TRIAS

# Eindrapportage-formulier TRIAS projecten
# Final report format for TRIAS projects.

When a TRIAS project has finished, or is about to finish, a Final Report is required. This report serves several goals simultaneously:

- it enables the program commission to check whether the project has met its goals,
- it enables NWO-ALW to finalize the project administratively, e.g. pay the final part of the personnel costs of the project,
- it provides some of the information needed for evaluation purposes,
- it provides information which can be publicized, e.g. via a web site.

Please send in the filled out forms within a month after the project is completed to:

Netherlands Organisation for Scientific Research
Earth and Life Sciences
Carmen van Meerkerk and/or Theo Saat
P.O. Box 93510
2509 AM The Hague

Part I

General information, also intended for publication through the TRIAS website

01 **Project Title.**

# Ecosystem Stability Analysis (ESA): towards a quantitative guide for user oriented soil management and ecological soil quality assessment

*After consulting ALW and TRIAS representatives, we have integrated the questionnaires from TRIAS and ALW into one, in order to prevent the need to fill in the same answers twice.*

02 **TRIAS/ALW project number or file number**

TRIAS project 835.80.008

03 **Research period**

The programme consisted of 3 subprojects:

Project 1: *Effects on the structure, stability and functioning of the populations of soil organisms*. Wageningen University, 01/01/2002 - 31/12/2005.
Project 2: Effects of stress on the structure, stability and functioning of soil food webs and soil ecosystem processes. Vrije Universiteit, 01/09/2001 - 31/08/2005.
Project 3: Effects on the structure and stability of microbial populations and ecosystem processes. Utrecht University, Alterra, 01/12/2001 – 23/03/2006.

04 **Names of the researchers involved, the names and addresses of the institutes where the research work was carried out.**

*PhD Researchers*

Project 1, Agnieszka Doroszuk, Laboratory of Nematology, Wageningen University,, Binnenhaven 5, 6709 PD, Wageningen, The Netherlands.

Project 2, Frans Kuenen, Department of Animal Ecology, Vrije Universiteit Amsterdam, Faculty of Earth and Life Sciences, Institute of Ecological Science, De Boelelaan 1085, 1081 HV Amsrerdam, The Netherlands.

Project 3, Marysia Tobor-Kaplon, Utrecht University, Faculty of Geosciences, Heidelberglaan 2 3584 CS Utrecht.

*Staff and supervisors*

Project 3, Prof. P.C. de Ruiter, Department of Environmental Sciences, Copernicus Research Institute for Sustainable Development and Innovation, Utrecht University, P.O. Box 80115, 3508 TC Utrecht, The Netherlands.
Project 3, Dr. J. Bloem, Alterra, P.O. Box 47, Soil Sciences Centre, 6700 AA Wageningen, The Netherlands.
Poroject 2, Prof. H. Verhoef, Department of Animal Ecology, Vrije Universiteit Amsterdam, Faculty of Earth and Life Sciences, Institute of Ecological Science, De Boelelaan 1085, 1081 HV AMSTERDAM, The Netherlands.

Project 1, Dr. J.E. Kammenga, Laboratory of Nematology, Wageningen University, Binnenhaven 5, 6709 PD, Wageningen, The Netherlands.
Project 1, Prof. J. Bakker, Laboratory of Nematology, Wageningen University,, Binnenhaven 5, 6709 PD, Wageningen, The Netherlands.

## 05 Short scientific summary in English of: main research objective, research methods, results and conclusion

### Objective

The objective of this programme was to develop a quantitative guide for soil quality assessment. This guide should be based on a set of soil ecosystem quality indicators that can be observed and quantified, are consistent, refer to important societal needs (life support systems) and have a sound scientific basis. Central attention was given to soil ecosystem stability, as a measure of resistance against long term and multiple stress events.

