD28	0.31	0.14	0.67	0.48	0.31	0.33
126	Red Kite	BIRD39	0.55	0.09	0.67	0.29	0.31	0.33
127	Red-crested Pochard	BIRD23	0.26	0.08	0.67	0.58	0.31	0.33
128	Brimstone	BFLYc	0.43	0.20	0.33	0.28	0.30	0.30
129	Red Admiral	BFLYa	0.39	0.20	0.33	0.31	0.30	0.30
130	Mallard	BIRDa	0.46	0.08	0.67	0.36	0.30	0.32
131	Spoonbill	BIRD26	0.30	0.08	0.67	0.49	0.29	0.31
132	Pintail	BIRD34	0.40	0.09	0.67	0.31	0.27	0.29
133	Twaite Shad	FISH5	0.20	0.15	1	0.43	0.26	0.30
134	Allis Shad	FISH3	0.18	0.14	1	0.36	0.23	0.27
135	Greylag Goose	BIRD9	0.26	0.05	0.67	0.33	0.21	0.24

Appendix 10 – MCA results Ivermectin

Ivermectin results: rank for scenario 1, species name and code, scores for each category, and final scores using two scenarios: scenario 1: weights A = 0.333, B = 0.333 and D = 0.333; scenario 2: weights A = 0.317, B = 0.317, C = 0.05, D = 0.317.

Rank	Species	Code	Main category A	Main category B	Main category C	Main category D	Scenario 1	Scenario 2
1	Slow Worm	REP3	0.79	0.23	0.67	0.72	0.58	0.59
2	Viviparous Lizard	REPa	0.61	0.33	0.67	0.78	0.57	0.58
3	Mole	MAMa	0.82	0.16	0	0.67	0.55	0.52
4	Sand Lizard	REP5	0.59	0.28	0.67	0.74	0.54	0.54
5	Alcon Blue	BFLY2	0.65	0.20	0.33	0.74	0.53	0.52
6	Alpine Newt	AMPH1	0.49	0.33	0.67	0.76	0.53	0.53
7	Bullhead	FISH7	0.62	0.28	0.33	0.65	0.52	0.51
8	Palmate Newt	AMPH6	0.49	0.33	0.67	0.73	0.52	0.52
9	Great Crested Newt	AMPH3	0.49	0.31	0.67	0.73	0.51	0.52
10	Dusky Large Blue	BFLY7	0.58	0.20	0.33	0.74	0.51	0.50
11	Scarce Large Blue	BFLY16	0.58	0.20	0.33	0.74	0.51	0.50
12	Common Adder	REP1	0.62	0.20	0.67	0.64	0.49	0.50
13	Poolfrog	AMPHa	0.47	0.30	0.67	0.67	0.48	0.49
14	Large Blue	BFLY20	0.57	0.20	0.33	0.66	0.48	0.47
15	Great Reed Warbler	BIRD13	0.52	0.17	0.33	0.74	0.48	0.47
16	Common Spadefoot	AMPH4	0.58	0.28	0.67	0.57	0.48	0.49
17	Marsh Fritillary	BFLY15	0.50	0.20	0.33	0.73	0.48	0.47
18	Savi's Warbler	BIRD44	0.74	0.19	0.33	0.48	0.47	0.46
19	Green Hawker	DFLY2	0.42	0.19	0.33	0.79	0.47	0.46
20	Coot	BIRDg	0.74	0.09	0.33	0.57	0.47	0.46
21	Water Rail	BIRD51	0.76	0.15	0.33	0.49	0.47	0.46
22	Norfolk Damselfly	DFLY4	0.44	0.24	0.33	0.71	0.46	0.46
23	Three-spined Stickleback	FISHb	0.37	0.36	0.33	0.66	0.46	0.46
24	Stone Loach	FISH2	0.45	0.32	0.33	0.61	0.46	0.45
25	Green Treefrog	AMPH2	0.46	0.30	0.67	0.62	0.46	0.47
26	Scooty Copper	BFLY6	0.51	0.20	0.33	0.67	0.46	0.45
27	Black-tailed Godwit	BIRD14	0.68	0.13	0.33	0.57	0.46	0.45
28	Purple-edged Copper	BFLY17	0.51	0.20	0.33	0.67	0.46	0.45
29	Oystercatcher	BIRDh	0.65	0.10	0.33	0.63	0.46	0.45
30	Small Pearl-Bordered Fritillary	BFLY23	0.52	0.20	0.33	0.66	0.46	0.45
31	Brown Argus	BFLY5	0.51	0.20	0.33	0.66	0.46	0.45
32	Mazarine Blue	BFLY12	0.51	0.20	0.33	0.66	0.46	0.45
33	Smooth Snake	REP2	0.61	0.19	0.67	0.56	0.45	0.46
34	Glanville Fritillary	BFLY22	0.50	0.20	0.33	0.66	0.45	0.45
35	Dark Green Fritillary	BFLY10	0.49	0.20	0.33	0.66	0.45	0.44
36	Lapwing	BIRDi	0.68	0.13	0.33	0.54	0.45	0.44
37	Grey Heron	BIRDf	0.71	0.07	0.33	0.57	0.45	0.44
38	Hairy Dragonfly	DFLY3	0.44	0.19	0.33	0.71	0.45	0.44
39	Grizzled skipper	BFLY1	0.46	0.20	0.33	0.67	0.44	0.44
40	Tawny Pipit	BIRD6	0.58	0.17	0.33	0.58	0.44	0.44
41	Blackbird	BIRDd	0.67	0.13	0.33	0.53	0.44	0.44
42	Little Ringed Plover	BIRD20	0.71	0.18	0.33	0.43	0.44	0.43

