Using a landscape perspective to refine exposure scenarios

Lawrence (Larry) Kapustka, Ph.D.

LK Consultancy

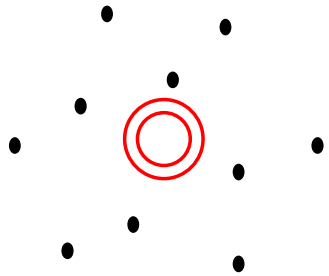
Turner Valley, Alberta Canada

kapustka@xplornet.com

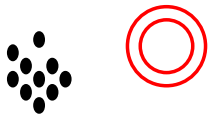
Important Foundational Literature

- **Mandelbrot, Benoit** – see Gleick, James (1987). *Chaos: Making a New Science*. London: Cardinal. p. 229
- **May, Robert M. 1976**. Simple mathematical models with very complicated dynamics. *Nature* 261:459-467
- **Rittel H, Webber M. 1973**. Dilemmas in a general theory of planning. *Policy Sci* 4:155–169.
- **Thoreau, Henry David. 1854**. *Walden; or Life in the Woods*. Ticknor and Fields, Boston.
- **Taleb, Nassim Nicholas. 2001.** *Fooled by Randomness: The Hidden Role of Chance in Life and in the Markets*. Random House, New York
- **Taleb, Nassim Nicholas. 2007.** *The Black Swan: The Impact of the Highly Improbable*. Random House, New York
- **Gladwell, Malcolm. 2005**. *Blink: the Power of Thinking without Thinking*. Little Brown, and Company, New York

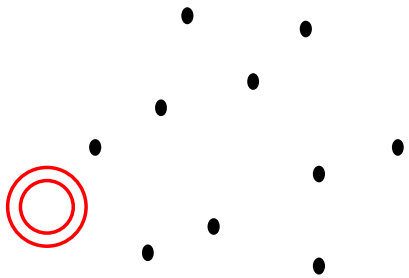
“It is better to be roughly right, than precisely wrong.”
John Maynard Keynes (Economist, journalist, and financier, 1883 – 1946)