### Research methods

First we analysed *in situ* effects of long-term multi-stressors on populations of soil organisms (mainly microbes and nematodes but also other soil invertebrates) originating from the Bovenbuurt field (near Bennekom, The Netherlands) where four copper treatments were combined with four pH treatments in a fully randomized block design with replicates. By means of mathematical modeling, the observed population effects were used to analyse the effects on community structure and stability, and subsequently effects on soil ecosystem processes (decomposition organic matter, C- and N-mineralisation). Finally, the outcome of the various kinds of models was integrated into so-called Information Indices within an Ecosystem Network Analysis, as to establish the effects on overall soil ecosystem properties, i.e. overall system activity, trophic efficiency, nutrient retention times, ecological complexity and diversity. These properties are known to be indicative for ecosystem stability and are connected to the life support function of the soil. For the calculation of information indices, for each group data on the inflow (consumption), flow to detritus (natural death rate and excretion), respiration, outflow (part of biomass consumed by higher trophic level), import (immigration) and export (emigration) was used for each functional group in the food web. Here we assumed that there was no import or export to and from all functional groups except for import to roots and detritus. We used a food web structure of the Lovinkhoeve system with minor modifications (Fig. 1).

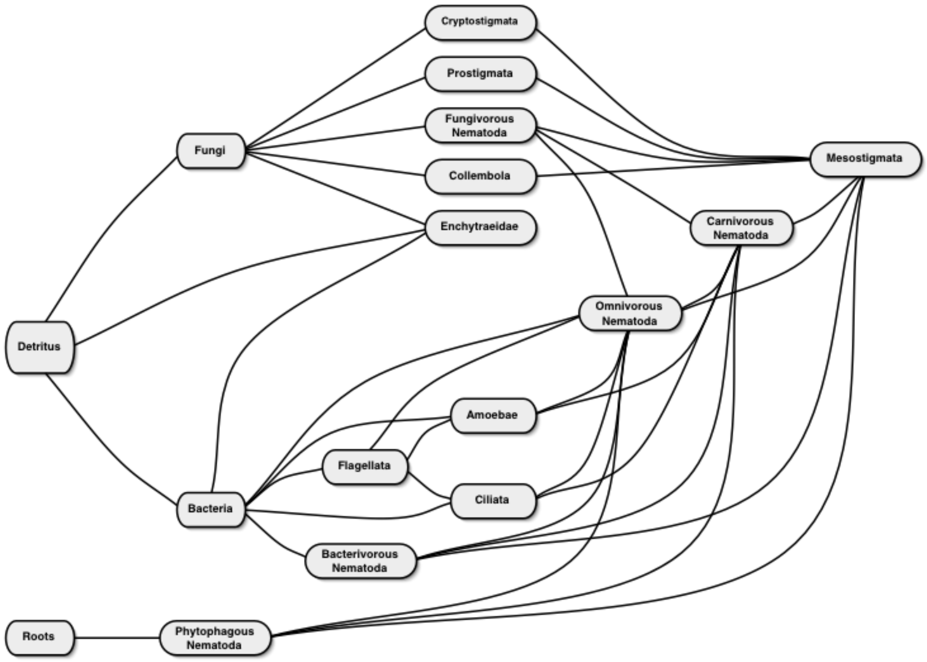


**Figure 1.** Diagram of the potential food web structure in the soils of the experimental field.

**Main results**

- Copper and soil pH had a marked effect on soil dwelling organisms. Bacterial, fungal, nematode biomass and soil respiration, which is a measure of the activity of the overall population of soil organisms, were negatively affected by copper and pH. With regard to the soil bacteria, the results indicated increased tolerance toward stressors of a different kind. For instance in relatively acidic soils, bacteria were more tolerant to low soil moisture conditions compared to alkaline soils. In general, the highest bacterial resistance was found in the more contaminated soils with low pH and/or high copper contamination. The long term effects of soil contamination with copper and pH also resulted in genetic changes of nematode life cycles showing that total reproduction was maintained at the expense of a prolonged reproductive period. Data on other invertebrate species such as pot worms, springtails and spiders were not conclusive, possibly because these are relatively fast moving animals and therefore only exposed for a brief period.
- The adverse effect of the stressors was observed only when the two stressors (high copper concentration and low pH) were combined. These results indicate that soil communities are at increased risk when exposed to a combination of stressors.
- The effects of copper and pH differed strongly among the different seasons of the year which influenced the dynamics of various species.
- Information indices from Ecosystem Network Analysis can be used to quantify an ecosystem in terms of its size and organization. There are two types of indices, i.e. 1) absolute indices that describe the size of an ecosystem and 2) relative indices which describe the organization. Relative indices give information about the organization of flows, i.e., the level of specialization of flows and how ‘tight’ the ecosystem is organized. The information about the ‘tightness’ of organization is given by RA (Relative Ascendency), which can range between zero and one. RA seems to be the most versatile quantitative indicator because of its dimensionless character that allow comparison between systems of different size and organization (Figure 2).

