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Wildlife vulnerability and risk maps for combined pollutants

Joost Lahr [a,*], Bernd Münier [b], Hendrika J. De Lange [a], Jack F. Faber [a], Peter Borgen Sørensen [c]

[a] Alterra, Wageningen UR, PO Box 47, 6700 AA Wageningen, The Netherlands
[b] National Environmental Research Institute, Aarhus University, P.O. Box 358, 4000, Roskilde, Denmark
[c] National Environmental Research Institute, Aarhus University, P.O.Box 314, 8600 Silkeborg, Denmark

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ABSTRACT

Ecological risk and vulnerability maps can be used to improve the analysis of pollutant risks and communication to stakeholders. Often, such maps are made for one pollutant at the time. We used the results of wildlife vulnerability analysis, a novel trait-based risk assessment approach, to map overall vulnerability of habitats in Denmark to various metals and one insecticide. These maps were combined with maps of estimated soil concentrations for the same compounds divided by their Maximum Permissible Concentrations. This combination yielded relative risk maps that can be used to assess where the highest risk conditions to wildlife from these individual pollutants in Denmark occur (hot spot identification). In order to show how cumulative risk maps can be made, the maps of the individual pollutants were combined assuming different mechanisms of joint toxicity: no addition, concentration addition, antagonism and synergism. The study demonstrated that with an accurate set of geographical and ecological data one can use the results of vulnerability analysis to make relevant ecological risk maps that show hot spot areas for risks of single or cumulative risks from soil pollutants.

1. Introduction

Environmental risk maps allow scientists and risk assessors to explore the spatial nature of the effects of environmental stressors such as toxic substances. They are also a very useful tool to communicate environmental risk assessment results to the general public and particular stakeholders (see Lahr and Koostra, 2009). For instance, they allow policy makers to take well informed decisions in spatial planning in relation to the position of polluted sites, and web-based risk maps inform inhabitants of particular areas about pollution sources close to their homes. Computerised Geographic Information Systems (GIS) have greatly facilitated map making over the past years, making it more rapid and enabling electronic and internet-based maps. GIS also allows the user to combine different map layers in an easy way and to apply algorithms in this process. For our purpose, this development means that particular risk assessment models may be incorporated in the GIS.

Besides some exceptions (e.g., coplanar PCB congeners with a similar mode of action), traditional environmental risk assessment for toxic substances is often concerned with the risks of individual compounds only. For the same reason, many risk maps also show concentrations, (potential) exposure or (potential) effects of single substances only (Lahr and Koostra, 2009). In the real world, however, organisms are seldom exposed to a single stressor. For a more realistic risk assessment, one therefore has to consider combined effects of multiple stressors, such as combinations of different chemical stressors and combinations of chemical and natural stress. Over the past years the European project NOMIRACLE (NOvel Methods for Integrated Risk Assessment of CumuLative stressors in Europe) has developed novel methods for this very purpose (this issue of STOTEN) and the principles of cumulative risk assessment are increasingly used for making risk maps.

Another recent development, particularly in ecological risk assessment of chemicals, is to put more focus on the risk receptors. Ecological properties of the receptors, most often species, are used to determine their sensitivity or vulnerability to pollutants. This approach is called trait-based ecological risk assessment, as opposed to the traditional substance-based risk assessment (Baird and van den Brink, 2007; Baird et al., 2008). Although ranking or indexing vulnerability of species is not new (e.g. King and Sanger, 1979; Golden and Rattner, 2003; Hiscock and Tyler-Walters, 2006; see De Lange et al., submitted for publication, 2010-this issue, for a review), the approach is currently gaining more momentum. A new method was also developed in the NOMIRACLE project. It serves to estimate the relative ecological vulnerability of wildlife species to soil pollutants, based on various traits such as life cycle characteristics, physiology, food preferences and dispersal and migration behaviour (De Lange et al., 2009). The concept of ecological vulnerability that De Lange et al. (2009) apply not only includes sensitivity of species to the chemical of concern but also potential exposure and potential population recovery. All three factors, exposure, sensitivity and recovery potential, are quantified on the basis of physiological,

* Corresponding author. Tel.: +31 317 485399; fax: +31 317 419000.
E-mail address: joost.lahr@wur.nl (J. Lahr).

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behavioural and life cycle data. The result is a vulnerability score for each wildlife species that is used to make a ranking of species. This vulnerability analysis, therefore, provides more insight into the possible impact of a pollutant to a species at the population level than sensitivity or toxicity alone. Recently, the existing scores for the ecological vulnerability of wildlife species (mammals, birds, reptiles, amphibians, fish, butterflies, dragonflies) provided by De Lange et al. (2009) were used to estimate the overall vulnerability of habitats to some common soil contaminants (De Lange et al., submitted for publication).