Table MCA results Ivermectin (continued)

Rank	Species	Code	Main category A	Main category B	Main category C	Main category D	Scenario 1	Scenario 2
43	Siberian Winter Damselfly	DFLY6	0.38	0.24	0.33	0.70	0.44	0.43
44	Norfolk Hawker	DFLY1	0.43	0.19	0.33	0.70	0.44	0.43
45	Niobe Fritillary	BFLY8	0.45	0.20	0.33	0.66	0.44	0.43
46	Whitethroat	BIRDj	0.62	0.19	0.33	0.50	0.44	0.43
47	Grass Snake	REP4	0.62	0.18	0.67	0.51	0.44	0.45
48	Hen Harrier	BIRD3	0.59	0.11	0.33	0.60	0.43	0.43
49	Scarce chaser	DFLY5	0.43	0.21	0.33	0.64	0.43	0.42
50	Badger	MAM1	0.60	0.00	0	0.68	0.43	0.41
51	Geoffroy's Bat	MAM5	0.42	0.23	0	0.63	0.43	0.41
52	Natterjack Toad	AMPH5	0.60	0.27	0.67	0.41	0.43	0.44
53	Large Chequered Skipper	BFLY19	0.34	0.20	0.33	0.74	0.43	0.42
54	White Stork	BIRD30	0.59	0.05	0.33	0.63	0.42	0.42
55	Snipe	BIRD52	0.59	0.16	0.33	0.52	0.42	0.42
56	Greater Mouse-eared Bat	MAM6	0.40	0.20	0	0.66	0.42	0.40
57	Spotted Crake	BIRD35	0.74	0.16	0.33	0.36	0.42	0.42
58	Common Tern	BIRD50	0.37	0.15	0.33	0.73	0.42	0.41
59	Brown Hairstreak	BFLY18	0.30	0.20	0.33	0.74	0.41	0.41
60	Hooded Crow	BIRDe	0.61	0.08	0.33	0.54	0.41	0.41
61	Northern Vole	MAM4	0.60	0.19	0	0.44	0.41	0.39
62	Northern Water Shrew	MAM7	0.49	0.21	0	0.53	0.41	0.39
63	Little Owl	BIRD45	0.46	0.14	0.33	0.62	0.41	0.40
64	Bittern	BIRD40	0.64	0.09	0.33	0.49	0.41	0.40
65	Common Rat	MAMb	0.52	0.14	0	0.55	0.40	0.38
66	Natterer's Bat	MAM2	0.42	0.24	0	0.55	0.40	0.38
67	Pearly Heath	BFLY21	0.33	0.20	0.33	0.67	0.40	0.40
68	Small Skipper	BFLY9	0.33	0.20	0.33	0.66	0.40	0.39
69	Chequered Skipper	BFLY4	0.32	0.20	0.33	0.67	0.40	0.39
70	Little Tern	BIRD7	0.57	0.17	0.33	0.44	0.39	0.39
71	Large Copper	BFLY24	0.32	0.20	0.33	0.65	0.39	0.39
72	Sedge Warbler	BIRD38	0.47	0.20	0.33	0.50	0.39	0.39
73	Pearl-Bordered Fritillary	BFLY3	0.31	0.20	0.33	0.66	0.39	0.39
74	Catfish	FISH4	0.51	0.09	0.33	0.56	0.39	0.38
75	Corncrake	BIRD25	0.58	0.14	0.33	0.44	0.39	0.38
76	Avocet	BIRD21	0.50	0.13	0.33	0.52	0.38	0.38
77	Kingfisher	BIRD16	0.47	0.19	0.33	0.48	0.38	0.38
78	Redshank	BIRD48	0.51	0.15	0.33	0.48	0.38	0.38
79	Little Grebe	BIRD4	0.44	0.14	0.33	0.55	0.38	0.37
80	Sand Martin	BIRD29	0.40	0.19	0.33	0.54	0.38	0.37
81	Carp	FISHa	0.47	0.05	0.33	0.61	0.38	0.37
82	Bluethroat	BIRD2	0.38	0.18	0.33	0.56	0.37	0.37
83	Field Vole	MAMd	0.56	0.19	0	0.37	0.37	0.36
84	White Bream	FISH6	0.36	0.18	0.33	0.57	0.37	0.37
85	Silver-spotted Skipper	BFLY14	0.31	0.20	0.33	0.59	0.37	0.37
86	Common Blue Damselfly	DFLYa	0.41	0.33	0.33	0.36	0.37	0.37
87	Garganey	BIRD55	0.54	0.12	0.33	0.43	0.36	0.36
88	Whinchat	BIRD32	0.50	0.19	0.33	0.39	0.36	0.36
89	Bank Vole	MAMc	0.57	0.20	0	0.31	0.36	0.34
90	Black Grouse	BIRD22	0.39	0.08	0.33	0.60	0.36	0.36

Table MCA results Ivermectin (continued)