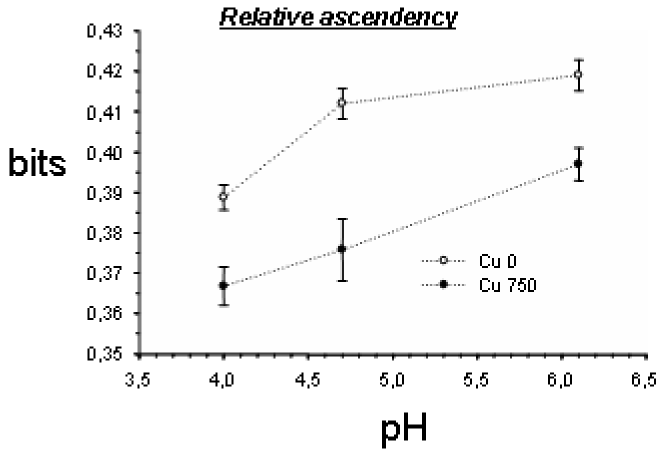


**Figure 2.** Effect of field treatments on Relative Ascendency (RA). Open circles represents Cu 0, and grey circles Cu 750 soils (means ± s.e.m). On the vertical axis are bits of information. These units are taken from the information theory and represent the measure of information inherent in a single binary.

**Conclusions**

- Long-term exposure to a combination of pH and copper affects the biological soil quality which is indicated by poor performance of microbial communities and soil invertebrate populations in contaminated soils.
- In the dominant bacterivorous nematode populations, life-history traits determine the response of biomass turnover rates and production to environmental stress. The adaptive character of the life-history changes implies that rapid microevolutionary processes are responsible for the response of functional population parameters. With regard to pH tolerance, we found evidence that total reproduction was maintained but at low pH the animals reproduced longer to achieve this level.
- No consistent results could be obtained for other soil organisms because of large temporal fluctuations.
- In combination, the aforementioned effects of chronic stress have lead to a set back of ecosystem development – that is – the soil ecosystem becomes less specialized under stressed conditions.
- Chronic stress affected the functional stability of microbial populations.
- The Ecosystem Network Analysis model which was developed on the basis of carbon flow, indicated that the level of specialisation decreased with an increase of stress. The Relative Ascendency (RA) has potential as a quantitative guide for user oriented soil management and ecological soil quality assessment. Its properties were indicative for ecosystem stability and connected to the life support function of the soil. The RA is a versatile quantitative indicator because of its dimensionless character that allow comparison between ecosystems of different size and organization.

06 **Popular summary to inform the general public (1/2 to 2 pages of text) in Dutch.**
**The funding organisations of TRIAS (SKB, NWO-ALW and Delft Cluster) want to inform a more general audience about the results of the TRIAS Research projects. That is why we ask you to give an executive summary of the project in a popularising way and written in the Dutch language.**

**Achtergrond**

In veel gebieden in Nederland is de bodem langdurig verontreinigd met chemische stoffen al dan niet in combinatie met eutrofiering (voedselverrijking) en verzuring. Momenteel streeft het bodembeleid naar een gebruiksgerichte benadering waarbij geldt dat relatief lage gehaltes van stoffen worden geaccepteerd zolang deze geen aantoonbare schade veroorzaken voor mens en milieu. Dit standpunt betekent dat al in een vroeg stadium het effect van langdurige blootstelling aan milieuvreemde stoffen op het ecosysteem moet kunnen worden vastgesteld, met name in combinatie met andere milieufactoren zoals verzuring.

Het doel van onderhavig project was het onwikkelen van een meetbaar instrument voor het vaststellen van effecten van verontreiniging op het bodemleven. Deze meetinstrumenten zijn representatief voor de bodemgezondheid en voor de biologische functies die de bodem moet kunnen verrichten. Centraal in deze benadering staat dat de stabiliteit van het ecosysteem de maat is voor weerstand tegen lange termijn verstoringen.

