David Spurgeon
Centre for Ecology and Hydrology
Wallingford

Extrapolating laboratory toxicity data to predict toxic effects in the field – challenges for trace metals.

Standard toxicity tests

- Developed as part of the pesticide registration process.
- Aim to use surrogate species to estimate toxicity
- Need to be standardised – same chemical = same result.
- Use for wider chemical risk assessment (not just pesticides)

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Standard soil toxicity tests

- Carbon mineralisation (OECD, ISO)
- Nitrogen mineralisation (OECD, ISO)
- Non-target plant toxicity (OECD, ISO)
- Earthworm toxicity (OECD, ISO)
- Enchytraeid toxicity (ISO)
- Springtail toxicity (ISO)
- Nematode toxicity (ASTM)

Standard toxicity tests - earthworm

Eisenia fetida

Mean adult weight 0.4 g

Live in organic rich environments such as compost and manure heaps

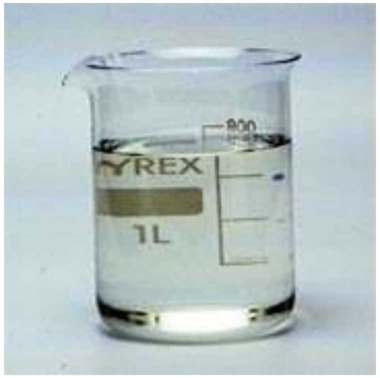
Can tolerate high density

Produce over 2 cocoons from each worm per week

More than one juvenile can hatch from each cocoon.

Standard toxicity tests - soil

Something consistent was needed

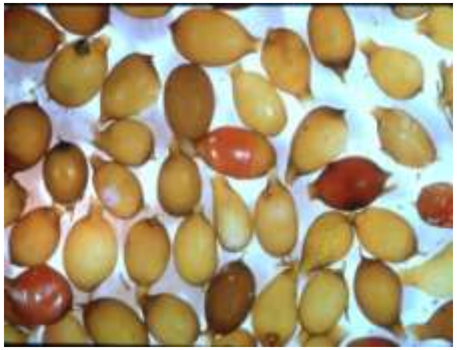


70% sand

20% kaolin clay

10% peat

33% w/w water



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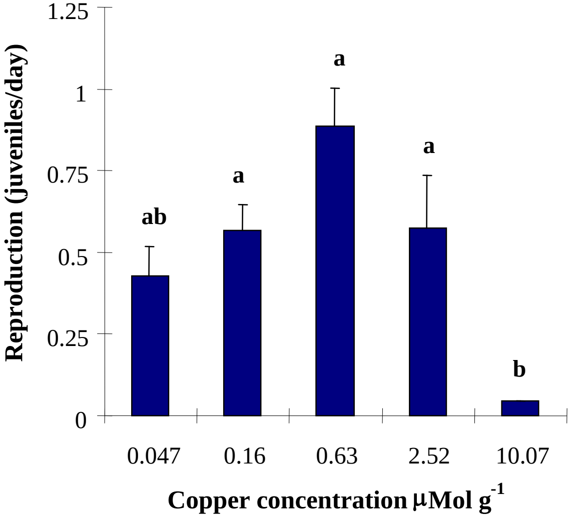
Example data-set

Copper - cocoon production

"Hormesis", but significantly lower at highest exposure

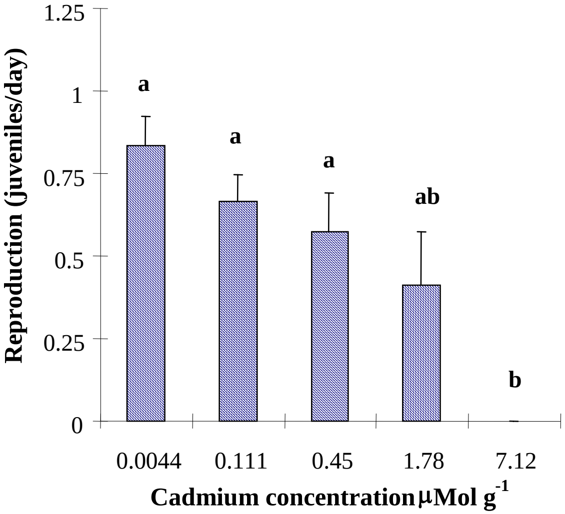
EC_{50} = 5.17 (2.7 - 5.87) µM Cu g^{-1}