Ecological vulnerability maps and ecological risk maps can be produced by combining the results of this analysis with a habitat map and maps of the pollutant concentration levels in soils. In this paper we present a demonstration case utilising geographical data from Denmark. First habitat vulnerability maps for wildlife and soil concentration maps are produced for individual soil pollutants, in this case the metals copper, zinc, cadmium and nickel and the organophosphate insecticide chlorpyrifos. Secondly, these two types of maps are combined into ecological risk maps. Finally we construct some examples of cumulative ecological risk maps for the metals combined and for the four metals plus a single application of the insecticide.

2. Methods

2.1. Study area

The country of Denmark was chosen for the study due to availability of the necessary digital geographical data and maps for research purposes (Table 1). As software we used ArcGIS v. 9.3 from the Environmental Systems Research Institute (ESRI). All GIS analysis was carried out for the entire country at a spatial resolution of 25 × 25 m using raster data. From this data set, a smaller area was selected for presentation purposes to illustrate local variability and the high spatial resolution of the maps. The different types of maps shown in this paper represent the area around the Saml Belt ('Little Belt'), a straight between the Danish mainland (Jutland) to the west and the island of Funen to the east. This area was selected because of its varying landscapes, because it contains most Danish habitat types and because it has distinct gradients in metal concentrations in soil.

2.2. Habitat map

A suitable habitat map was constructed from the Danish topographical map database (Table 1) and a map of protected natural and semi-natural nature types (Table 1). These polygon map were converted into raster map with grids of 25 × 25 m. Then all Danish habitat categories were assigned to the inland habitat types used by De Lange et al. (submitted for publication). This produced the final habitat map. The Dutch inland habitat types are originally based on so-called 'nature target types' used for nature conservation management purposes in The Netherlands (Bal et al., 2001).

2.3. Vulnerability analysis

The method to estimate the vulnerability of wildlife species is explained in more detail by De Lange et al. (2009) and the application of this method to habitats is described by De Lange et al. (submitted for publication). Briefly, quantitative and semi-quantitative data on the ecological traits of wildlife species is collected from the literature or retrieved from experts with specific ecological field knowledge. The traits are divided into four categories, those that under field conditions determine external exposure, internal exposure, sensitivity, and population recovery of the species. The data for each species are then subjected to a Multi Criteria Analysis (MCA) using weight factors for each trait and each category of traits that vary according to the (type of) toxic substance. The outcome is a score between 0 and 1 per species and per toxicant. The higher the value of this score, the more vulnerable the species is for the substance. These scores are not absolute but relative measures of vulnerability. They can be used to compare the ecological vulnerability of a species to different pollutants or the vulnerability of different species to the same pollutant. The method was originally developed for the soil pollutants Cd, Cu, Zn, DDT, chlorpyrifos and ivermectin (De Lange et al., 2009). In this paper we only use the results on chlorpyrifos and the three metals. There were no geographical data for soil pollution with DDT or ivermectin. Since we are also interested in vulnerability to nickel, we deduced weight factors for this metal and carried out a vulnerability analysis for this metal as well.

2.4. Vulnerability maps

Since different habitats contain different assemblages of species, the overall vulnerability of a habitat can be estimated by calculating the average vulnerability score of the species that are characteristic for the habitat (De Lange et al., submitted for publication). This calculation yields one average vulnerability score per habitat. The arithmetic average vulnerability score was chosen because it represents the total assemblage of the species present in the habitat with an equal weight per species (another approach would have been to use only the species with maximum vulnerability score, i.e., as a worst case approach).

We used the habitat vulnerability scores calculated by De Lange et al. (submitted for publication) and combined these with the habitat map made described above. This combination yielded habitat vulnerability maps for Denmark for each of the four metals and for chlorpyrifos with the relative vulnerability shown on a continuous scale.

2.5. Hazard maps

A soil texture map of Denmark (Table 1) served as the basis for constructing concentration maps for the four metals. Larsen et al. (1996) established general relationships between soil characteristics and the average background concentrations of metals in Danish soils. These relationships were used in combination with a table of the

Table 1
List of map layers used for mapping ecological vulnerability and risks for wildlife in Denmark.

Mapping theme and map layer	Data owner/copyright	Georeference unit	Approx. scale
Topographic base map (forest, wetlands, heath lands, built up areas, roads, water courses, lakes, ...) — http://www.kms.dk	KMS (National Survey and Cadastre)	Polygon	1:10.000
National protected nature areas (semi-natural terrestrial biotopes) — http://miljoeportal.dk/	Environmental Portal of Denmark (Miljøportal)	Polygon	1:25.000
Soil type, classification by texture and soil organic matter content — http://www.djfgeodata.dk/datasaml//jord2.html	DJF/Aarhus University	Polygon	1:50.000
LPIS, Land Parcel Information System, agricultural database of crops grown in each field — https://fvm.glr-chr.dk/portal/page/portal/glrchr	Ministry of Food, Agriculture and Fisheries	Polygon	1:10.000