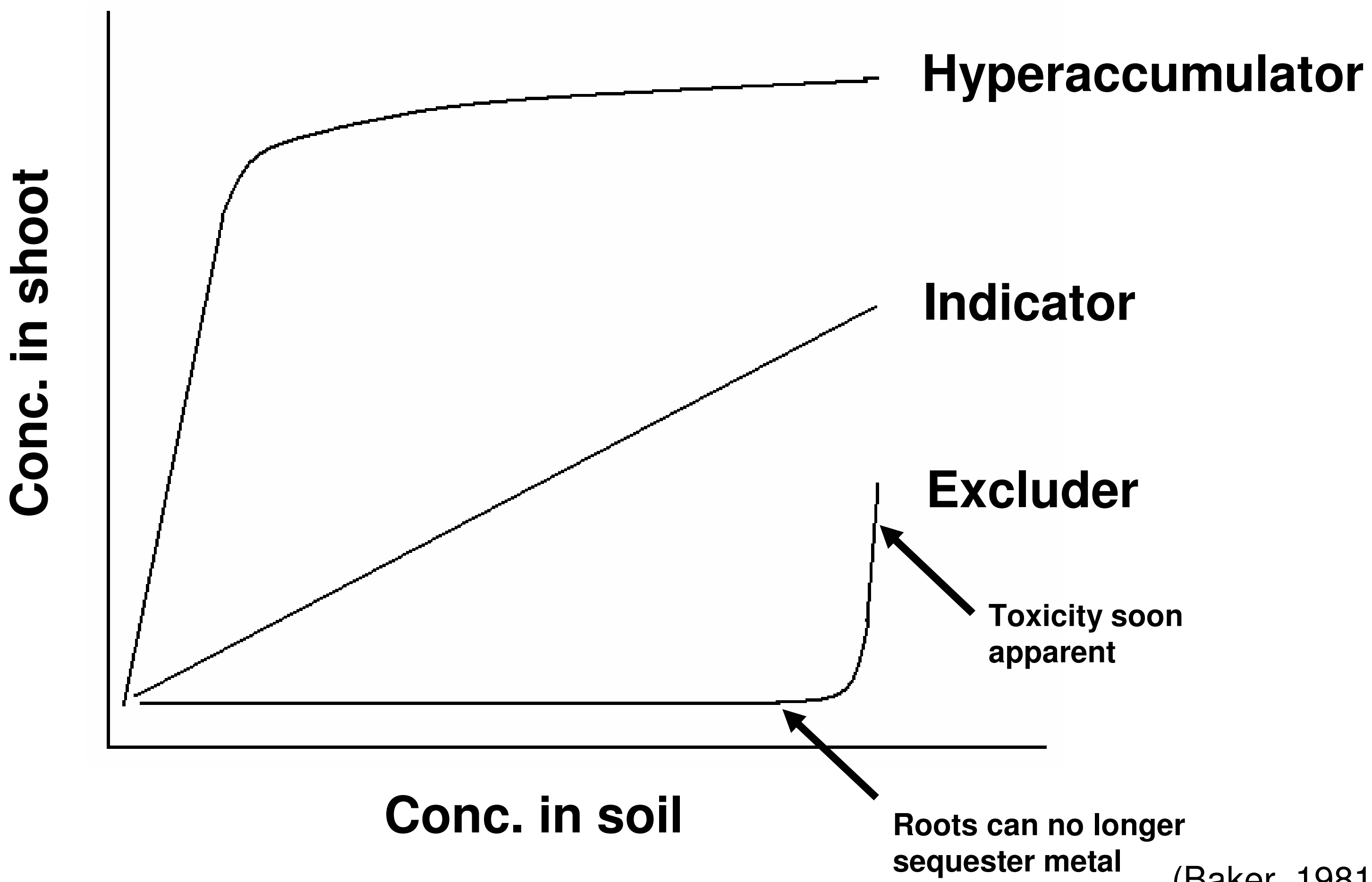
Trace metals in the soil-plant system and beyond