High Accuracy, Low Precision

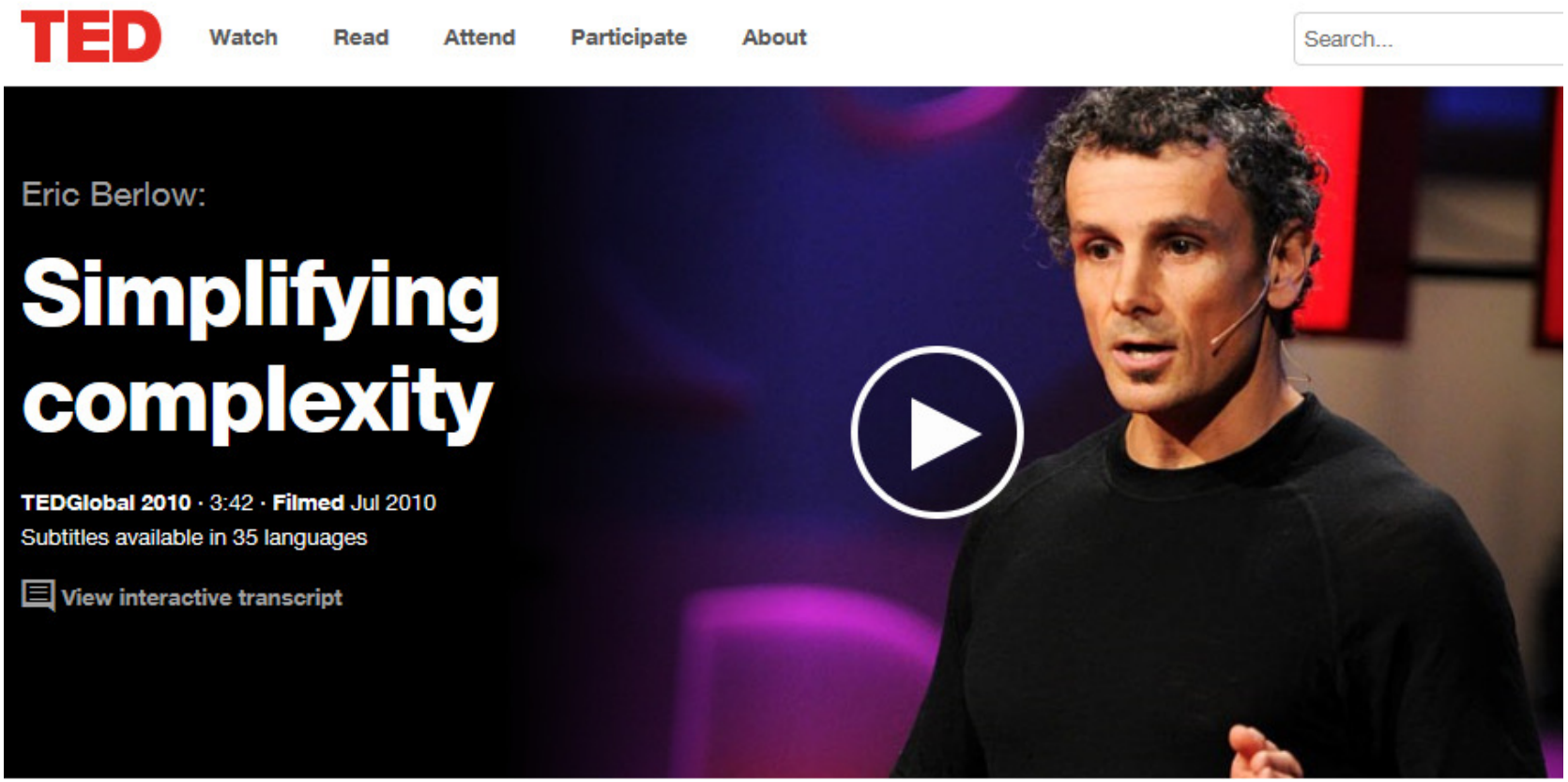


Low Accuracy, High Precision



Low Accuracy, Low Precision

High Accuracy, High Precision

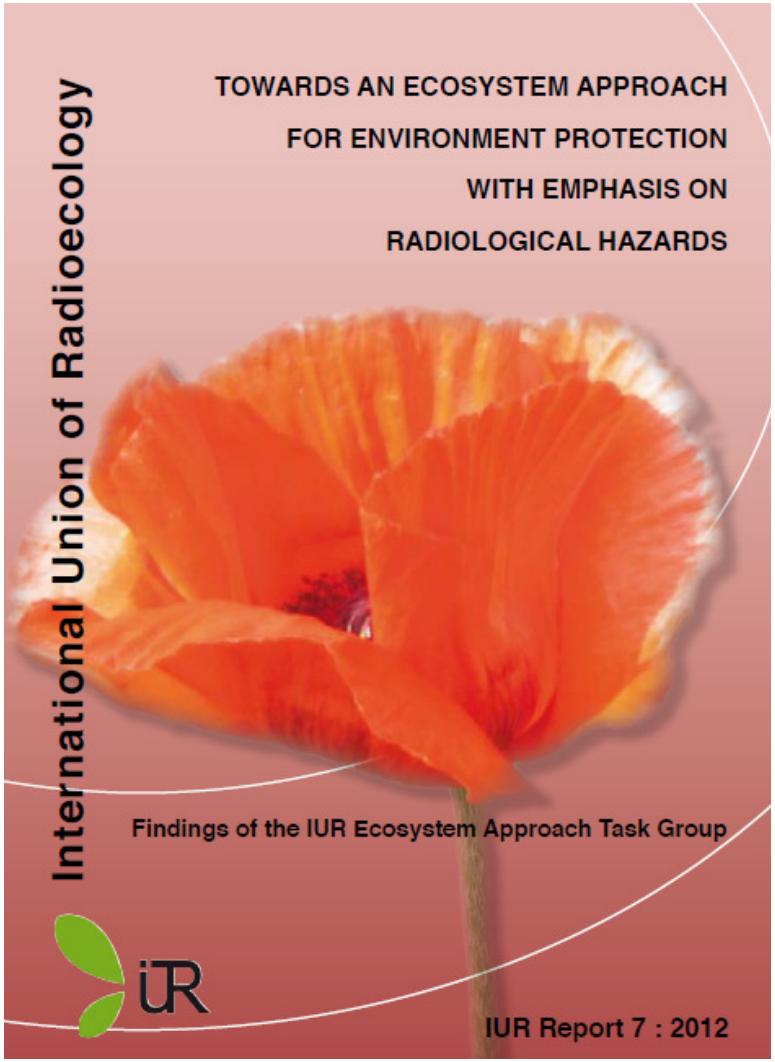


http://www.ted.com/talks/eric_berlow_how_complexity_leads_to_simplicity

Wicked Problems are…

- Those that cannot be defined so all agree on the problem to solve
- Require complex judgment about the level of abstraction at which to define the problem
- Have no clear stopping rules
- Have no right/wrong answer; just better/worse conditions
- Have no objective measure of success
- Require iteration – every trial counts
- Have no given alternative solutions – these must be discovered
- Often have strong moral, political, or professional dimensions

***Rittel and Webber, 1973**



IUR Task Group gathering proficiencies beyond the only field of radiation

Report now published (free distribution to all members, annual fee cleared)

Order at: www.iur-uir.org

Short communication to Journal of Environmental Radioactivity

Using an Ecosystems Approach to Complement Protection Schemes based on Organism-level Endpoints.

Bradshaw et al. (in press)

Highlights

- An Ecosystem Approach to radiation safety complements the organism-level approach
- Emergent properties in ecosystems are not captured by organism-level endpoints
- The proposed Ecosystem Approach better aligns with management goals
- Practical guidance with respect to system-level endpoints is needed
- Guidance on computational model selection would benefit an Ecosystem Approach