Het project bestaat uit veld- en laboratoriumexperimenten waarvan de uitkomsten met wiskundige modellen worden geanalyseerd. In het project hanteren we een benadering, gebaseerd op de volgende oorzaak-gevolg relatie. Het project start met de *in situ* analyse van lange-termijn effecten van koper en zuurgraad op populaties van bodemorganismen (zoals aaltjes, bacterien en schimmels). Door middel van modellering worden deze effecten doorvertaald naar effecten op de structuur en stabiliteit van populaties, voedselwebben en ecosysteemprocessen (afbraak van organisch materiaal en C- en N-mineralisatie). De uitkomsten worden verwerkt in een zgn. Ecosysteem Netwerk Analyse om de uiteindelijke invloed op ecosysteem eigenschappen te bepalen, zoals totale systeem activiteit, trofische efficiëntie, nutriënt retentie tijden en biologische diversiteit. Deze indicatoren zijn indicatief voor ecosyteem stabiliteit en direct gerelateerd aan de 'life support' functies van de bodem. Voorzien wordt dat de netwerk benadering een belangrijk instrument oplevert voor ecosysteem gerichte bodemkwaliteitsanalyse.

**Resultaten**

Binnen het project is gekeken naar de effecten van langdurige verontreiniging door combinaties van koper en verzuring op het bodemecosysteem. Beiden hadden een negatief effect op de bodemorganismen. De totale biomassa van bacterieën, schimmels en aaltjes en de totale bodemademhaling nam af bij hogere koper concentraties en lagere pH. Het bleek dat er zich in bacterie- en nematodenpopulaties een weerstand had opgebouwd t.a.v. van koper en pH die gevolgen had voor het functioneren van deze groepen. Zo waren de aan lage pH aangepaste bacterieën ook tolerant tegen uitdroging van de bodem. Er werd ook tolerantie waargenomen in de aaltjespopulaties. Bij blootstelling aan hogere koperconcentraties en lagere pH bleef de totaal aantal nakomelingen gelijk maar dit werd bereikt gedurende een veel langere periode. De kracht van deze effecten was sterk afhankelijk van het seizoen en de weersomstandigheden ook al was er geen sterke samenhang vast te stellen. De effecten van koper en verzuring werden alleen waargenomen indien deze in combinatie voorkwamen. Hoge kopergehaltes hadden alleen effect bij een relatief hoge zuurgraad.

Wiskundige modellering (door zgn. Ecosystem Network Analysis op basis van koolstof kringloop) bracht aan het licht dat blootstelling aan koper en pH leidde tot een afname van specialistische soorten in het bodemecosysteem. De meest blootgestelde levensgemeenschappen waren minder efficiënt in hun energiehuishouding dan de controle gemeenschapppen. Deze modellen kunnen adhv de mate van voedelweb-specialisatie laten zien of het betreffende bodemecosysteem gestressed is of niet.

De organisatiegraad (Relative Ascendency, RA) bleek de meest veelbelovende kwantitatieve maat voor bodemkwaliteit. RA is dimensieloos en kan hierdoor gebruikt worden in zeer uiteenlopende ecoystemen.

07 **What impact and relevance has this project’s outcome for practicing soil protection and / or soil remediation? Again, please motivate.**

In polluted soils lower densities of soil organism populations and reduced biomasses are usually a sign of a disturbed ecosystem. Our results indicated that secondary production (amount of animal biomass produced) was more sensitive to soil contamination than population density (number of individuals). We also showed that it was especially the combination of stressors that caused adverse effects in soil ecosystem functioning rather than the single stressors. Further results indicated that long-term exposition to stress reduced microbial performance, affected the functional stability of microbial communities and set back the stage of ecosystem development (less specialization).

The indicators that have been developed and tested (bacterial and fungal biomass, bacterial growth rate and growth efficiency, and information indices from Ecosystem Network Analysis) can be used to assess whether or not the soil ecosystem is under stress. Based on these findings it is advocated that future policies for soil protection should be based on a small number of parameters (soil invertebrate and bacterial biomass and production) which underlie the Ecosystem Network Parameters.

