available at www.sciencedirect.com

ScienceDirect

www.elsevier.com/locate/scitotenv

Field effects of pollutants at the community level — Experimental challenges and significance of community shifts for ecosystem functioning

*Michiel Rutgers**

Laboratory for Ecological Risk Assessment, National Institute for Public Health and the Environment, Antonie van Leeuwenhoeklaan 9, 3621 MA Bilthoven, The Netherlands

ARTICLE INFO

Article history:
Received 28 May 2008
Accepted 30 May 2008
Available online 21 July 2008

Keywords:
Metal polluted sites
Community shifts
Amendment cover (toemaakdek)
Nematodes
Bacteria
Pollution-induced community tolerance

ABSTRACT

In the Stimulation Program System-oriented Ecotoxicological Research (SSEO) three sites in The Netherlands were investigated for field effects of the grey veil of pollutants. At each site several studies were performed in order to arrive at an adequate weight of evidence and to improve causal inference of pollutant effects. This paper contains a synthesis of results of the studies, performed at one of the sites, the Demmerikse polder. This site is characterized by an anthropogenic layer of soil (in old Dutch: 'toemaakdek') on top of the natural peat. Lead, copper and zinc concentrations were elevated, with lead concentrations above a Netherlands environmental quality criterion (Intervention Value) in 66% of the samples. Issues discussed in the paper are: the sampling strategy, selection of maximum gradient and suitable community end-points, both in space and in time. Specific emphasis was given to causal inference of ecological effects of pollutants, related to direct versus indirect effects, functioning of ecosystems, normal operation range and risk assessment. The plausibility of metal effects could be demonstrated on a number of occasions. In the Demmerikse polder changes in the bacterial and nematode communities could be related significantly to metal concentrations and separated from other environmental variables, such as organic matter content and pH.

1. SSEO and the issue of demonstrating field effects

In The Netherlands, large areas are polluted with metals due to atmospheric distribution, sedimentation in floodplain areas, and use of manure and artificial fertilizers in agro ecosystems. This type of pollution is denoted as the 'grey veil'. Despite stringent environmental policy to reduce sources of pollution, concentrations of metals in the grey veil are still increasing (MNP, 2004). So, questions become manifest to what extent these metals affect ecosystems in soils and sediments. Current soil protection policy in The Netherlands is focused on the solution for adverse effects from point sources with high pollutant concentrations. Is it necessary to expand environmental policy and land-use management to this grey veil?

The first challenge is to demonstrate adverse effects of metal pollution in the field at concentrations below or around the quality criteria. The generic criteria are set from the precautionary principle for protecting the environment from effects of pollutants, for instance The Netherlands Intervention Values. Effect in this context is defined as any change in

* Tel.: +31 30 274 20 40.
E-mail address: michiel.rutgers@rivm.nl.

0048-9697/$ – see front matter © 2008 Elsevier B.V. All rights reserved.
doi:10.1016/j.scitotenv.2008.05.055

ecosystem attributes like species abundance, community composition, ecological processes and functions. Once these effects are proven, and the occurrence of type 2 errors is excluded (i.e. observations do not reveal an effect of pollution, while in reality there is one), the next step is to relate these findings to a quantitative and integrated measure of ecosystem effect. The significance of this exercise with the grey veil resides in the combination of small effects over relatively large surfaces, while the ecological relevance of the findings should be integrated to a higher level of organization. The final step is to weigh the outcome in the broader context of site management and the willingness of the land user and authorities to reduce adverse effects. The latter steps should be part of a site-specific ecological risk assessment, which is not an issue of this paper (Rutgers and Den Besten, 2005; Posthuma et al., 2008—this issue; Faber, 2006; Suter, 2006).

All the sites selected in the SSEO are moderately polluted with a grey veil of heavy metals, and sometimes with organic pollutants as well (PAH, PCB). In this paper the characteristics of a peat area in the central-western part of The Netherlands is described in more detail. For the other sites the reader is referred to companion papers in this special issue (Van Gestel, 2008—this issue; Klok and Kraak, 2008—this issue).