Rank	Species	Code	Main category A	Main category B	Main category C	Main category D	Scenario 1	Scenario 2
91	Queen of Spain Fritillary	BFLY13	0.40	0.20	0.33	0.46	0.35	0.35
92	Yellowhammer	BIRD8	0.36	0.17	0.33	0.53	0.35	0.35
93	Otter	MAM8	0.47	0.01	0	0.58	0.35	0.34
94	Black Tern	BIRD56	0.37	0.17	0.33	0.52	0.35	0.35
95	Red-backed Shrike	BIRD11	0.40	0.17	0.33	0.48	0.35	0.35
96	Little Bittern	BIRD54	0.38	0.15	0.33	0.52	0.35	0.35
97	Bearded Tit	BIRD1	0.41	0.20	0.33	0.43	0.35	0.35
98	Hoopoe	BIRD15	0.37	0.17	0.33	0.49	0.34	0.34
99	Shoveler	BIRD43	0.64	0.10	0.33	0.29	0.34	0.34
100	Northern Wheatear	BIRD46	0.38	0.18	0.33	0.47	0.34	0.34
101	Stonechat	BIRD41	0.38	0.19	0.33	0.45	0.34	0.34
102	Montagu's Harrier	BIRD10	0.38	0.12	0.33	0.52	0.34	0.34
103	Night Heron	BIRD24	0.36	0.10	0.33	0.55	0.34	0.34
104	Green Woodpecker	BIRD12	0.45	0.11	0.33	0.44	0.33	0.33
105	Barbel	FISH1	0.36	0.08	0.33	0.55	0.33	0.33
106	Raven	BIRD37	0.46	0.05	0.33	0.48	0.33	0.33
107	Red-crested Pochard	BIRD23	0.32	0.08	0.33	0.58	0.33	0.33
108	Tufted Duck	BIRDc	0.43	0.10	0.33	0.44	0.32	0.32
109	Arctic Tern	BIRD28	0.35	0.14	0.33	0.48	0.32	0.32
110	Partridge	BIRD33	0.42	0.12	0.33	0.42	0.32	0.32
111	Great Grey Shrike	BIRD19	0.37	0.14	0.33	0.44	0.32	0.32
112	Ortolan Bunting	BIRD31	0.45	0.17	0.33	0.33	0.32	0.32
113	Ide	FISH8	0.38	0.11	0.33	0.46	0.32	0.32
114	Nightjar	BIRD27	0.39	0.14	0.33	0.41	0.31	0.31
115	Barn Owl	BIRD18	0.48	0.12	0.33	0.33	0.31	0.31
116	Kestrel	BIRD47	0.42	0.14	0.33	0.36	0.31	0.31
117	Large Tortoiseshell	BFLY11	0.27	0.20	0.33	0.44	0.30	0.30
118	Spoonbill	BIRD26	0.34	0.08	0.33	0.49	0.30	0.30
119	Wryneck	BIRD5	0.37	0.19	0.33	0.34	0.30	0.30
120	Short-eared Owl	BIRD49	0.38	0.12	0.33	0.40	0.30	0.30
121	Buzzard	BIRDb	0.38	0.09	0.33	0.42	0.30	0.30
