Food-Web Modelling for Ecological Assessment of Terrestrial Pollution (EcolMAT)

An ESF scientific programme

The European Science Foundation acts as a catalyst for the development of science by bringing together leading scientists and funding agencies to debate, plan and implement pan-European initiatives.

Terrestrial pollution has been an issue mainly dealt with from a soil protection point of view. Risk assessment for terrestrial pollution is focused on direct human intake and on derived intake (through leaching via groundwater to drinking water). Impacts of terrestrial contamination on functioning and integrity of terrestrial ecosystems have not been taken into account. However, in addition to the present focus on point source pollution, there is a need for a better ecotoxicological assessment of the combined impact of a mixture of multiple, low-level loads of persistent contaminants. Ecosystem modelling and, more specifically, modelling of food-web processes, provides a proper vehicle to study these impacts. Transfer of contaminants in food-chains may enlarge the impact by direct accumulation processes and by indirect effects such as predator prey interactions, and interactions involving mutualisms and chemical signals (e.g. kairomones). These effects do not occur at random in an ecosystem but usually involve a specific sequence of species that form a critical pathway due to a combination of physiologies and exposures.

Disturbances of food-web interactions not only result from accidental, catastrophic releases of contaminants in the environment, but also from the steady, long-term influence of a dispersed, mixed load of persistent contaminants on ecosystem structure and processes. Although single contaminant loads may be small, the combined total load may be considerable.

The EcolMAT programme aims to stimulate the development of whole or partial food-web models for risk assessment of pollution in the terrestrial environment, including soil contamination. It could provide a "trait-d'union" between monitoring and validation-oriented ecotoxicological programmes currently running in European countries.

Scientific scope

In general, one may distinguish between simple (strategic) and complex (tactical) food-web models. Simple food-web models have a few variables. All trophic levels are typically considered to be in steady state except for one or two factors that are of interest. The number of parameters is low and default values may be provided by correlation with powerful characteristics of substances and species such as octanol-water partitioning and adult weight. Explicit solutions for the differential equations involved can usually be obtained. Since these models require relatively little data, they are successfully applied in cases where information is scarce (e.g. new chemicals), where the field situation is not very complex (e.g. accumulation of organochlorines in aquatic systems) and where predictions are urgently needed, but only in terms of trends rather than exact concentrations or densities (e.g. phytoplankton control by zooplankton exposed to pesticides). Complex models have many variables and allow extensive non-equilibrium calculations, usually by means of numerical approximations of the equations (computer simulation). Their predictions are more accurate but at a cost of requiring many data. Complex models can give good predictions, but sometimes for the wrong reasons. In ecotoxicology, such models have been developed and calibrated for a few substances and ecosystems only.

The type of model needed depends on the questions to be answered. In environmental management both simple and complex models are needed. They may also support each other – simple models can help to select cases to be studied in detail with complex models, results from complex models may be extrapolated to other conditions using more simple models, etc. It is hoped that proponents of both types of modelling will participate in EcolMAT.

The use of food-web models will allow the endpoints of ecological assessment to be defined better. With regard to the protection of ecosystems in the areas of environmental policy, as far as we know, there have been no defined endpoints or target variables in terms of characteristics at ecosystem level. It is assumed that an ecosystem is sufficiently protected when all species inhabiting that ecosystem are protected. Rather than single-species endpoints, higher level targets should be defined such as:

- vitality (productivity)
- organisation (ecosystem structure)
- resilience (powers of recuperation or toughness).

These variables conform closely to the general objectives of the European policy regarding the environment and nature conservation. In addition, target variables at the species level are relevant for the protection of designated species in a food-chain which are of particular value in terms of nature conservation policy. For these species endpoint could be defined as follows:

- average population size
- pseudo-extinction (likelihood of local extermination)
- resilience.

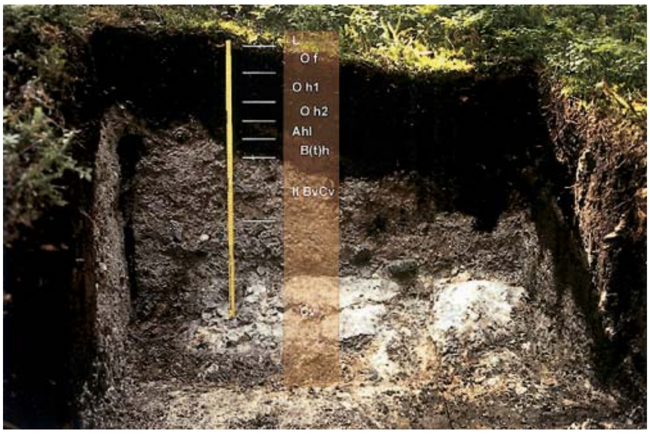
It is precisely these target variables that can be determined using the food-web approach. Classical food-web models are eminently well-suited to determine assessment endpoints at the ecosystem level. Hybrid food-web/population models can be used to determine such variables at the population level. Currently available food-web models cannot generate results in terms of species diversity and genetic diversity within species (policy objectives in the area of biodiversity). Further discussion is required to arrive at a selection of relevant target variables for the use of food-web models. In addition to the recommended general target variables, various specific endpoints should be considered. One such group consists of target variables relating to specific environmental functions, e.g. production, regulation and information functions. Another group consists of target variables arising from further elaboration of the biodiversity policy objective.