Iain Green

The School of Applied Sciences

Metallophyte Strategies



(Baker, 1981)

Tolerance mechanisms

- **Sequestration-**
  - Peptides - Phytochelatins/GSH
  - Proteins - Metallothioneins
  - Organic acids – Citrate, malate
  - Amino acids - esp. Histidine
- **Vacuolisation**
- **Binding to cells wall components**
- **Translocation to shoot**

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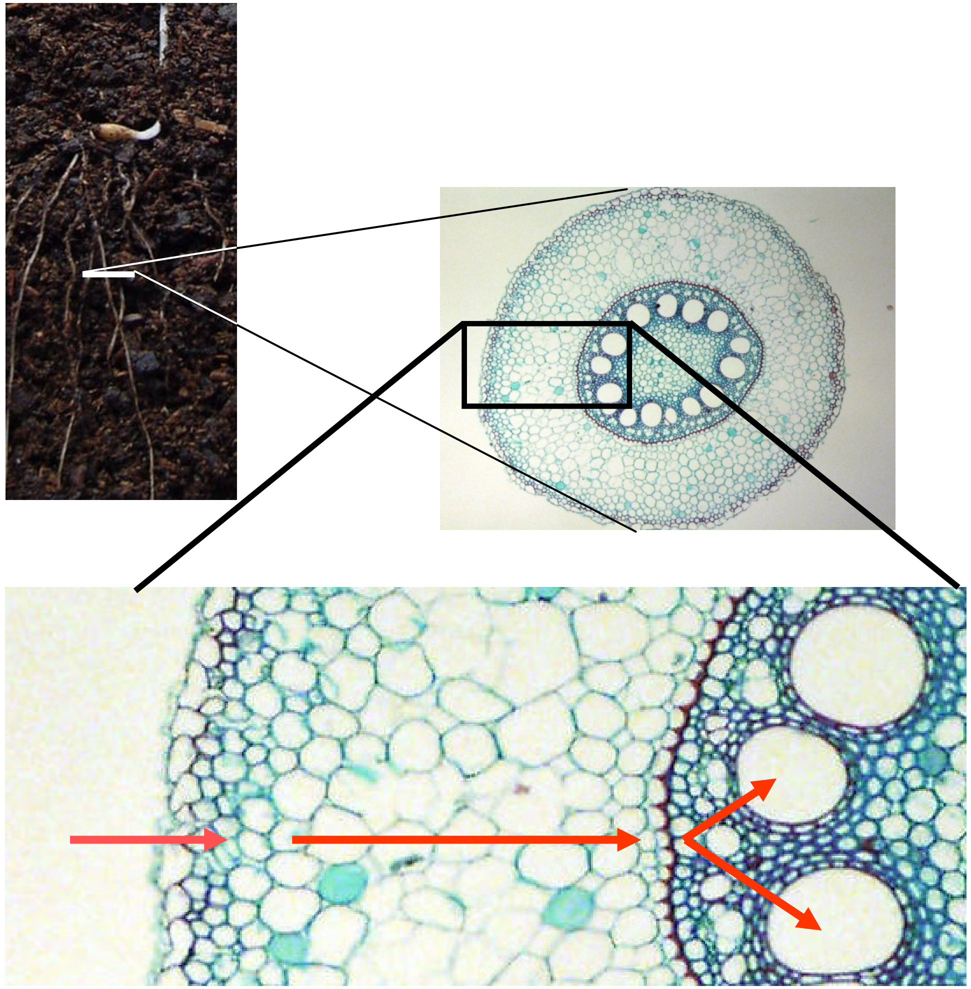
Transport & Translocation

Active transport proteins fundamental to these processes!