122	Purple Heron	BIRD36	0.35	0.09	0.33	0.44	0.29	0.30
123	Woodchat Shrike	BIRD42	0.40	0.16	0.33	0.32	0.29	0.30
124	Pine Marten	MAM3	0.42	0.07	0	0.38	0.29	0.28
125	Golden Oriole	BIRD53	0.35	0.14	0.33	0.38	0.29	0.29
126	Mallard	BIRDa	0.42	0.08	0.33	0.36	0.29	0.29
127	Large White	BFLYb	0.26	0.20	0.33	0.37	0.28	0.28
128	Pintail	BIRD34	0.42	0.09	0.33	0.31	0.27	0.28
129	Twaite Shad	FISH5	0.23	0.15	0.33	0.43	0.27	0.27
130	Ruff	BIRD17	0.35	0.15	0.33	0.29	0.26	0.27
131	Greylag Goose	BIRD9	0.39	0.05	0.33	0.33	0.26	0.26
132	Red Kite	BIRD39	0.39	0.09	0.33	0.29	0.26	0.26
133	Brimstone	BFLYc	0.28	0.20	0.33	0.28	0.25	0.26
134	Red Admiral	BFLYa	0.22	0.20	0.33	0.31	0.24	0.25
135	Allis Shad	FISH3	0.20	0.14	0.33	0.36	0.23	0.24

Appendix 11 – Review of literature toxicological sensitivities

Copper

Species	Code	Endpoint	Concentration	Lab/field	Reference
Invertebrates					
Onychiurus armatus		NOEC growth	2800 mg/kg food	lab	1
Lymantria dispar		NOEC mortality	50 mg/kg food	lab	2
Lymantria dispar		NOEC reproduction	10 mg/kg food	lab	2
Lymantria dispar		NOEC growth	10 mg/kg food	lab	2
Birds					
Gallus domesticus		NOEC	150 mg/kg food	lab	3
poultry		acute toxicity	30 mg/kg food	lab	4
Mammals					
Ovis amon aries		NOEC	7 mg/kg food	lab	3
Mus musculus		NOEC	40 mg/kg food	lab	3
Sus scrofa domesticus		NOEC	250 mg/kg food	lab	3
Rattus norvegicus	MAMb	NOEC	265 mg/kg food	lab	3
swine		acute toxicity	30 mg/kg food	lab	4
Fish					
Cyprinus carpio	FISHa	NOEC	50 μg/l water	lab	5
Cyprinus carpio	FISHa	LC_{50}	661 μg/l water	lab	6
Noemacheilus barbatulus	FISH2	NOEC	120 μg/l water	lab	5
Noemacheilus barbatulus	FISH2	LC_{50}	260 μg/l water	lab	7
Gasterosteus aculeatus	FISHb	LC_{50}	227 μg/l water	lab	8