Cadmium - cocoon production

Simple dose dependence. Lower at highest exposure

EC50 = 1.78 (0.79 - 2.93) µ M Cd g^{-1}



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Factors influencing toxicity in the field (Van Straalen and Denneman, 1989)

Increase toxicity in the field

- In the laboratory, organisms are tested under optimal conditions
- In the field, organisms are exposed to mixtures of stressors
- Adaptation often entails cost in ecological performance
- In the field, exposure is long term compared to short term in lab tests

Reduce toxicity in the field

- In the field, biological availability is lower than in laboratory tests
- In the field ecological compensation and regulation mechanisms are operating
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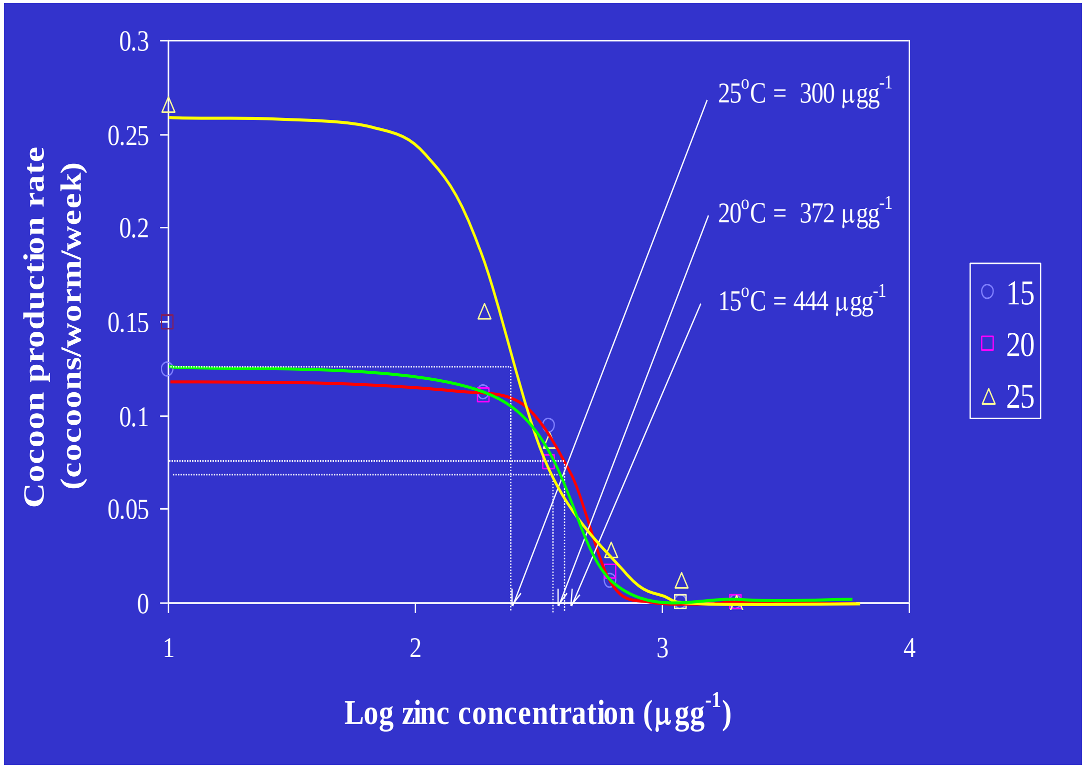
Sub-optimal temperature effects

- Effects of zinc on the earthworm *Eisenia fetida*

- Toxicity at three temperature. One above optimal (25^{o}C), one at optimal (20^{o}C) (standard temperature used in laboratory tests), one below optimal (15^{o}C)

Sub-optimal temperature effects



- Cocoon production rate is temperature dependent
- Toxicity (expressed as EC_{50}) increases (lower values) as temperature increases
- So in the field, toxicity is greater than in the laboratory when temperature exceeds 20°C