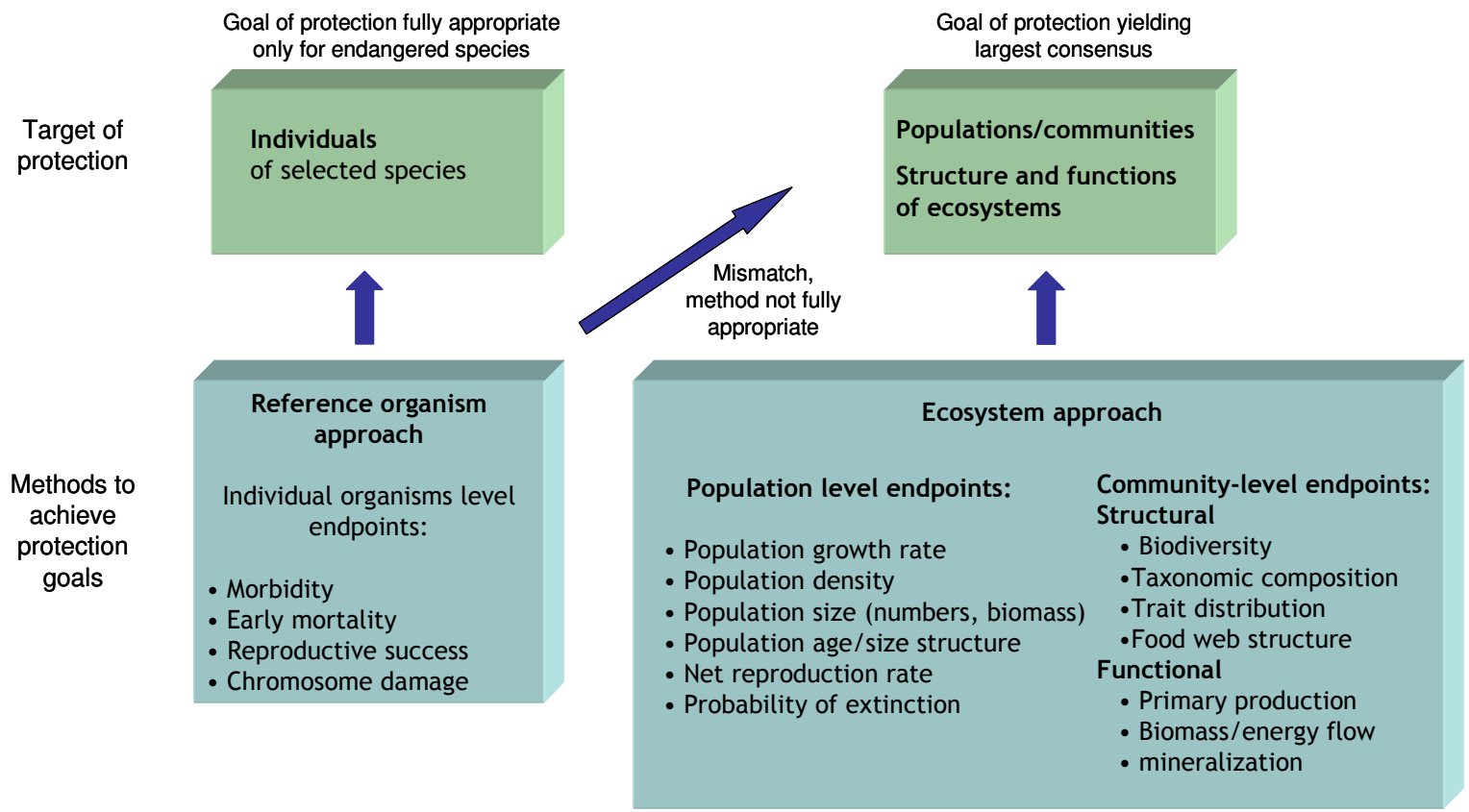


Figure 1. Target objectives of environment protection versus methods to achieve them

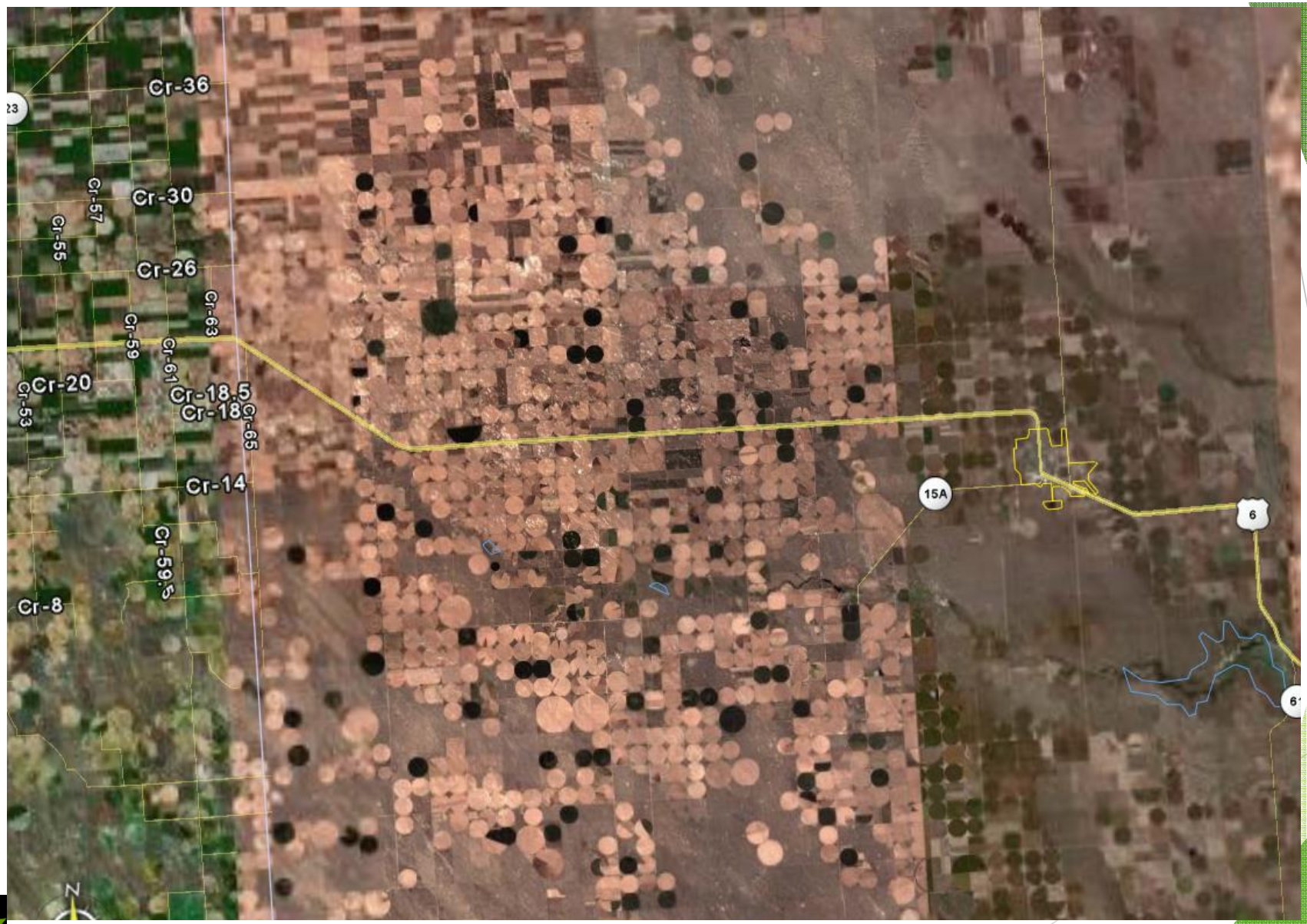
From Bradshaw el al. (in press) Journal of Environmental Radioactivity