In the literature many data on field effects of pollution are presented. Jensen and Pedersen (2006) reviewed efforts to demonstrate field effects of pollutants at four sites, i.e. a metal-smelter region in the UK (Avonmouth, Wales; Filzek et al., 2004), a metal smelter region in The Netherlands (Kempen, N-Brabant; Posthuma et al., 2001), a copper polluted area in Denmark (Hygym), and a number of dioxin polluted sites in Denmark. Very often, effects of pollutants on one or more groups of soil dwelling organisms or soil processes could be demonstrated, although the issue of a lack of causality often hampered a clear-cut interpretation of the results. A general conclusion from these studies was that availability of a proper reference site, reference samples, or reference literature data is of utmost importance for a convincing demonstration of effects. The ideal reference is never available. However, mathematical techniques like multivariate analysis or multidimensional scaling can be used to relate environmental variables to soil ecosystem characteristics in complex matrices and can partly offer a solution to the issue of confounding (Kedwards et al., 1999). In a strict sense, causal inference of field effects of pollutants is impossible (Everitt and Dunn, 2001). However, latent variables from a multidimensional space can be used as theoretical constructs in risk assessment, providing statistical meaningful relationships between pollutants and system attributes.

The cases described in the literature are generally characterized by quite high levels of pollutants, around and well above environmental quality criteria set to protect the environment. Especially at smelter sites high metal concentrations are the rule rather than the exception (e.g. at Avonmouth). Samples from soils nearby the smelter can be compared with samples from more distant areas, providing large metal concentration gradients. It is to be expected that effects at lower concentrations in the field are much more difficult to capture, or can not be captured at all, due to a lack of experimental and statistical power in the field surveys. The reason is that ecosystems are shaped by the whole set of environmental parameters and small effects of pollutants are often over-shadowed by the confounding factors. The question whether small ecological effects of pollutants should trigger measures like adaptive soil management is not a scientific issue, but part of a risk assessment and requires a dialogue and societal interference.

A concept aiming to circumvent some of the problems related to the issues of confounding and causality is pollution-induced community tolerance (PICT). Blanck et al. (1988) recognized the significance of PICT for risk assessment, and since then, PICT was demonstrated in marine, freshwater and terrestrial ecosystems (Blanck, 2002; Boivin et al., 2002; Van Beelen et al., 2004). PICT is based on classic ecological principles. Tolerant populations thriving under conditions with high pollutant concentrations will out-compete more sensitive populations, resulting in an overall increased community tolerance. This can be determined in the laboratory under controlled conditions in dose–effect studies with the autochthonous communities. Increased community tolerance can be considered as a strong indication of field effects of pollutants, but should be combined with data on reduced ecosystem structure and functioning (Boivin et al., 2002).

When pollutant effects are expected to be small, the use of small organisms like bacteria and nematodes for effect characterization is preferred for two reasons. First, small soil organisms live in intimate contact and interaction with their environment because of the dimensions and surface to volume ratio and will therefore react quickly and sensitively to pollution (Fairbrother et al., 2002; Rutgers and Breure, 1999). There is evidence that microorganisms are far more sensitive to heavy metal stress than soil animals and plants (Giller et al., 1998; Boivin et al., 2006b), and might be used as early indicators of ecosystem stress. Furthermore, larger organisms are able to escape the pollution, while microorganisms can be regarded as sessile. As a result, distribution of microorganisms can be linked easily to the small scale distribution of pollutants in the soil, providing a more solid relationship between pollutant measurements and field observations.

Second, sampling of small organisms is generally cheap, handling of samples in the laboratory is easy and analyses can be automated. Consequently, demonstration of plausible effects of pollution will require a minimum amount of effort and will reduce the occurrence of false negative observations.

Of course there are problems. In ecotoxicology, the concept of protecting the ecosystem via the protection of different species has been materialized in so-called species sensitivity distributions (SSD; Posthuma et al., 2008—this issue). However, this approach is not particularly useful for microbial communities. For instance, the definition of a bacterial species is debated and the occurrence of ample redundancy in microbe mediated processes seems to contrast the need for protection of species (Naeem, 1998; Rosenfeld, 2002). In a recent study at a zinc polluted site, changes in the bacterial community composition were observed (Lock and Janssen, 2005), which were not accompanied by changes in microbe mediated soil processes (Smolders et al., 2004). This notion forces to include other types of end-points in the effects assessment as well. Ideally, demonstration of shifts in soil communities due to the presence of pollutants should address the food web structure, the soil functioning, and the above