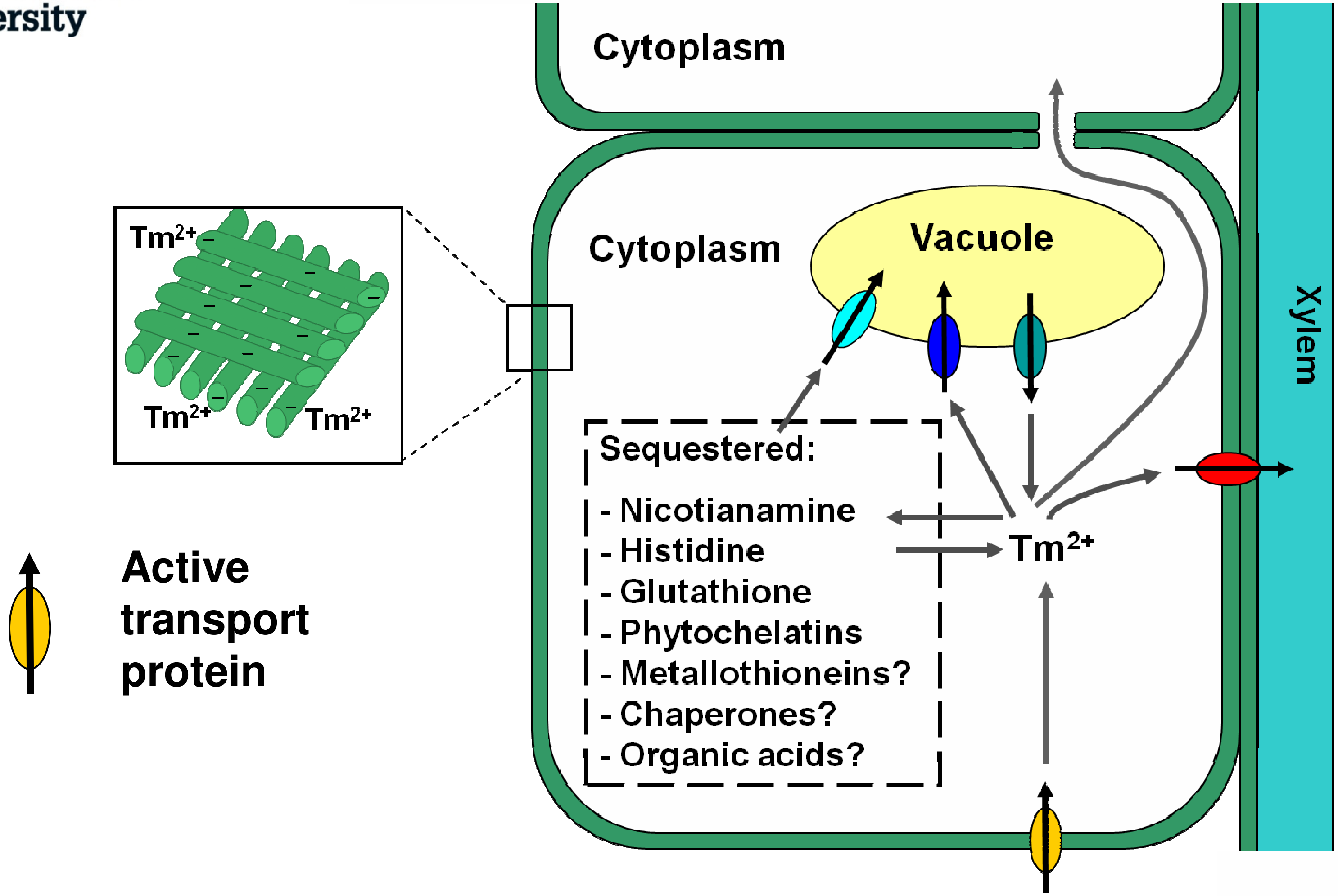
Shoot

Transpiration stream

Root uptake → Endodermis → Xylem loading



Metals in the cell



Transport - uptake of metals

- ZIP/IRT - Cd^{2+}, Ni^{2+}, Zn^{2+}
- Ca^{2+} channels & Fe^{2+} uptake transporters (Nramp) - Cd^{2+}
- Yellow-stripe 1 like (YSL) proteins – Metals complexed with nicotianamine (NA) **-** Cu^{2+}, Ni^{2+}, Zn^{2+}
- COPT family of transporters - Cu^{2+}
- Sulphate transporters – Se
- Phosphate transporters - As