Landscape Ecology

- Formal characterization of spatial patterns of physiognomy/vegetation (type)
  - grain size
  - patch size (extent)
  - connectivity
- Builds upon classical ecology measures of communities, life-forms, distribution and abundance of species
- Readily amenable to mapping routines including GIS techniques to create multiple “views” developed using different spatial scales of resolution
- Geo-referenced layers (e.g., distribution of stressors such as chemicals, radionuclides, biota, physical parameters) link various databases to achieve multiple computational steps


Nunavut
Northwest Territories


Fort McMurray
© 2006 Europa Technologies
© 2006 Navteq
Image © 2006 TerraMetrics
©2005 Google
Pointer 57°12'08.75" N 111°06'58.73" W elev 1499 ft
Streaming 100%
Eye alt 84.55 mi
63


Cr-36
Cr-30
Cr-57
Cr-55
Cr-26
Cr-63
Cr-59
Cr-61
Cr-20
Cr-53
Cr-18.5
Cr-18
Cr-65
Cr-14
Cr-59.5
Cr-8
15A
6
N


1 km


Marazoleja
Etreros
Sangarcía
Juarros de Ri
Cobos de Segovia
Bercial
SG-V-3221
SG-322
SG-V-3131
Image © 2014 DigitalGlobe
© 2014 Google
Google
Tour Guide
2009
Imagery Date: 10/28/2012 40°55'21.72" N 4°22'08.95" W elev 925 m eye alt 12

Relevant spatial scales – a landscape perspective

Image from www.omfra.gov.on.ca accessed June 2014

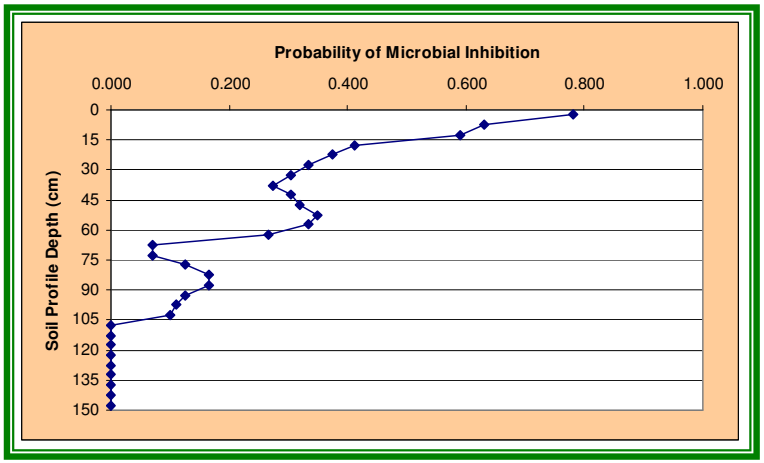
Bacteria - <1 to a few mm^3
Fungi – a few cm^3 to a few km^3
…

Variance in 1 m x 1 m plot = variance in 1 km x 1 km plot!

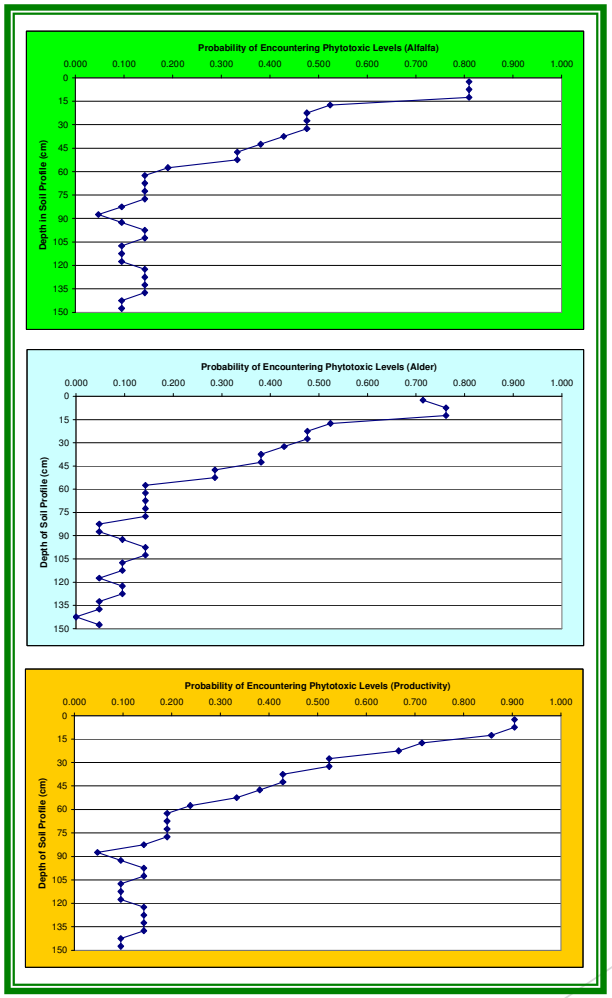
Paul, E. A., R. J. K. Meyers, and W. A. Rice. 1971. Nitrogen fixation in grassland and associated cultivated ecosystems. In T. A. Lie and E. G. Mulder, eds., pp. 295-507, Biological Nitrogen Fixation in Natural and Agricultural Habitats. Special Vol. Plant and Soil.

Distribution of mine waste metals in riparian soils (Grant-Kohrs

Distribution of mine waste metals in riparian soils (Grant-Kohrs Ranch, Deer Lodge, MT USA)



Probability of encountering toxic levels of CoC to microbes at depth in the GRKO riparian area.