## 08 Please list the presentations held in connection to this project

**Platform presentations**

1. Doroszuk. A. & Kammenga J.E. *Adaptive divergence of nematode populations as a response to long term stress*. Symposium Soil&Water, Zeist June 2-3 2004.
2. Doroszuk. A. & Kammenga J.E. *Adaptive divergence of nematode field populations as a response to long term stress.* Experimental Evolution Workshop, 4-5 October 2004, Fribourg, Switzerland.
3. Doroszuk. A. & Kammenga J.E. *Rapid evolution of G matrices in nematode field populations.* 10th Congress of European Society for Evolutionary Biology, 15-20 August 2005, Krakow, Poland.
4. Tobor-Kapłon M.A., Bloem J., Römkens P.F.A.M, de Ruiter P.C. *Functional stability of microbial communities in contaminated soils.* BES Annual Meeting 7-9 September 2004, Lancaster, UK.
5. Tobor-Kapłon M.A., Römkens P.F.A.M, Bloem J. and de Ruiter P.C. *Functional stability of microbial communities in contaminated soils.* 2nd National Scientific Soil Symposium "Bodemdiep", 4th-5th June, 2003. Zeist, NL.

**Poster presentations**

1. Tobor-Kapłon M.A., Römkens P.F.A.M, Bloem J. and de Ruiter P.C. Does soil contamination affect the functional stability of microbial communities? Proceedings of National Scientific Soil Symposium "Soil & Water", 1th -2nd June, 2005. Zeist, NL.

2. Tobor-Kapłon M.A., Bloem J. and de Ruiter P.C. The effects of stress on soil microbial communities. Proceedings of National Scientific Soil Symposium "Soil & Water", 2nd-3rd June, 2004. Zeist, NL

3. Tobor-Kapłon, M.A., Römkens P.F.A.M, Bloem J. and de Ruiter P.C. Functional stability of microbial communities in contaminated soils near a zinc smelter. The Raison d'Etre of environmental toxicology and chemistry. 15th Annual Meeting of SETAC Europe, 22-26 May 2001, Lille, France: 292

4. Tobor-Kapłon, M.A., Römkens P.F.A.M, Bloem J. and de Ruiter P.C. Microbial indicators of stress. The Raison d'Etre of environmental toxicology and chemistry. 15th Annual Meeting of SETAC Europe, 22-26 May 2005, Lille, France: 297

## 09 Please list publications (published and submitted) in connection to this project. Please indicate publication took place in either a refereed journal, a non-refereed journal (incl. conference proceedings); whether it was published as a chapter of a book, as a monography or as a dissertation.

**PhD Theses**

The output of the programme wil result in three PhD theses. So far the date for the thesis defense of Marysia Tobor-Kaplon is set at September 18, 2006.

**Publication in refereed journals**


1. Doroszuk, A., Te Brake, E., Gonzalez, D.C. Kammenga, J.E. *Response of secondary production and its components to combinations of environmental stressors in nematode field populations.* Accepted, J. Appl. Ecol.

2. Doroszuk, A., Wojewodzic, M.W., Kammenga, J.E. *Rapid adaptive divergence of life-history traits in response to abiotic stress within a natural population of a parthenogenetic nematode.* Accepted, Proc. Roy. Soc. London, Biological Series.

3. Doroszuk, A. et al. *Evolution of G-matrices*. submitted

4. Kuenen, F.J.A., C.A.M. van Gestel, H.A. Verhoef. Extracting soil microarthropods with olive-oil: A novel extraction method for immobile and mobile stages of mesofauna from sandy soils. (in prep)

5. Kuenen, F.J.A., H. Veenema, C.A.M. van Gestel, H.A. Verhoef. Culturing coloured mites for testing soil microarthropod extraction methods (in prep)

6. Kuenen, F.J.A., C.A.M. van Gestel, H.A. Verhoef. The effects of toxic stress on the structure, stability and functioning of a soil food web. (in prep).