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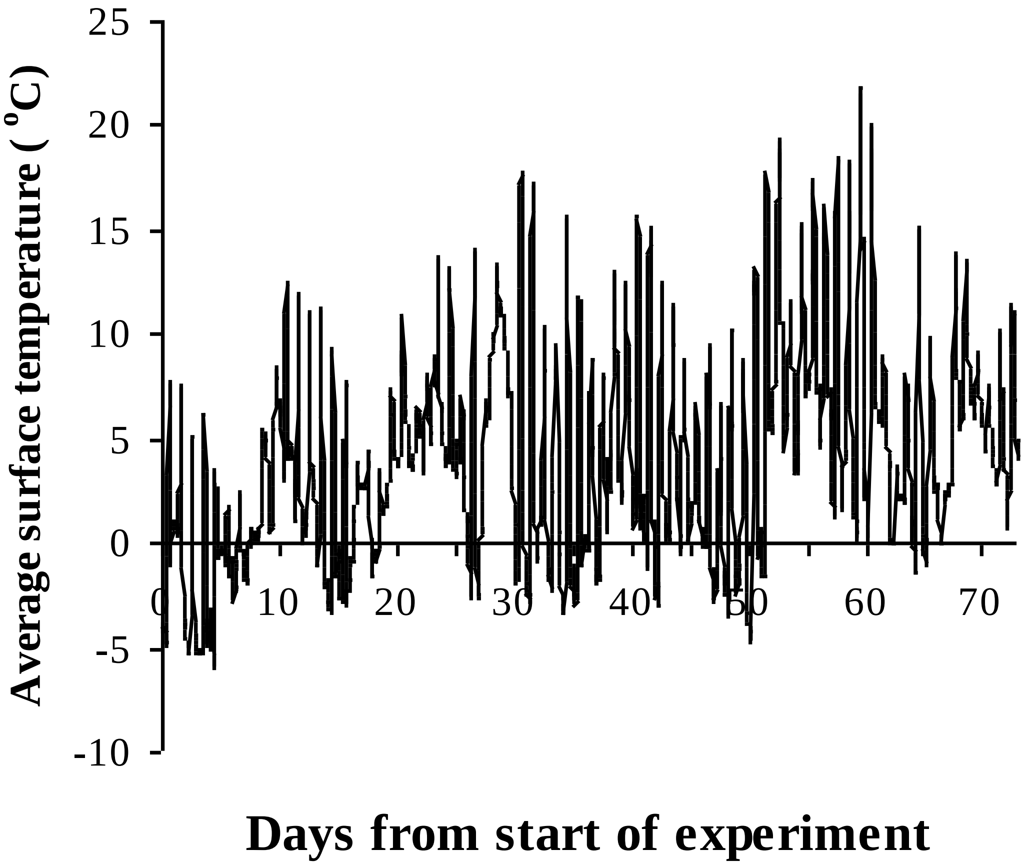
Soil temp at 10 cm depth SE England



- Almost all year temperature at 10cm is less than 20^{o}C, so toxicity in field usually lower than optimal used in laboratory tests.
- Toxicity only greater than predicted in the laboratory (in summer in tropics)