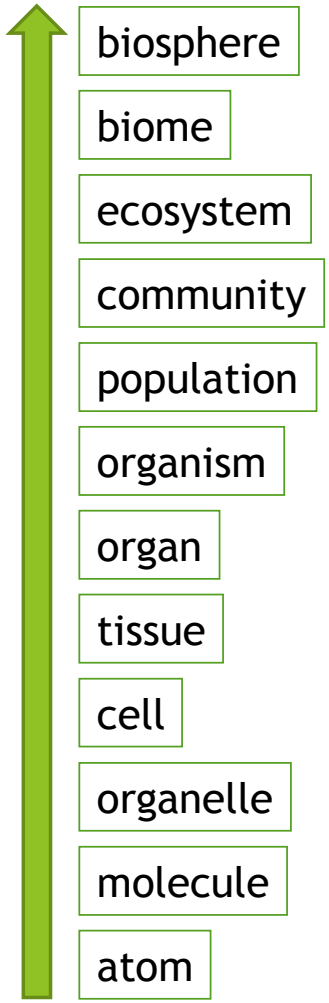
Semi-variograms suggested that spatial heterogeneity would require sampling locations would have to be <u>no more than 0.5 m apart</u> to obtain reliable kreiging displays.

Kapustka LA. 2002. Natural Resource Injury Assessment Report on Riparian and Upland Areas of the Clark Fork River, Montana. Final Report. National Park Service – Grant-Kohrs Ranch National Historic Site and Bureau of Land Management Parcels. U.S. Department of Interior.

Mammal	Number per 50-acre site	Home range (%)
Black-tailed jackrabbit	2.5	?
Coyote	<1	0.25
Long-tail weasel	1.5	6
Mule deer	2	18
Raccoon	<1	25
Red fox	<1	5
White-tailed deer	2	10

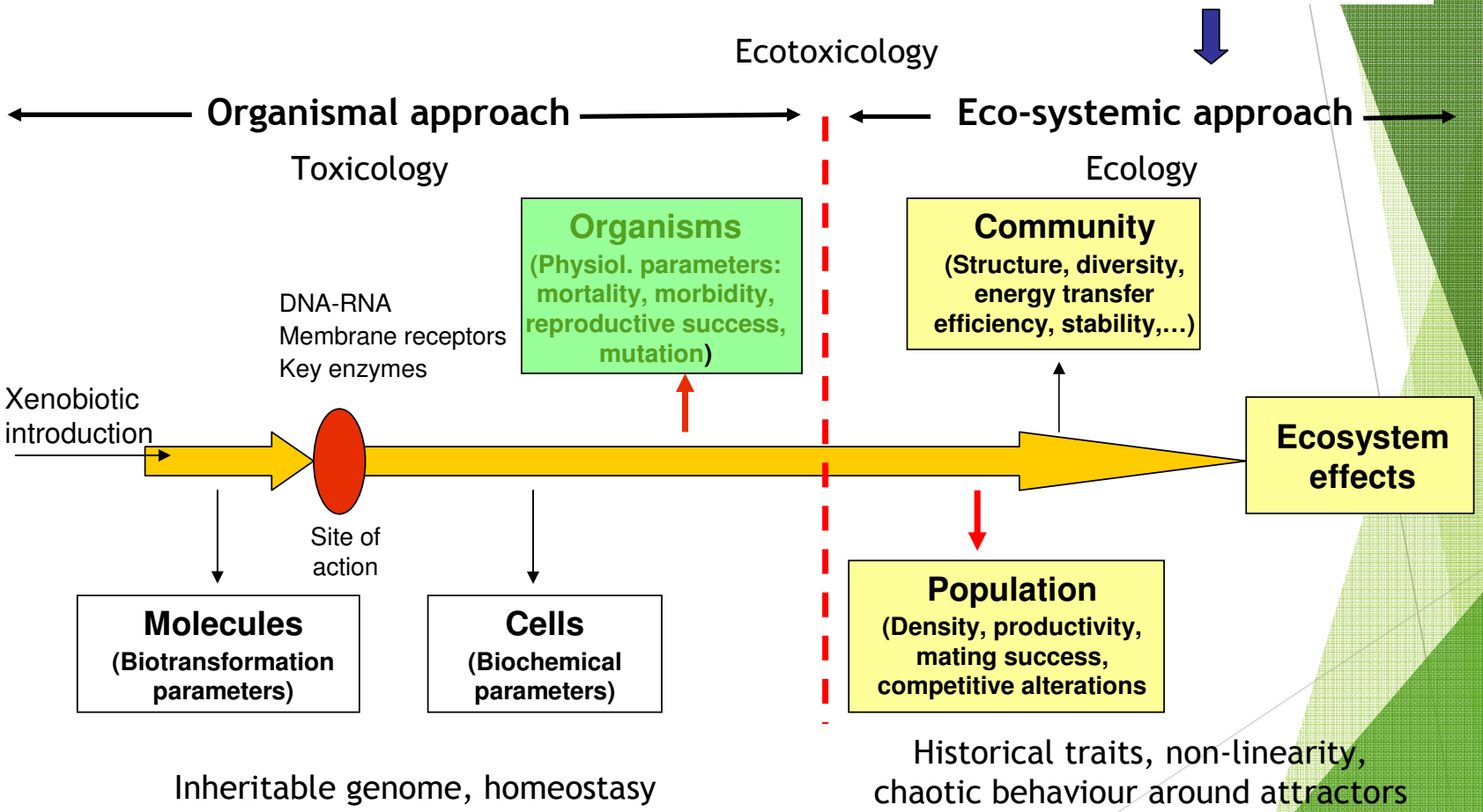
From Tannenbaum (2005) IEAM 1:66-72

- Simple System – Linearity



- Complex System – Emergent Properties
- Emergent Properties
  - Novel, non-reducible attributes that arise from the fundamental components of a lower hierarchy
  - Unexpected, unanticipated behaviours
  - The sum is greater than the parts
- Hierarchical Theory
  - One level up for context
  - Focal interest
  - One level down for mechanism of action