Zinc

Species	Code	Endpoint	Concentration	Lab/field	Reference
Invertebrates					
Lymantria dispar		NOEC mortality	100 mg/kg food	lab	2
Lymantria dispar		NOEC reproduction	100 mg/kg food	lab	2
Lymantria dispar		NOEC growth	100 mg/kg food	lab	2
Birds					
Gallus domesticus		NOEC	1000 mg/kg food	lab	3
Anas platyrhynchos	BIRDa	LC_{50}	3000 mg/kg food	lab	9
Mammals					
Ovis amon aries		NOEC	150 mg/kg food	lab	3
cattle, sheep, pig, horses		acute toxicity	> 1000 mg/kg food	lab	4
Fish					
Cyprinus carpio	FISHa	LC_{50}	7800 μg/l water	lab	10
Noemacheilus barbatulus	FISH2	LC_{50}	2500 μg/l water	lab	7
Amphibians					
Triturus cristatus	AMPH3	LC_{50}	3000 μg/l water	lab	9

Cadmium

Species	Code	Endpoint	Concentration	Lab/field	Reference
Invertebrates					
Lymantria dispar		NOEC mortality	50 mg/kg food	lab	2
Lymantria dispar		NOEC reproduction	10 mg/kg food	lab	2
Lymantria dispar		NOEC growth	2 mg/kg food	lab	2
Folsomia candida		NOEC mortality	350 mg/kg soil	lab	11
Folsomia candida		NOEC reproduction	36 mg/kg soil	lab	11
Folsomia candida		NOEC growth	160 mg/kg soil	lab	11
Folsomia candida		NOEC reproduction	89 mg/kg soil	lab	12
Orchesella cincta		NOEC reproduction	43 mg/kg food	lab	13
Orchesella cincta		NOEC growth	2.9 mg/kg food	lab	13
Enallagma cyathigerum	DFLYa	LC_{50}	650 mg/l water	lab	14
Birds					
Anas platyrhynchos	BIRDa	NOEC reproduction	1.6 mg/kg food	lab	3
Anas platyrhynchos	BIRDa	renal damage	20 mg/kg food	lab	15
Anas platyrhynchos	BIRDa	renal damage	2.0 mg/kg food	lab	16
Anas platyrhynchos	BIRDa	LC_{50}	3065 mg/kg food	lab	17

Cadmium (continued)

Species	Code	Endpoint	Concentration	Lab/field	Reference
Meleagris gallopavo		NOEC growth	0.2 mg/kg food	lab	3
Gallus domesticus		NOEC mortality	12 mg/kg food	lab	3
Coturnix japonica		NOEC growth	38 mg/kg food	lab	3
Streptopelia risoria		NOEC reproduction	1.9 mg/kg food	lab	3
chicken		LC_{50}	56.5 mg/kg food	lab	18
Mammals					
Macaca mulatta		NOEC growth	3 mg/kg food	lab	3
Ovis amon aries		NOEC growth	15 mg/kg food	lab	3
Rattus norvegicus	MAMb	NOEC growth	10 mg/kg food	lab	3
Rattus norvegicus	MAMb	NOEC growth	42 mg/kg food	lab	3
Bos primigenius taurus		NOEC growth	40 mg/kg food	lab	3
Sus scrofa domesticus		NOEC growth	40 mg/kg food	lab	3
Sus scrofa domesticus		NOEC growth	50 mg/kg food	lab	3
dogs		acute toxicity	2.5 mg/kg food	lab	4
Fish					
Cyprinus carpio	FISHa	LC_{50}	240 μg/l water	lab	10
Noemacheilus barbatulus	FISH2	LC_{50}	2000 μg/l water	lab	7
Amphibians					
Bufo americanus		LOEC	5 μg/l water		19
Rana sphenocephala		LOEC	5 μg/l water		19
Xenopus laevis		LC_{50}	0.8 mg/l water		20
Xenopus laevis		LC_{50}	7.36 mg/l water		20
Bufo melanostictus		LC_{50}	8.18 mg/l water		20