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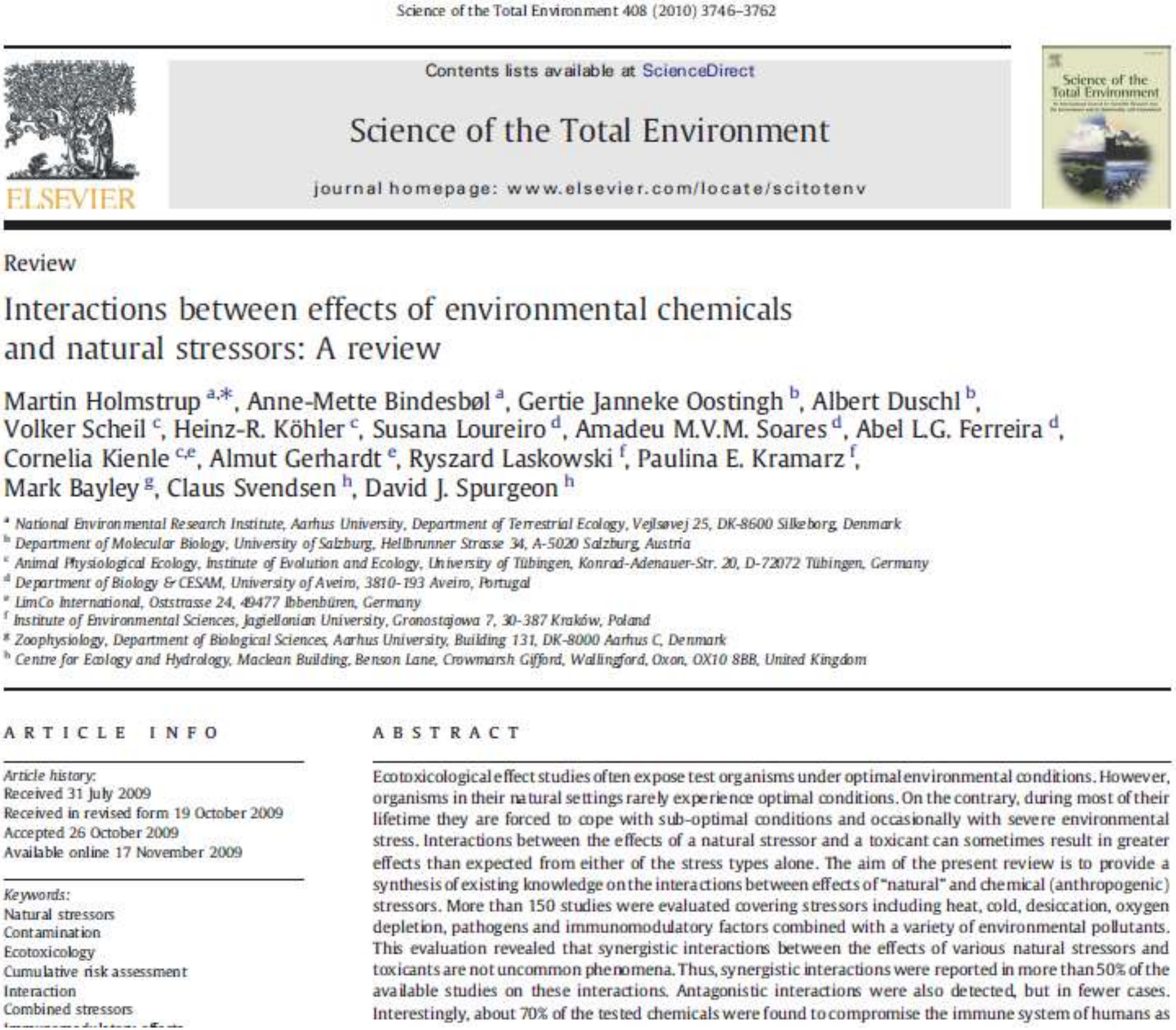
Lots of studies of this type



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Review

Interactions between effects of environmental chemicals and natural stressors: A review

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ABSTRACT

Ecotoxicological effect studies often expose test organisms under optimal environmental conditions. However, organisms in their natural settings rarely experience optimal conditions. On the contrary, during most of their lifetime they are forced to cope with sub-optimal conditions and occasionally with severe environmental stress. Interactions between the effects of a natural stressor and a toxicant can sometimes result in greater effects than expected from either of the stress types alone. The aim of the present review is to provide a synthesis of existing knowledge on the interactions between effects of "natural" and chemical (anthropogenic) stressors. More than 150 studies were evaluated covering stressors including heat, cold, desiccation, oxygen depletion, pathogens and immunomodulatory factors combined with a variety of environmental pollutants. This evaluation revealed that synergistic interactions between the effects of various natural stressors and toxicants are not uncommon phenomena. Thus, synergistic interactions were reported in more than 50% of the available studies on these interactions. Antagonistic interactions were also detected, but in fewer cases. Interestingly, about 70% of the tested chemicals were found to compromise the immune system of humans as