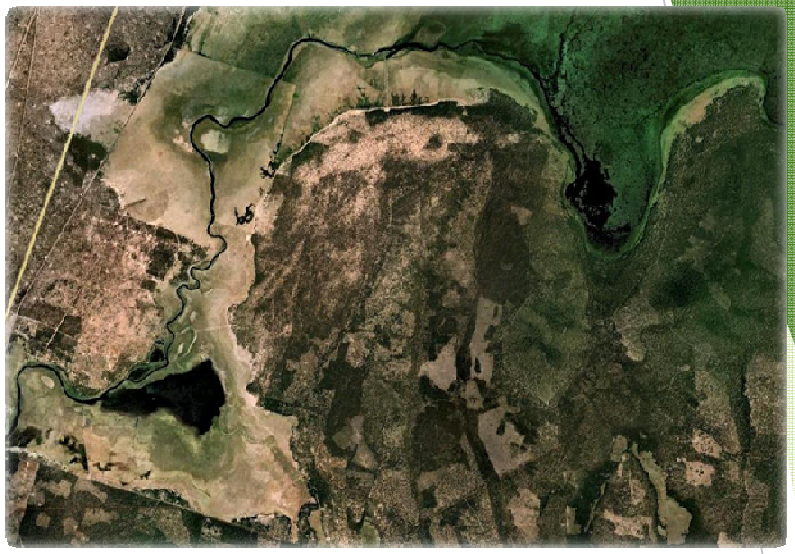
Biocentric approach partially meets EP objectives

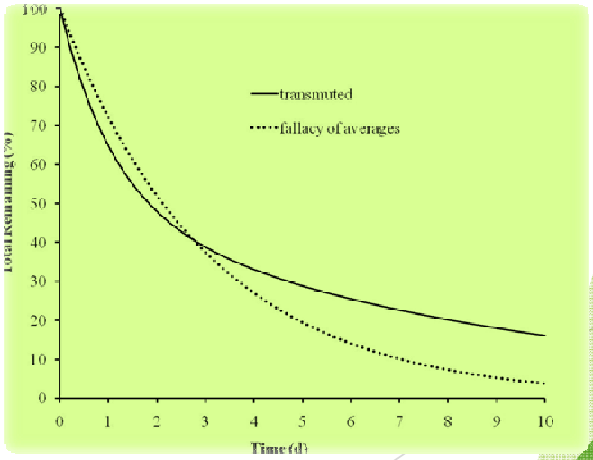


Fallacy of Averages

1. Heterogeneity in Ecological Systems (non-random distribution)
   - Physical features
   - Biotic features
2. Non-linear processes

Requires segregating landscape types into bins along gradients or at discontinuities (consistent with polygon delineation in mapping; GIS)

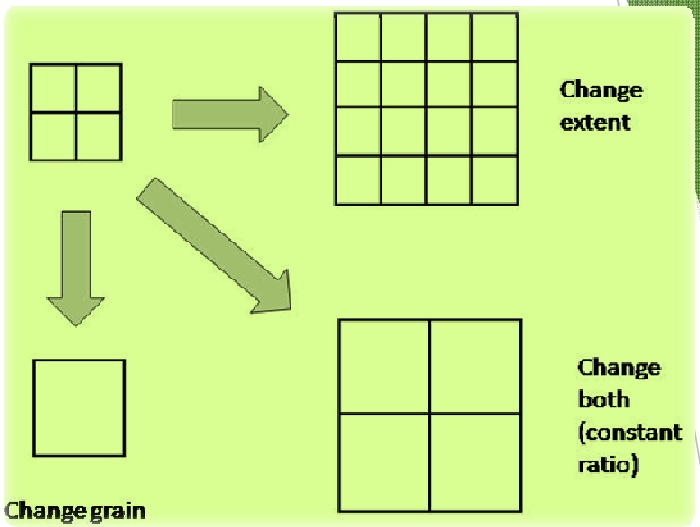




Predicted degradation of a hypothetical contaminant in a thermally-stratified lake. (Johnson and Turner 2010)

Ecological Fallacy

- Improper inferences made from data where individual responses are aggregated into groups
- Changing the spatial grain of the data, by aggregating individuals or small groups into larger groups (i.e., an extrapolation across scale) affects computed correlations