DDT

Species	Code	Endpoint	Concentration	Lab/field	Reference
Invertebrates					
Gryllus pennsylvanicus		LC_{50}	10 mg/kg soil	lab	1
Ischnura damselfly		LC_{50}	42 μg/l water	lab	21
Lestes damselfly		LC_{50}	175 μg/l water	lab	21
Ophiogomphus dragonfly		LC_{50}	32 μg/l water	lab	21
Birds					
bird		decrease in abundance	5.6 kg/ha	field	22
Anas platyrhynchos	BIRDa	thinner egg shell	4.6 mg/kg food	lab	23
Anas platyrhynchos	BIRDa	NOEC reproduction	3.3 mg/kg food	lab	24
Anas platyrhynchos	BIRDa	LC_{50}	875 mg/kg food	lab	25
Falco tinnunculus	BIRD47	thinner egg shell	3.2 mg/kg food	lab	26
Tyto alba		thinner egg shell	1.2 mg/kg food	lab	27
Falco peregrinus		thinner egg shell	0.1 mg/kg food	field	28
Falco peregrinus		reduced reproduction	0.3 mg/kg food	lab	29
Gallus domesticus		NOEC reproduction	0.6 mg/kg food	lab	24
Coturnix japonica		NOEC reproduction	10 mg/kg food	lab	24
Falco sparverius		NOEC reproduction	5.6 mg/kg food	lab	24
Otus asio		NOEC reproduction	2.8 mg/kg food	lab	24
Phasianus colchicus		NOEC reproduction	50 mg/kg food	lab	24
Mammals					
Rattus norvegicus	MAMb	NOEC reproduction	20 mg/kg food	lab	24
Mus musculus		NOEC reproduction	25 mg/kg food	lab	24
Saimura sciureus		NOEC mortality	28.4 mg/kg food	lab	24
Microtus pennsylvanicus		NOEC mortality	100 mg/kg food	lab	24
Macaca mulatta		NOEC mortality	200 mg/kg food	lab	24
Canis domesticus		NOEC mortality	400 mg/kg food	lab	24
Fish					
Cyprinus carpio	FISHa	LC_{50}	110 μg/l water	lab	21
Noemacheilus barbatulus	FISH2	LC_{50}	11.5 μg/l water	lab	21
Leuciscus idus	FISH8	LC_{50}	200 μg/l water	lab	21
Amphibians					
Rana spp		LC_{50}	260 μg/l water	lab	21
Bufo spp		LC_{50}	2 mg/l water	lab	21
Triturus spp.		LC_{50}	250 μg/l water	lab	21