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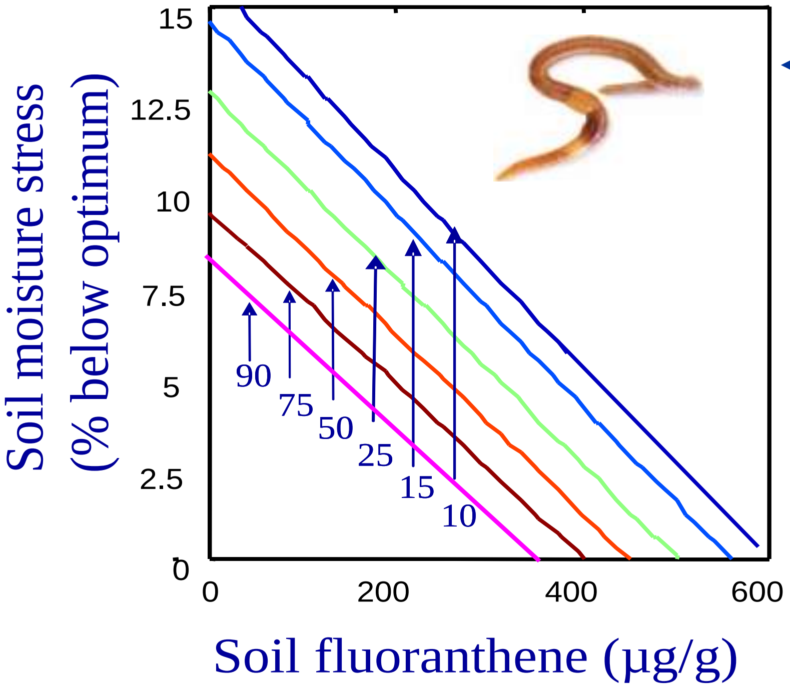
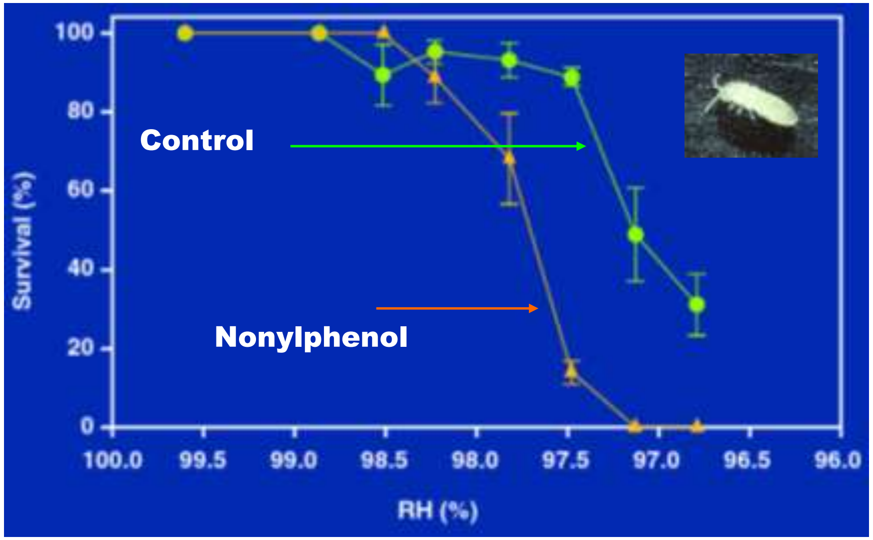
Results from combined stressor studies

Studies have shown that these are often additive according to the principle of response addition but can deviate



Additive or synergistic?



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Longer exposure greater toxicity?

Summary

Do multiple stressor effects increase toxic effects in the field?

Often additive (when both in effect range)

Can be more than additive

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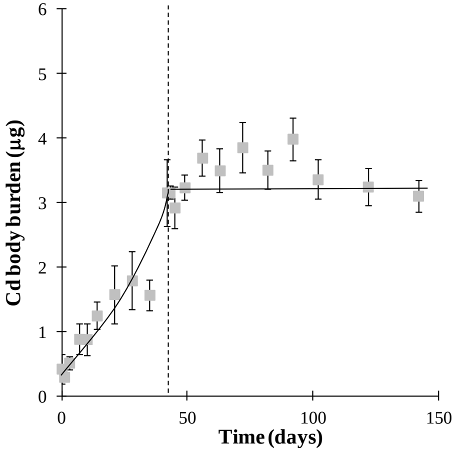
Longer exposure greater toxicity?

- Based on the assumption that toxicity is time dependent
- Time dependence based on assumption that body concentrations increases with time
- So time dependent patterns in body concentration give insight into effects of exposure duration

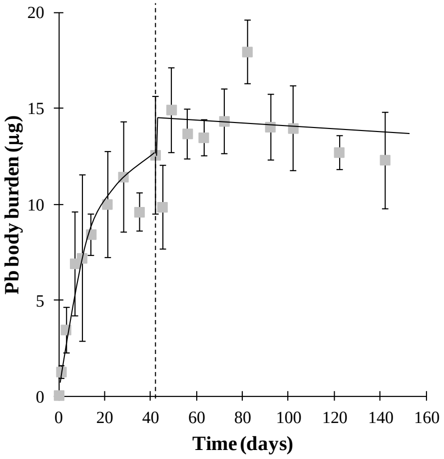
Metal uptake *Eisenia fetida* in field soil