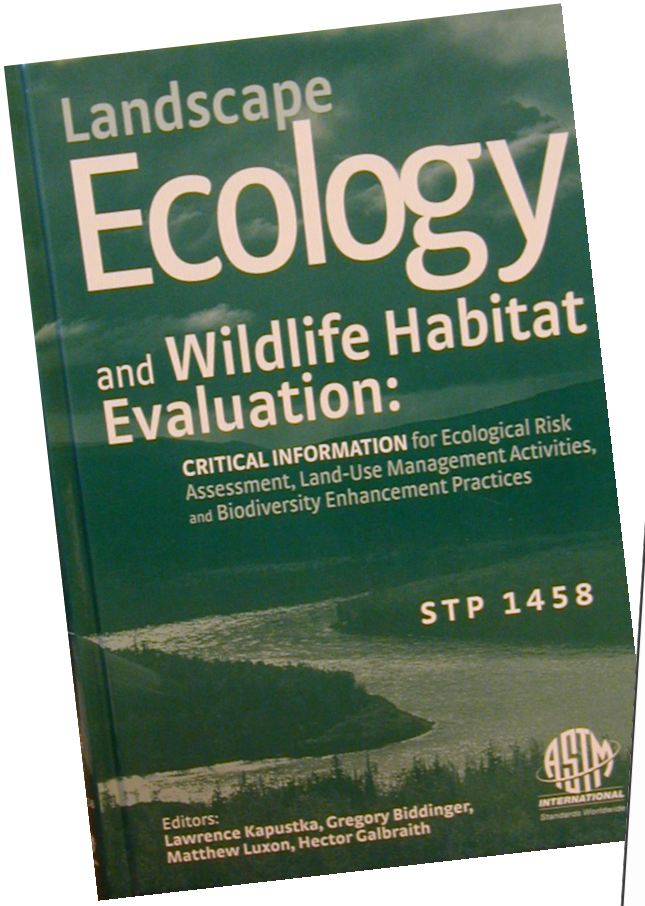


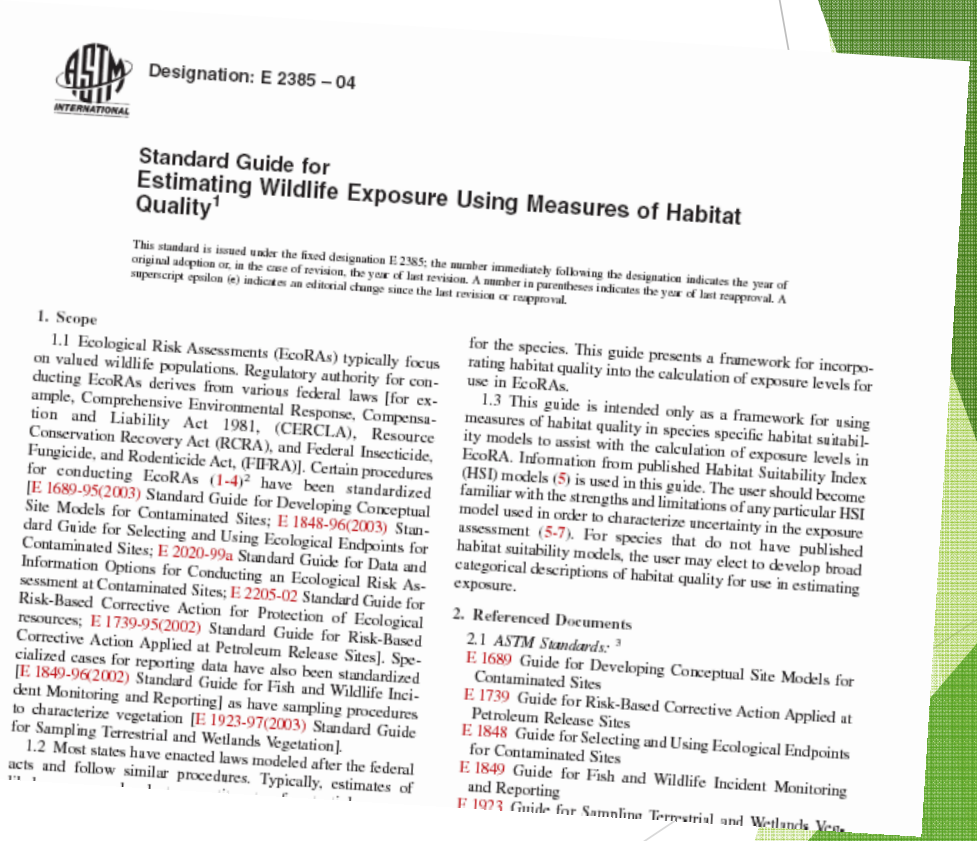
Human presence and biodiversity

- Positive correlation at grain >1 km
- Negative correlation at finer scale
- Over at least four orders of magnitude, the correlation varies linearly with the logarithm of scale (grain or extent)

Pautasso M. 2007. Scale dependence of the correlation between human population presence and vertebrate and plant species richness. *Ecol Lett 10:16-24.*

Johnson and Turner (2010)





Designation: E 2385 – 04

Standard Guide for Estimating Wildlife Exposure Using Measures of Habitat Quality[1]

This standard is issued under the fixed designation E 2385; the number immediately following the designation indicates the year of original adoption or, in the case of revision, the year of last revision. A number in parentheses indicates the year of last reapproval. A superscript epsilon (ε) indicates an editorial change since the last revision or reapproval.

1. Scope

1.1 Ecological Risk Assessments (EcoRAs) typically focus on valued wildlife populations. Regulatory authority for conducting EcoRAs derives from various federal laws [for example, Comprehensive Environmental Response, Compensation and Liability Act 1981, (CERCLA), Resource Conservation Recovery Act (RCRA), and Federal Insecticide, Fungicide, and Rodenticide Act, (FIFRA)]. Certain procedures for conducting EcoRAs (1-4)[2] have been standardized [E 1689-95(2003) Standard Guide for Developing Conceptual Site Models for Contaminated Sites; E 1848-96(2003) Standard Guide for Selecting and Using Ecological Endpoints for Contaminated Sites; E 2020-99a Standard Guide for Data and Information Options for Conducting an Ecological Risk Assessment at Contaminated Sites; E 2205-02 Standard Guide for Risk-Based Corrective Action for Protection of Ecological resources; E 1739-95(2002) Standard Guide for Risk-Based Corrective Action Applied at Petroleum Release Sites]. Specialized cases for reporting data have also been standardized [E 1849-96(2002) Standard Guide for Fish and Wildlife Incident Monitoring and Reporting] as have sampling procedures to characterize vegetation [E 1923-97(2003) Standard Guide for Sampling Terrestrial and Wetlands Vegetation].

1.2 Most states have enacted laws modeled after the federal acts and follow similar procedures. Typically, estimates of

for the species. This guide presents a framework for incorporating habitat quality into the calculation of exposure levels for use in EcoRAs.

1.3 This guide is intended only as a framework for using measures of habitat quality in species specific habitat suitability models to assist with the calculation of exposure levels in EcoRA. Information from published Habitat Suitability Index (HSI) models (5) is used in this guide. The user should become familiar with the strengths and limitations of any particular HSI model used in order to characterize uncertainty in the exposure assessment (5-7). For species that do not have published habitat suitability models, the user may elect to develop broad categorical descriptions of habitat quality for use in estimating exposure.

