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Ecological theory meets soil ecotoxicology: Challenge and chance

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Abstract

The degradation of soils due to various anthropogenic stress factors is alarming. Although chemicals are a major reason for soil degradation, most ecologists are not interested in studying such effects. We try to wake their interest by addressing a number of unsolved soil ecotoxicological problems that are related to disturbance ecology, biodiversity, ecosystem functioning and modelling. Features distinguishing chemical from natural stress render promising new aspects in disturbance ecology. Ecotoxicological studies are ideal models of disturbance, particularly regarding frequency, intensity or multitude of stress. Patterns of secondary succession after a major chemical damage can directly be related to the intermediate disturbance hypothesis. More knowledge on altered life history patterns following stress could support both evolutionary ecology and risk assessment. We raise the question if inherent resource competition makes communities more vulnerable to stress. Three aspects of ecotoxicological risk assessment are introduced: (1) exposure and bioavailability, which is directly connected to environmental heterogeneity; (2) tests on ecosystem functioning, suffering from major drawbacks; and (3) modelling. Here, promising approaches exist but need substantial input for being applicable to soils. Ecological modelling should put more emphasis on simulating both natural and chemical disturbances, including behavioural aspects and environmental variability. Finally, research needs for ecological risk assessment in soils are derived such as a simple system to assess the impact of chemicals on soil biodiversity, the inclusion of behavioural changes of keystone species or the consideration of density-dependent effects. Common research efforts of basic ecologists and soil ecotoxicologists could render a lot of mutual benefits.

Zusammenfassung

Die durch verschiedene anthropogene Stressoren verursachte Degradation von Böden ist erschreckend. Obwohl Chemikalien eine Hauptursache für Bodendegradation sind, interessieren sich die meisten Ökologen nicht für die Untersuchung solcher Effekte. Wir versuchen ihr Interesse zu wecken indem wir eine Reihe ungelöster ökotoxikologischer Probleme aufzeigen, die Bezug zu Störungsökologie, Biodiversität, ökosystemaren Funktionen und Modellierung haben. Eigenschaften, die chemischen von natürlichem Stress abgrenzen.

Liefern vielversprechende neue Aspekte für die Störungsökologie. Ökotoxikologische Untersuchungen sind ideale Störungsmodelle, insbesondere was Häufigkeit, Intensität oder Vielfalt der Einwirkungen betrifft. Muster der

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Sekundärsukzession nach einem größeren chemischen Schaden lassen sich direkt auf die intermediate disturbance hypothesis beziehen. Mehr Wissen zu veränderten Lebensdaten nach Stresseinwirkung wäre sowohl für Evolutionsökologie als auch für die Risikoabschätzung von Nutzen. Wir werfen die Frage auf, ob starke Ressourcenkonkurrenz Gemeinschaften empfindlicher gegenüber Stress macht. Drei Aspekte der ökotoxikologischen Risikoabschätzung werden vorgestellt: (1) Exposition und Bioverfügbarkeit, die in direkter Verbindung zur Umweltheterogenität stehen, (2) Tests zu ökosystemaren Funktionen, die erhebliche Nachteile aufweisen, (3) Modellierung. Hier gibt es vielversprechende Ansätze, die aber noch erheblich erweitert werden müssen um in Böden anwendbar zu sein. Ökologische Modellierung sollte sich vermehrt mit der Simulation sowohl natürlicher als auch chemischer Störungen befassen, einschließlich Verhaltensaspekten und Umweltheterogenität. Schließlich wird Forschungsbedarf für ökologische Risikoabschätzung in Böden abgeleitet, darunter ein einfaches System, um den Einfluss von Chemikalien auf die Biodiversität abzuschätzen, die Einbeziehung von Verhaltensänderungen von Schlüsselarten oder die Heranziehung dichteabhängiger Effekte. Gemeinsame Forschungsanstrengungen von Grundlagen- und anwendungsorientierten Ökologen könnten eine Menge gegenseitigen Nutzens hervorbringen.

Keywords: Biodiversity; Disturbance; Ecosystem functions; Environmental heterogeneity; Interdisciplinarity; Modelling; Risk assessment; Soil protection; Terrestrial ecosystems

Introduction

It is increasingly recognised that the protection of soils and their inherent communities have to become a prime goal of environmental policy worldwide (Römbke, Förster, Jänsch, Scheffczyk, & Garcia, 2005; Sijm, van Wezel, & Crommentuijn, 2002). However, 47% of the world's land is moderately to very severely degraded, and 22% of all cropland, pasture, forest, and woodland have been degraded only since 1950 (GLASOD, 2004). Soils are highly variable in space and time and host very diverse communities with a large proportion of generalists (André, Ducarme, & Lebrun, 2002). Many well established ecological rules do not apply for soil food webs (Scheu & Setälä, 2002). Omnivory is widespread, and high levels of redundancy and indirect effects are encountered (Filser, 2000).

We are way behind a fundamental understanding of the soil's organisms or processes, nor of how much external impact, including chemicals, soils can tolerate before their crucial functions collapse.

Breure, Mulder, Römbke, & Ruf (2005) summarised the state of the art of ecological classification and assessment concepts in soil protection. However, there is still a gap between such concepts and those currently discussed in ecology. The impact of chemicals on vital soil functions has mostly been studied in reductionistic ecotoxicological test systems (Knacker, Förster, Römbke, & Frampton, 2003; Römbke et al., 2003). More complex approaches, covering both risk assessment and ecosystem functioning, have been pursued by Weigmann (1992) and Salminen, Setälä, and Haimi (1997).

> *Little guidance (from theoretical ecology) can be given at the moment as to the question how to proceed with reinforcing the ecological basis of soil protection* (Van Straalen, 2002).

Basic ecological research could make more use of ecotoxicological experiments and approaches as ideal models of disturbance. We discuss the impact of chemicals on soils in the context of relevant concepts in ecology, pointing out similarities and distinctive features of chemical and "natural" disturbance and research challenges with special respect to biodiversity and ecosystem functioning.

Relevant ecological concepts: analyses and chances

Disturbance ecology

Any adverse effect of a chemical upon an ecosystem can be regarded as a disturbance (Van Straalen, 2003). In respect to disturbance frequency, a single chemical impact has different effects compared to low intensity chronic contamination, which only can be assessed in long-term studies (Yeates, Wardle, & Watson, 1999). However, even a single chemical application may result in strong effects on abundance and diversity, observable long beyond the detectability of the compound (Koehler, 1994). Frequent or severe disturbances may reduce biodiversity dramatically, including whole functional groups (Filser, Fromm, Nagel, & Winter, 1995). Key questions of disturbance ecology are thus the buffering capacity of ecosystems and the significance of changes in biodiversity and consequently ecosystem functioning (Moore & De Ruiter, 1997).

Table 1 summarises common and distinctive features of chemical and "natural" stress. Evidently, there are some common aspects but also pronounced differences like the diversity, accumulation and modification of stressors. Effects of chemicals on soil organisms may vary with other factors like temperature, drought, soil