7. Kuenen, F.J.A., Van Gestel, C.A.M., Mulder, C. D., Verhoef, H.A.
Comparison of soil food web stability as calculated by cascade modelling and allometric modelling. (in prep)

8. Kuenen, F.J.A., Van Gestel, C.A.M., Kooij, B.W., Verhoef, H.A. Effects of temperature on the stability of stressed and non-stressed soil food webs. (in prep)

9. Tobor-Kapłon M.A., Bloem J., Römkens P.F.A.M, de Ruiter P.C., 2005. *Functional stability of microbial communities in contaminated soils.* Oikos, 11: 119-129

10. Tobor-Kaplon M.A., Bloem J., Römkens P.F.A.M, de Ruiter P.C. Functional stability of microbial communities in contaminated soils near a zinc smelter (Budel, the Netherlands). Ecotoxicology 15(2):187-197

11. Tobor-Kapłon M.A., Bloem J., de Ruiter P.C. *Functional stability of microbial communities from long-term stressed soils to additional disturbance*. Environmental Toxicology and Chemistry, 2006, 25, 1993-1999.

12. Tobor-Kapłon M.A., Bloem J., Römkens P.F.A.M, de Ruiter P.C. *Microbial indicators of stress.* submitted

13. Tobor-Kapłon M.A., Holtkamp R. *Information indices as a tool for quantifying development of below-ground terrestrial ecosystems*. Accepted, Ecol. Modelling

14. Tobor-Kapłon M.A., Holtkamp R., A. Doroszuk, F. Kuenen, Scharler U., Bloem J., de Ruiter P.C. *Can information indices (Ecosystem Network Analysis) be used as indicators of environmental stress in terrestrial ecosystems?* submitted

**Other publications**

1. Agnieszka Doroszuk, Marcin W. Wojewodzic and Jan E. Kammenga *Effects of long-term exposure to copper on the performance of nematode populations.* Proceedings of the 2nd National Scientific Symposium Bodem Diep, 4th-5th June 2003, Zeist.
2. Agnieszka Doroszuk, Marcin W. Wojewodzic, Elske te Brake and Jan E. Kammenga *Adaptive divergence of nematode populations as a response to long term stress*. Netherlands Scientific Symposium Soil&Water, Zeist June 2-3 2004 (Proceedings).
3. Agnieszka Doroszuk, Emilie Fradin, Bas Waterbeemd, Joost Riksen & Jan Kammenga. *CB4856 /N2 Introgression Lines of Caenorhabditis elegans – a permanent population for QTL fine-mapping.* 4th Annual Meeting of the Complex Trait Consortium, 2005 Groningen (Proceedings).
4. A. Doroszuk, M.W. Wojewodzic, J.E. Kammenga. *Rapid evolution of **G** matrices in nematode field populations under stress.* Netherlands Scientific Symposium Soil & Water, Zeist, June 1-2 2005 (Proceedings)
5. A. Doroszuk, M.W. Wojewodzic, J.E. Kammenga. *Rapid evolution of **G** matrices in nematode field populations.* 10th Congress of European Society for Evolutionary Biology, 15-20 August 2005, Krakow, Poland (Proceedings)
6. Tobor-Kapłon M.A., Bloem J., Römkens P.F.A.M, de Ruiter P.C., 2004. Functional stability of microbial communities in contaminated soils. BES Annual Meeting 7-9 September 2004, Lancaster, UK. page number(s)
7. Tobor-Kapłon M.A., Römkens P.F.A.M, Bloem J. and de Ruiter P.C. 2003. Functional stability of microbial communities in contaminated soils. 2nd National Scientific Soil Symposium "Bodemdiep", 4th-5th June, 2003. Zeist, NL. p. 28-31.
8. Tobor-Kapłon M.A., Römkens P.F.A.M, Bloem J. and de Ruiter P.C., 2005.
Does soil contamination affect the functional stability of microbial communities?
National Scientific Soil Symposium "Soil & Water", 1th -2nd June, 2005. Zeist, NL. p. 45.
9. Tobor-Kapłon M.A., Bloem J. and de Ruiter P.C., 2004. The effects of stress on soil microbial communities. National Scientific Soil Symposium "Soil & Water", 2nd-3rd June, 2004. Zeist, NL. p. 67.
10. Tobor-Kapłon, M.A., Römkens P.F.A.M, Bloem J. and de Ruiter P.C., 2005. Functional stability of microbial communities in contaminated soils near a zinc smelter. The Raison d'Etre of environmental toxicology and chemistry.
Abstracts of the 15th Annual Meeting of SETAC Europe, 22-26 May 2005, Lille, France. p. 292.
11. Tobor-Kapłon, M.A., Römkens P.F.A.M, Bloem J. and de Ruiter P.C., 2005.
Microbial indicators of stress. The Raison d'Etre of environmental toxicology and chemistry. Abstracts of the 15th Annual Meeting of SETAC Europe, 22-26 May 2005, Lille, France. p. 297.
12. Kuenen, F.J.A., Van Gestel, C.A.M., Verhoef H.A. Food webs in stress. Proc. Nat. Scie. Symp. "Soil and Water", 1 – 2 June, 2005.
13. Kuenen, F.J.A., Van Gestel, C.A.M., Verhoef H.A. Effects of copper on structure, stability and functioning of soil food webs. 15th Annual Symposium of SETAC Europe, 22-26 May, 2005, Lille, France.