EcolMAT should try to organise round robin, and model shoot-out workshops (workshops in which various models are circulated among the different modellers, and tested by running a similar data-set) in order to combine already existing models which cover physico-chemical binding processes, physiological uptake and internal transfer processes, population biological, population dynamic, system structure and system process modelling. Characteristic in this context is the multidisciplinary cooperation of physico-chemists, physiologists and biochemists, and ecologists.

Although a number of well known and well studied toxic compounds seem to be reasonably controlled by environmental policy, the following aspects are still insufficiently investigated with respect to persistent and toxic compounds like heavy metals, organochlorines, and PAHs:

Cantherellus cibarius. Some organisms may play an important role in the food chain by withdrawing pollutants from the environment.
© Flemming Rune

1. The total mixture of combined impacts of low level persistent compounds are hardly understood, let it be properly assessed;
2. Quantitative assessment of the ultimate fate of a persistent compounds when transferred in an ecosystem is only partly (for some compounds) developed;
3. In this assessment, the real fate (including dynamic sorption in the environment, internal degradation and sorption in target organisms and their organs, and biodegradation by micro-organisms) has been included only incidentally;
4. Proper ecological assessment of the potential impact of new compounds is still weakly developed (this could comprise compounds with a very specific mode of action like endocrine disrupters or compounds with a very specific transfer route like cadmium uptake via willow bark to beavers);
5. Indirect impacts by interfering food-chain or more complex relations (chemical signals) are still hardly studied;



Alpine soil, probably covered with spruce; the exposed soil section is not a spectacular case. The B-horizon is slightly changing into the C-horizon.

6. Food-chain models which describe these kinds of phenomena are promising tools to describe long term implications of these phenomena;

7. These have to be combined with a) an ecological analysis in the field of the real transfer routes and target species and b) a literature study about the potential physico-chemical availability under variable (dynamic) conditions and resulting (eco)toxicological processes.

Food-web models are effective aids to a better understanding of the consequences of disturbances to these relatively complex relationships. The classical food-web models enable predictions to be made concerning the effects of toxic substances on ecosystem processes such as nutrient cycling and energy flows. This is because feeding relationships play an essential part in such processes. With such models, predictions can be made concerning effects on structural features of ecosystems such as their stability and resiliency. With hybrid food-web/population models, which combine classical food-web models with detailed population models, predictions can be made concerning the effects on the populations of certain individual species (in terms of population densities and likelihood of extinction).

Relative to work carried out in the area of aquatic ecosystems, food-web research and model-building in relation to terrestrial ecosystems are lagging behind. Currently available terrestrial food-web models are restricted to a few agricultural systems. They usually deal only with interactions in the subsurface (detritus web). In a report in 1997 the Standing Committee on Ecotoxicology of the Health Council of the Netherlands recommended that such models be expanded to include interactions with above-ground elements of the terrestrial food-web (plants, herbivores and the like). Also in the aquatic-sediment models this detritus cycle is of great importance to model the fate and impact of contaminants.

In the Committee's view, an important obstacle to the use of food-web models in ecotoxicological risk assessment is the lack of hard data, or more precisely a database containing these data. This includes ecophysiological and life-history parameters (data on consumption, mortality and the like, as well as data on concentration-effect relationships for those parameters) for the various functional groups in an ecosystem. It is not sufficient simply to apply extrapolation methods to a limited amount of toxicity data. In various ecosystems rather specific environmental conditions occur which have a major impact on the fate and behaviour of different contaminants. Moreover, it is important that the same set of default values and basic biological parameters is used in order to make the output of the various models properly comparable. This is all the more important when models of aquatic and terrestrial ecosystems are coupled to assess consequences of pollution in the framework of environmental outlooks.

The provision of data for food-web models is often a bottleneck. We believe that it is not necessary per se to collect a vast amount of new data before food-web models for risk assessment can be developed. The data needed as input for food-web models can be found scattered in the literature. For example, in soil invertebrate research there is a wealth of (partly internal) research reports providing the data as mentioned above. What is needed is the creation of a database in which these data can be brought together in a consistent way.

Another significant bottleneck is that the results of most ecotoxicological food-web models have not been validated against field data. A problem here is a lack of information on the densities and biomasses of major groups of species in contaminated and uncontaminated ecosystems. This validation against field data, which deserves high priority, is not the only way to obtain insight into the uncertainties surrounding the results obtained from models. Tools such as sensitivity analysis and uncertainty analysis can be used to resolve this issue. Other approaches include validation of individual components of food-web models, for example the parts which describe major sub-processes. Pending the results of validation tests, sensitivity analyses and uncertainty analyses, no well-founded judgements can be put forward concerning the reliability of results obtained using currently available food-web models.