Non-essential metals

Cadmium



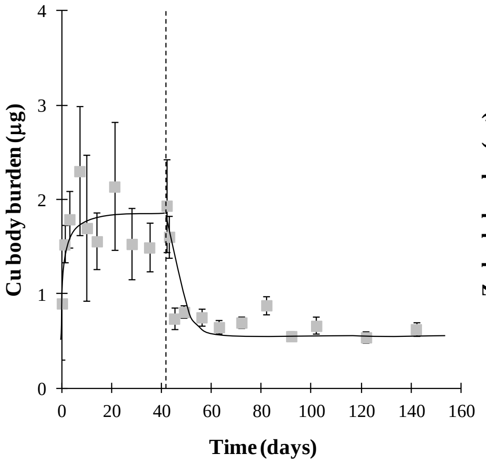
Lead



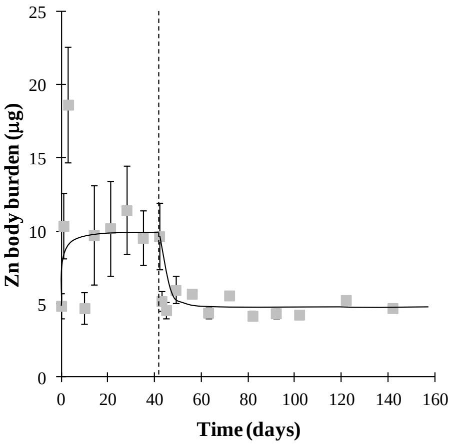
- Low rates of elimination
- Body burden is time dependent

Essential metals

Copper



Zinc



- High rates of elimination
- Body burden only time dependent over 7 days

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Longer exposure greater toxicity?

Summary

Does long-term increase toxic

effects in the field

Chemical dependent

Need kinetic data

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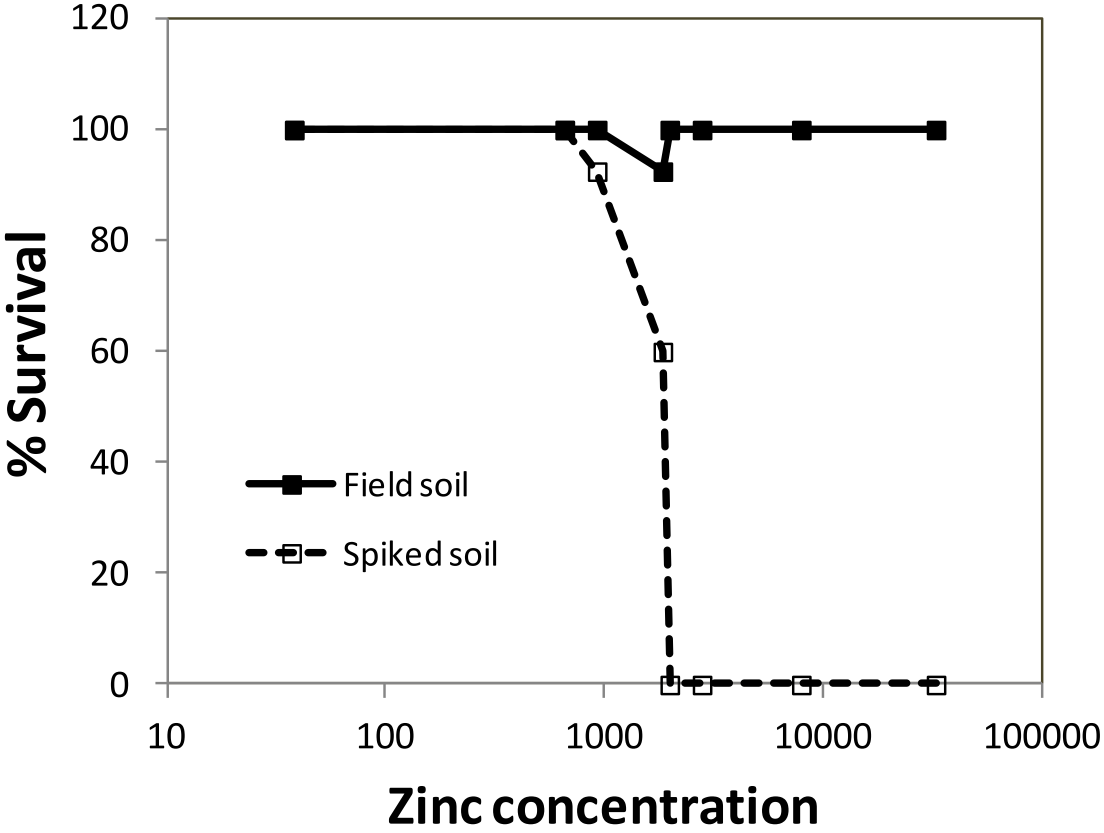
Field soil versus spiked exposures?