Vacuole trafficking

Into the vacuole

- MTP 1 - Cd^{2+}, Ni^{2+}, Zn^{2+} , possibly Cu
- CAX - Cd^{2+},
- ABC-type transporter – PC-Metal complex

Out of the vacuole

- NRAMP 3 - Fe^{2+}, Zn^{2+} & possibly Cd^{2+}

Long distance transport

Transporters

- P_{1B}-ATPases – Cu^{+} , Zn^{2+} & Cd^{2+}

 - e.g. Cd/Zn loading into xylem by HMA 2 & HMA 4

- IREG – Ni

Complexes

- Ni – increased loading of Histidine bound Ni
- YSL – NA complexed metals
- Other LMW molecules

Distribution of metals in plant

- Shoot biomass larger than root
- Hence translocation to shoot in hyperaccumulators
- But must still protect photosynthetic tissues from toxicity
- Efficient movement of metals in shoot
- Accumulation in epidermis
- Non-accumulators also use epidermal storage
- Leaf hairs may can also be site of storage

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Trophic transfer

- Metal levels in metallophyte tissues can be transferred to herbivores
- Applies to both hyper and non-hyperaccumulating plants

- e.g. Aphid *Brachycaudus lychnidis* feeding on *Silene vulgaris* accumulated 9,000 mg Zn kg^{-1} (Ernst et al., 1990)

Trophic transfer

- Shoot accumulation may be a defence adaptation
- Through feeding deterrence or toxicity to herbivores
- For inverts, shown for Cd, Ni, Zn & Se
- For mammals, shown for Se but not Ni
- As for defence through secondary metabolites, doesn't always work and herbivorves adapt

- e.g. Diamond back moth variety 'disarm' Se defence of Prince's plume (Freeman et al., 2006)