**Book chapter**

Bloem, J., A.J. Schouten, S.J. Sørensen, M. Rutgers, A. van der Werf and A.M. Breure 2006. Monitoring and evaluating soil quality. In "Microbiological Methods for Assessing Soil Quality" (J. Bloem, A. Benedetti and D.W. Hopkins, editors). CABI, Wallingford, UK

10 **Please list Patent applications or other professional products (including contracts, articles in the popular media, contributions to documentaries or scientific television or radio programs, CD-ROMS, DVD or other (electronic) media).**

None

Part II

Detailed information, primarily intended for administrative and statistical use by NWO-ALW

11a **Under item 5 you have filled in the main research objectives. Please list all the original research objectives as indicated in the project's application and both indicate as well as motivate, to what extent these goals were realised, and/or whether the original research objectives had to be adapted.**

1. *Field sampling of bacterivorous and fungivorous nematodes* – whole nematode population (also omnivorous, carnivorous and plant pathogenic nematodes) was sampled on, in total, 6 occasions in 2002 and 2003.
2. *Estimating population abundance, total biomass and production* - population abundance and total biomass was estimated for all feeding groups of nematodes for all 6 sampling events. Production was estimated for *Acrobeloides nanus*, a bacterivorous species that was chosen in original proposal for the analysis of production, biomass turnover and life-history traits.
3. *Modeling of life-history changes and fitness and its relation to biomass turnover rates for the nematode Acrobeloides nanus* – the changes in life-histories were investigated. We tested if the changes are result of adaptation or physiological acclimation. Fitness was calculated on the basis of part of the life-history experiments.
4. *field sampling of soil micro-organisms, arthropods and worms* was realized
5. *food web modeling was conducted*
6. *determination of soil ecosystem processes*: decomposition of plant residues, mineralisation of carbon and nitrogen was realized
7. *empirical stability analyses* through stress on stress experimentation was realized
8. *development of an ecosystem quality indicator* (Relative Ascendency, RA) through Ecosystem Network Analyses was realized

11b **Did the project also include objectives which were not scientific? For instance, did the project also intend to apply research results, or strengthen the economic position of certain businesses**?

The primary objectives were scientific but the outcomes of the soil ecosystem quality indicators can be applied for monitoring soil quality. As such the results emanating from this project may provide a basis for future incorporation into soil quality assessment protocols.

11c **Did the project's aims include the expanding the (international) network of contacts (at what level), providing education, improve communication, serve as input for policy drafting or policy decisions, etc.? Please motivate.**

Ecosystem Network Analysis was performed in co-operation with Dr. Ursula Scharler, Chesapeake Biological Lab, University of Maryland, Center for Environmental Studies, Solomons, USA.
Results of the project have been underpinning the use of soil quality indicators both at the national (Dutch Soil Quality Network) and the international level (EU COST action 831, resulting in a handbook on microbiological indicators for assessing soil quality). Stimulated by the EU Soil Strategy, monitoring options are discussed and implemented in many European countries.

12 **Do the results obtained match the original objectives?**
**Please provide a short motivation why they do or don't.**
Yes, please see above under 11a..

13 **Will the results of this project serve as input for an initiative integrating/and or generalizing input from several projects, for instance into a (numerical) model, or into more understanding at the higher/system level? If so, was this intended and optimised from the beginning or did it occur by chance/ spontaneous? Please elaborate.**

According to the original proposal the results of this project were integrated at the ecosystem level using Ecosystem Network Analysis. The aim was to parameterize the ecosystem network model with data obtained from lower levels of organization (individual, population, community). The three projects succeeded in doing so. The outcomes of both projects 1 and 2 were used to feed data into the model developed in project 3.