Exposed worms to

1. A field contaminated by smelter emissions over many decades
2. A laboratory soil containing the same concentrations of metals added as a solution of the nitrate salt as in a standard lab test.

Field vs spike bioavailability



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Field vs spike bioavailability

True

At least for metals in terrestrial systems. See the papers/reports of :

Spurgeon
Smit
Van Gestel
Smolders

Posthuma
Vjiver
Janssen(s)
McLaughlin

Field vs spike bioavailability

Now part of EU policy

3 fold lab - field extrapolation factor in metals risk assessment

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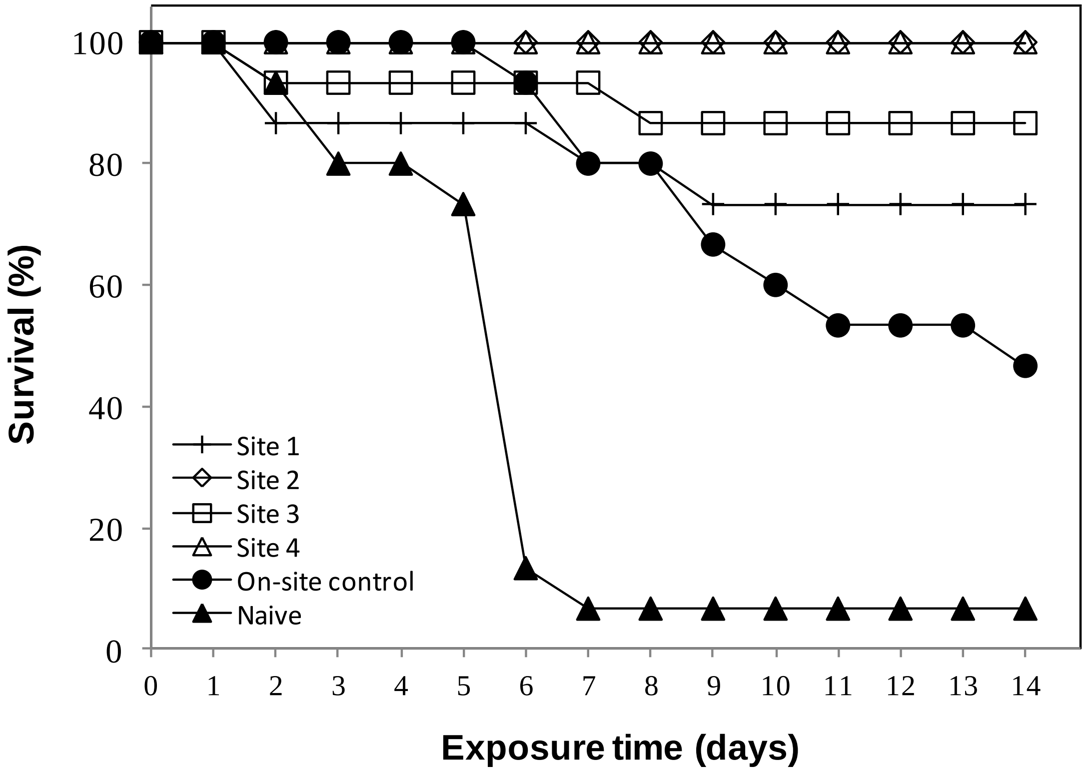
Lumbricus rubellus exposed to As - 6 populations