Herbivore-predator transfer

• High levels of metal in herbivore can be transferred to predators

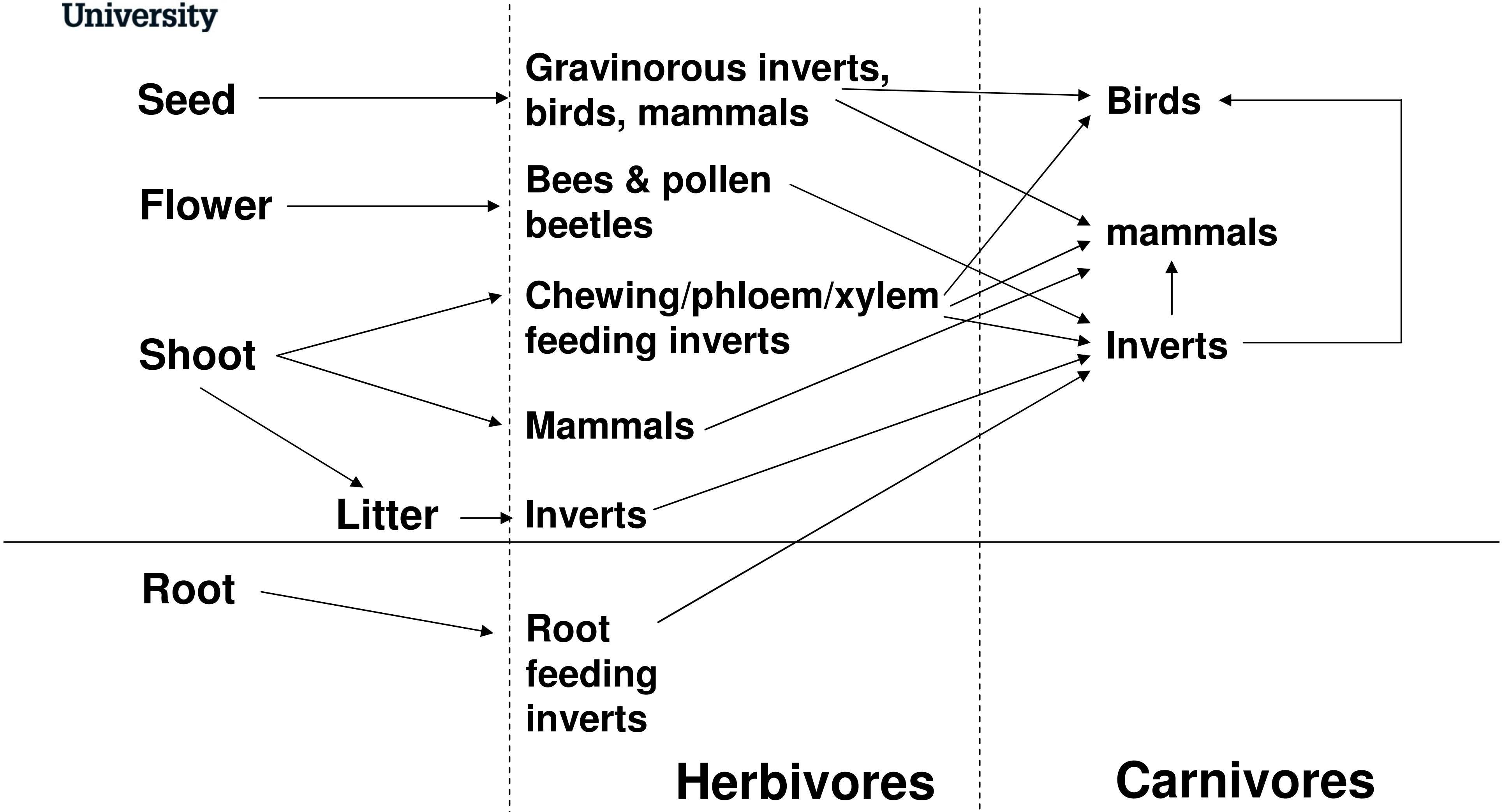
• Can be toxic to predators – secondary toxicity

-e.g.

Streptanthus polygaloides – Melanothrichus boydi – Misumena vatia

Spider *M. vatia* suffers secondary toxicity

Transfer pathways



Established pathways

- Soil-plant-seed-mammal **Cd, Cu, Zn**
- Soil-shoot-mammal **Cd, Pb, Zn**
- Soil – inverts -mammal **Cd, Cu, Pb, Zn**
- Soil – shoot herb insects **Cd, Ni, Zn**
- Soil-shoot-Herb insects-pred insects **Cd, Ni, Zn**
- Shoot-gastropod **Cd, Cu, Pb, Zn**
- Litter-isopod **Cd, Cu, Pb, Zn**

Ecological risk

- Two main risks

1) secondary toxicity

2) disruption of litter breakdown

- Difficult to predict

- Establish key pathways, e.g. shoot – gastropod – predators

- Accumulation can be poorly related to toxicity

- Inverts and mammals live in these metallic ecosystems

- Inverts can adapt to high metal environments

Ecological risk

• Transfer of metal to neighbouring ecological communities

- Insects as pollution vectors, carrying metals away from site

e.g. Carnivorous plants sensitive to Cd

• Mobile birds/mammals visiting sites and eating metallophytes or high metal animals resulting from them

Conclusion

- Metallophytes are unique group of plants characteristic of unique environments
- They can increase the flow of accumulate metals through food chain
- Although this is limited by deterrence/toxicity
- Predators may suffer secondary toxicity
- Unique ecology community of tolerant species likely to develop

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Conclusion

- Real risk is transport of metals to neighbouring communities
- But migrants into these communities may also be vulnerable
- Excluder species most desirable to render transport to a level as low as reasonably practical
- Biodiversity may be important in reducing exposure of higher trophic levels – increased pathways for energy
- Monitoring of metallophytes communities and their neighbours required to establish nature of risk