14 **To what extent has this research project pointed the way in which further research has to be undertaken? Please motivate the guiding role perceived**.

The outcomes of this collaborative programme show that soil quality assessment can be based on biological interactions underlying food-web dynamics. As such it holds promise for an ecosystem based approach for soil quality assurance. It may serve as the first example in which a systems approach underlies soil quality assessment and remediation .

15 **In what way, and to what extent, are the results reached of importance to research done by others? Please motivate or elaborate.**
We envisage that the results are not only of interest for soil quality assessment procedures but also for ecologists interested in multiple stressor effects at higher organisation levels. The present project is unique in the sense that we used a randomized block design with multiple replicates in a soil system which has been carefully controlled with regard to its pollution history. The results are therefore highly testable with great power. The outcomes also pave the way toward understanding evolutionary forces underlying food-web dynamics. Current knowledge about this aspect is scant and we believe that the present outcomes of this project may point into a direction where future research might be heading.

16 **Are you aware of any essential gaps or obstacles standing in the way of applying the results from your research project? Please elaborate.**

No

Part II - continued

Detailed information, primarily intended for administrative and statistical use by NWO-ALW

17 **Which new research questions were generated through this project? Were these new questions addressed within this research project itself? Or will these new questions, or the results from your research project lead to new research projects (to be) funded by either 1st , 2nd,or 3rd category funding or funding through international funding agencies? Please elaborate.**

A major question which surfaced during the research was "How long does it take microorganisms in stressed soils to recover when the stress is removed (by remediation)?". Microbial communities in polluted soils generally are less stable under additional stress. The underlying mechanisms are not clear yet. Possible causes are lower biodiversity, genetic adaptation or physiological adaptation (plasticity). The mechanisms involved have important consequences for the rate of recovery. In contaminated soil bacterial growth rate is reduced. However, we found high growth rates (thymidine incorporation into bacterial DNA) for bacteria from contaminated soil within a few hours after extraction in a clean suspension. This may indicate that bacteria can recover very rapidly, and that they have adapted to stress physiologically rather than genetically. It would be very interesting to investigate what happens (physiologically and genetically) when stressed communities are transplanted to sterilized clean soil, and vice versa.

The project showed that stressed microbial communities in contaminated soils are, in general, more stable to additional stress or perturbation. Also agricultural practices are imposing stress and perturbation. It would be interesting to use the methods developed in the current project to investigate whether or not soils under more sustainable management (e.g. reduced input of chemicals and fertilizers in agriculture) have a higher functional stability than soils under intensive management. The results would be relevant for sustainable soil management.

18 **In what way did you link this project to other projects within the TRIAS-program or link it to projects outside TRIAS? Did you cooperate within the TRIAS-program and did this cooperation lead to integrated results?**

We see future projects on ecosystem ecology and soil quality assessment in close collaboration with genomics programmes. Currently two genomic programmes have the potential to link up with food-web based research projects. One funded by the EU (project NOMIRACLE, http://viso.jrc.it/nomiracle/) and the second funded by the national government (Ecogenomics, http://www.ecogenomics.nl/index.php). The project vhas been linked to TRIAS project 835.80.011 "soils in transition".

19 **Can you elaborate on the impact on society as a whole of your results (e.g. societal organisations, NGO's, businesses, schools, municipal authorities, etc.)**

At the moment this would be too speculative but we foresee a closer connection with soil quality managers and risk assessors.

20 **What actions were taken to disseminate the results in the direction of the general public, besides the usual scientific channels?**

We have envisaged a joint paper: Tobor-Kapłon M.A., Holtkamp R., A. Doroszuk, F. Kuenen, Scharler U., Bloem J., de Ruiter P.C. *Can information indices (Ecosystem Network Analysis) be used as indicators of environmental stress in terrestrial ecosystems?* In prep.

21 **Have the researchers involved obtained a new position or employment after the project came to an end? Please specify and elaborate!**

Ms. A. Doroszuk has obtained a position as post-doc at the Laboratory of Nematology, WU. Ms. M. Tobor-Kaplon has a post-doc position at the VU. Mr. F.J.A. Kuenen has obtained a parttime position as a scientific co-worker at the RIVM.