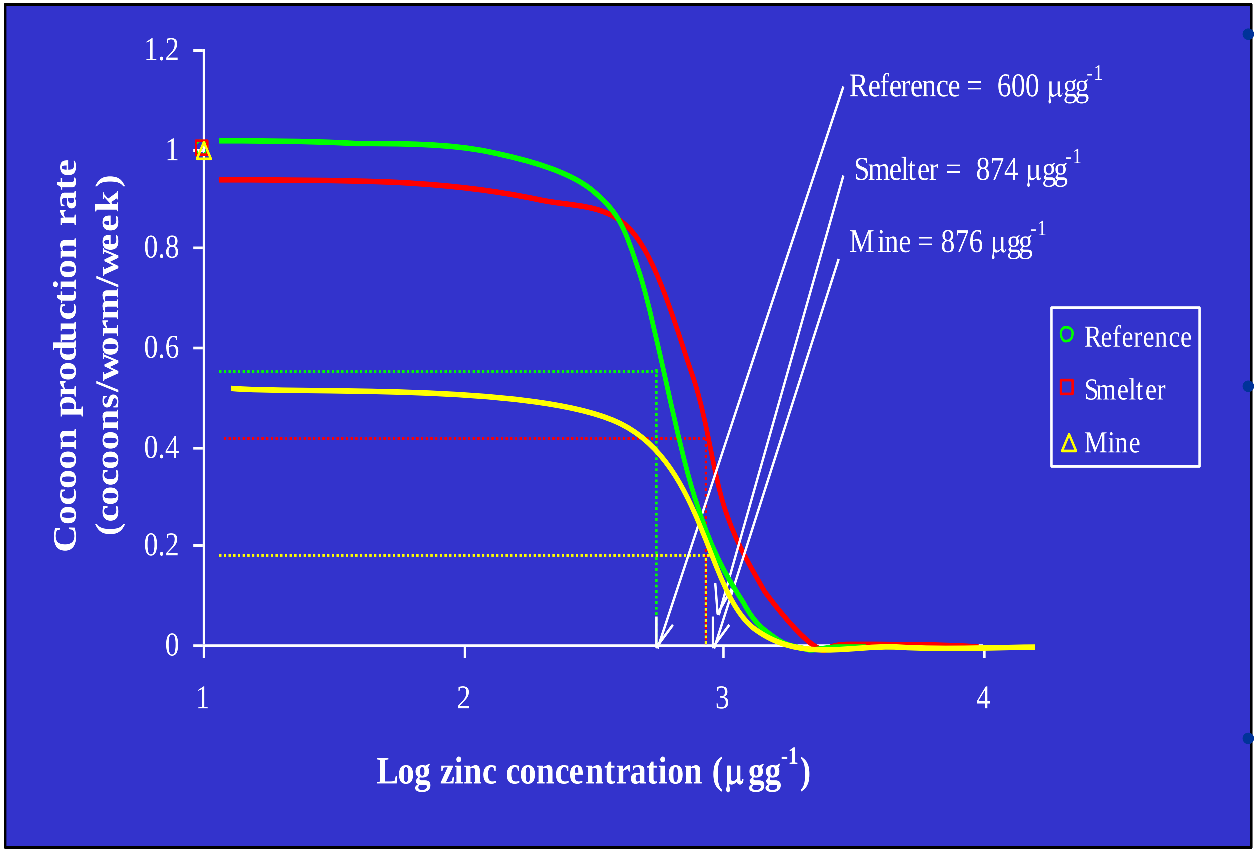


- Rapid mortality of the naive population and partial mortality of on-site controls

- High survival of most polluted population.

- Tolerance is conserved over 2 generation – genetic basis.

Lumbricus rubellus exposed to Zn - 3 populations



- Significant differences in the shapes of the dose response curves

- Toxicity (expressed as EC_{50}) lowest in reference population

- Considering the different exposure histories, difference in small

ADAPTATION AS AN EFFECT MITIGATION

For Arsenic

Evidence of development of genetic adaptation.

For Zinc

No clear evidence of substantial adaptation for polluted site populations even after 400 years exposure. EC_{50}s similar for the three populations.

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WHY NO ZN TOLERANCE IN THE FIELD?

- Selection pressure at the polluted sites is insufficient to promote resistance - UNLIKELY
- Meta-population effects prevent the development of resistance – POSSIBLE BUT WORMS SEDENTARY
- Physiological constraints limit resistance - zinc is essential, so the phenotypic variability of some species may be limited. The fact that the field species different from that in the laboratory may explain the anomalous results - POSSIBLE

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ADAPTATION AS AN EFFECT MITIGATION

In the field adaptation to

chemical stress may occur

Reduces toxic effects in field?

Not necessarily. Evidence of adaptation for some pollutants but not all.

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EXTRAPOLATION FACTORS - CONCLUSIONS

Increases toxicity in field

Exposure to non-optimal conditions increases field toxicity - depends on factor and the extent of change

Long-term exposure in the field increases toxicity in the field - chemical dependent

Mixed stressor increase effects – additive and can be synergistic

Reduces toxicity in field

Lower availability reduces toxicity in the field – lab to field comparative work indicates this is important

Adaptation reduces effect – not necessarily the case

OVERALL CONCLUSION

There are few simple relationships.

Need to think in the context of the biology of the stressor being considered

Mechanistic info valuable.

It’s Over