Chlorpyrifos

Species	Code	Endpoint	Concentration	Lab/field	Reference
Invertebrates					
Folsomia candida		LC_{50}	0.18 mg/kg soil	lab	30
Folsomia candida		NOEC	0.065 mg/kg soil	lab	30
earthworm		LC_{50}	330 mg/kg soil	lab	31
Pteronarcys californica		LC_{50}	10 µg/l water	lab	32
Pteronarcella badia		LC_{50}	0.38 µg/l water	lab	32
Claassenia subulosa		LC_{50}	0.57 µg/l water	lab	32
Gammarus lacustris		LC_{50}	0.11 µg/l water	lab	32
Gammarus pseudolimnaeus		LC_{50}	0.18 µg/l water	lab	32
Orconectes immunis		LC_{50}	6 µg/l water	lab	32
Birds					
Anas platyrhonchos		LC_{50}	190 mg/kg food	lab	32
Anas platyrhonchos		NOEC	80 mg/kg food	lab	32
Coturnix japonica		LC_{50}	300 mg/kg food	lab	33
Coturnix japonica		NOEC	10 mg/kg food	lab	32
Gallus domesticus		NOEC	25 mg/kg food	lab	32
Passer domesticus		NOEC	27 mg/kg food	lab	32
Phasianus colchicus		LC_{50}	550 mg/kg food	lab	32
Agelaius phoeniceus		LD_{50}	13.1 mg/kg body weight	lab	33
Anas platyrhynchos		LD_{50}	75.6 mg/kg body weight	lab	33
Colinus virginianus		LD_{50}	32 mg/kg body weight	lab	33
Columba livia		LD_{50}	10 mg/kg body weight	lab	33
Columba livia		LD_{50}	26.9 mg/kg body weight	lab	33
Coturnix japonica		LD_{50}	13.3 mg/kg body weight	lab	33
Gallus domesticus		LD_{50}	34.8 mg/kg body weight	lab	33
Passer domesticus		LD_{50}	10 mg/kg body weight	lab	33
Phasianus colchicus		LD_{50}	8.41 mg/kg body weight	lab	33
Quiscalus quiscala		LD_{50}	5.62 mg/kg body weight	lab	33
Sturnes vulgaris		LD_{50}	75 mg/kg body weight	lab	33
Mammals					
Rattus norvegicus	MAMb	LD_{50}	97 mg/kg body weight	lab	33
Rattus norvegicus	MAMb	NOED	0.3 mg/kg body weight	lab	32
Fish					
Cyprinus carpio	FISHa	LC_{50}	1.3 µg/l water	lab	33
Anguilla anguilla		LC_{50}	540 µg/l water	lab	33
Lepomis macrochirus		LC_{50}	3 µg/l water	lab	33
Oncorhynchus clarki		LC_{50}	13 µg/l water	lab	33
Oncorhynchus mykiss		LC_{50}	9 µg/l water	lab	33
Pimephales promelas		LC_{50}	540 µg/l water	lab	33
Salvelinus namaycush		LC_{50}	98 µg/l water	lab	33
Tilapia mossambica		LC_{50}	26 µg/l water	lab	33
Amphibians					
Bufo americanus		LC_{50}	1 µg/l water	lab	33
Bufo vulgaris formosus		LC_{50}	13000 µg/l water	lab	33
Rana pipiens		LC_{50}	3000 µg/l water	lab	33
Rana pipiens		LC_{50}	30000 µg/l water	lab	33

Ivermectin

Species	Code	Endpoint	Concentration	Lab/field	Reference
Invertebrates					
Daphnia magna		LC_{50}	0.025 µg/l water	lab	34
Daphnia magna		NOEC	0.01 µg/l water	lab	34
Eisenia foetida		LC_{50}	315 mg/kg soil	lab	34
Eisenia foetida		NOEC	12 mg/kg soil	lab	34
Corophium volutator		LC_{50}	0.18 mg/kg sediment	lab	35
Corophium volutator		NOEC	0.05 mg/kg sediment	lab	35
Asterias rubens		LC_{50}	23.6 mg/kg sediment	lab	35
Asterias rubens		NOEC	5 mg/kg sediment	lab	35
Crangon septemspinosa		LC_{50}	8.5 mg/kg food	lab	36
Crangon septemspinosa		NOEC	2.6 mg/kg food	lab	36

Ivermectin (continued)

Species	Code	Endpoint	Concentration	Lab/field	Reference
Birds					
Anas platyrhynchos *	BIRDa	LC_{50}	570 mg/kg food	lab	37
Anas platyrhynchos *	BIRDa	NOEC	80 mg/kg food	lab	37
Colinus virginianus *		LC_{50}	1318 mg/kg food	lab	37
Colinus virginianus *		NOEC	500 mg/kg food	lab	37
Fish					
Salmo gairdneri		LC_{50}	3 μg/l water	lab	34
Lepomis macrochirus		LC_{50}	4.8 μg/l water	lab	34
Salmo salar		LC_{50}	17 mg/l water	lab	38
Anguilla anguilla		LC_{50}	0.2 mg/l water	lab	38

* As tested for emamectin benzoate, a derivative of the natural avermectin product abamectin.

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