Again, the major limitation in this context is the existence of a proper database bringing together the detailed information about a number of extensive field studies and inventories carried out in the past decade; examples are the Swedish Rönnskär and Gusum areas, the English Avonmouth area and the Dutch-Flemish Kempen area, all contaminated with considerable amounts of heavy metals. An attempt will also be made to validate model output using data from the Doñana case and other environmental disasters in Europe.

Supplementary research in order to use food-web models for ecotoxicological risk assessment involves the further development of food-web models (modifying and extending their structure), especially models describing natural, complete terrestrial ecosystems. It also involves collecting the required input data and parameter values either in the laboratory or in the field. Furthermore, a comprehensive set of field data is required for validation purposes.

Expected concrete outcomes of the EcolMAT programme may be listed as follows:

- An ecological database supporting food-web modelling in the terrestrial environment
- An ecotoxicological database involving toxicity data for terrestrial species
- A selected number of food-web models for representative European ecosystems
- A system of higher-level ecological evaluation of potentially toxic chemicals
- A manual for food-web modelling in the terrestrial environment as related to environmental pollution, as well as several other books and scientific articles.

European added-value

There is a vast amount of expertise and knowledge regarding the impact of persistent, diffusely distributed contaminants in Europe. Moreover, in the last years at various institutions, promising groups of system modellers have been founded. By bringing these two groups of experts together and providing ample opportunity for in depth exchange of both different model approaches and the application of various models on different data sets, a scientific and policy instrument could be developed which enables the long term forecasting and the extrapolation of impacts of diffuse contaminants on areas which are relevant on the European scale, moreover, taking into account the variability of soil and climate conditions over these European ranges.

Activities

Programme activities will include:

Workshops

The organisation of a series of specialist workshops to compare the various approaches for different functional aspects developed for:

a. Dynamic binding and release mechanisms;

b. Uptake and internal transport mechanisms;

c. Physiological or population biological driven system models;

d. "Classical" biomass transfer food chain models;

e. Specific transfer route models.

Schools

The EcolMAT Steering Committee strongly recommends the combination of schools (training for young scientists) and Programme workshops.

Conferences

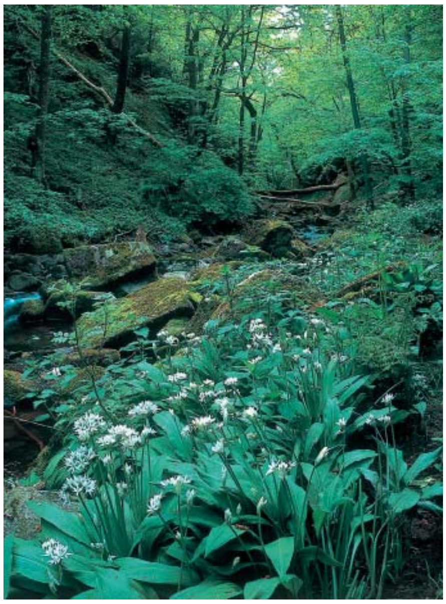
A study conference will be organised to describe the outlooks, respectively results of this joint and multidisciplinary modelling and field data interpretation approach.

Exchange Grants

EcolMAT exchange grants will be awarded to fund exchange visits of up to 2 months with the aim of initiating or strengthening links between different research groups.

Databases

The comprehensive ecotoxicological database is an urgent need for any modelling of toxic effects of chemicals on populations, communities and ecosystems. Although a number of toxicity databases do exist through the Internet most of them are restricted to aquatic environments or pesticides. Another limitation of most toxicity databases is the lack of good life history data of the test species. The aim of the database that will be created under the EcolMAT programme is to provide a single source of ecotoxicity data for a



Fringe of wood. Pollution may effect the balance between species and the biodiversity in the natural environment. © Flemming Rune number of terrestrial species and a wide array of chemicals, including both organic and inorganic toxicants. The database will also include detailed life history data of the test species. This will give the necessary background for food-web modelling and ecological assessment of terrestrial pollution – the ultimate goals of the programme.

Ongoing activities

The workshop, EcolMAT Database Project, which took place in Poland in November 2002, has already been successful in identifying the need for a uniform (eco)toxicological database search engine and experimental data generated towards modellers' needs.

Some of the further workshops planned will deal with:

- The food web approach in environmental risk assessment
- Food web modelling for risk assessment of diffuse terrestrial pollution: a screening of model approaches
- The assessment of the state-of-the-art of ongoing investigations about the effects of POPs to food-webs with particular regard to Alpine forest ecosystems
- The development of a guideline to select applicable mechanistic models aiming at assessment of the impact of pollutants in food chains.

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For the latest information on this programme consult the *EcolMAT* home page: www.esf.org/ecolmat

Cover picture:
Creosote bush from a polluted area.
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