2. Referenced Documents

2.1 *ASTM Standards:*[3]

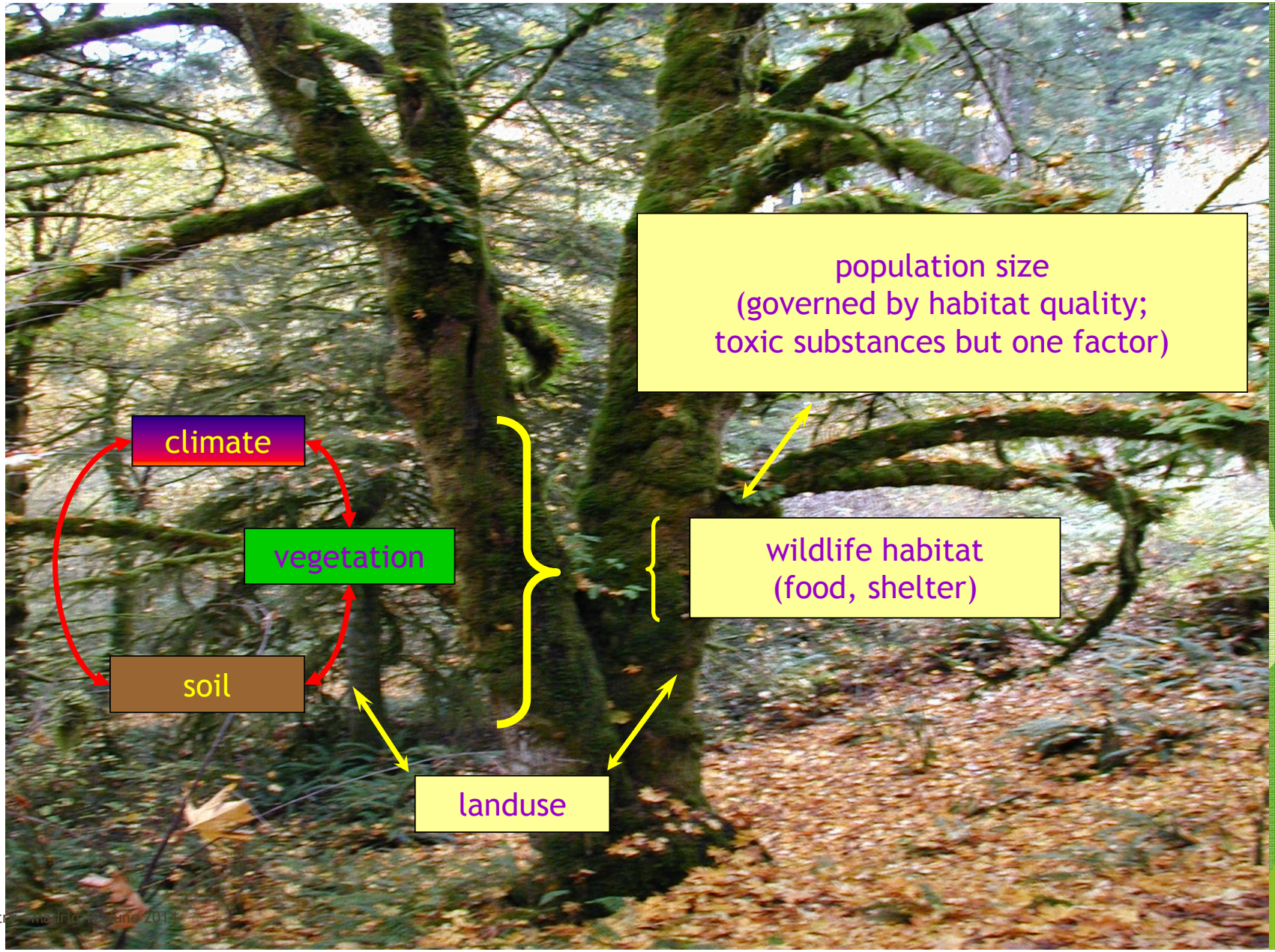
E 1689 Guide for Developing Conceptual Site Models for Contaminated Sites

E 1739 Guide for Risk-Based Corrective Action Applied at Petroleum Release Sites

E 1848 Guide for Selecting and Using Ecological Endpoints for Contaminated Sites

E 1849 Guide for Fish and Wildlife Incident Monitoring and Reporting

E 1923 Guide for Sampling Terrestrial and Wetlands Veg...


population size
(governed by habitat quality;
toxic substances but one factor)
climate
vegetation
soil
wildlife habitat
(food, shelter)
landuse

Importance of Habitat in EcoRA

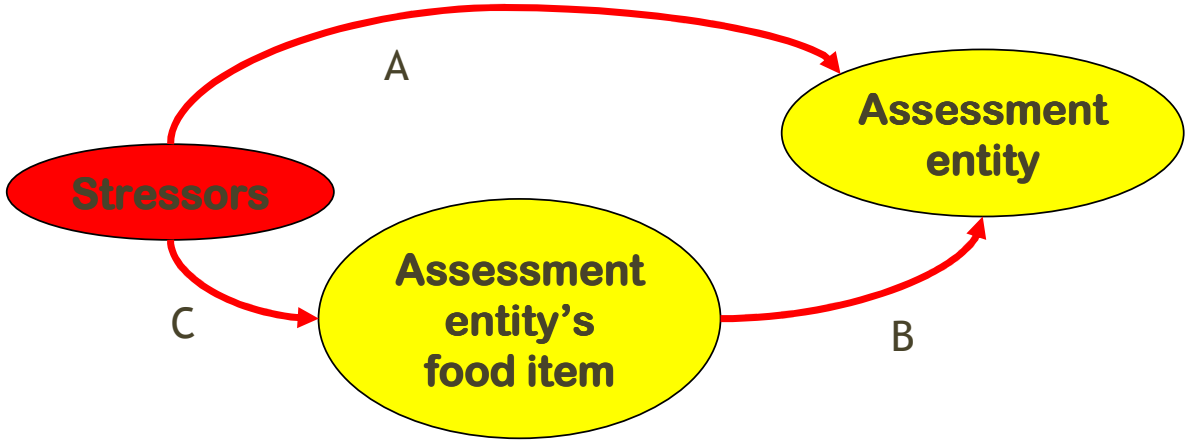
- Wildlife respond to differences in landscape features (attraction, avoidance)
- Spatial relationships between stressors and foraging activities influence exposure
  - Co-located distributions <u>increase</u> exposure
  - Disjoint distributions <u>decrease</u> exposure

Characterizing Habitat

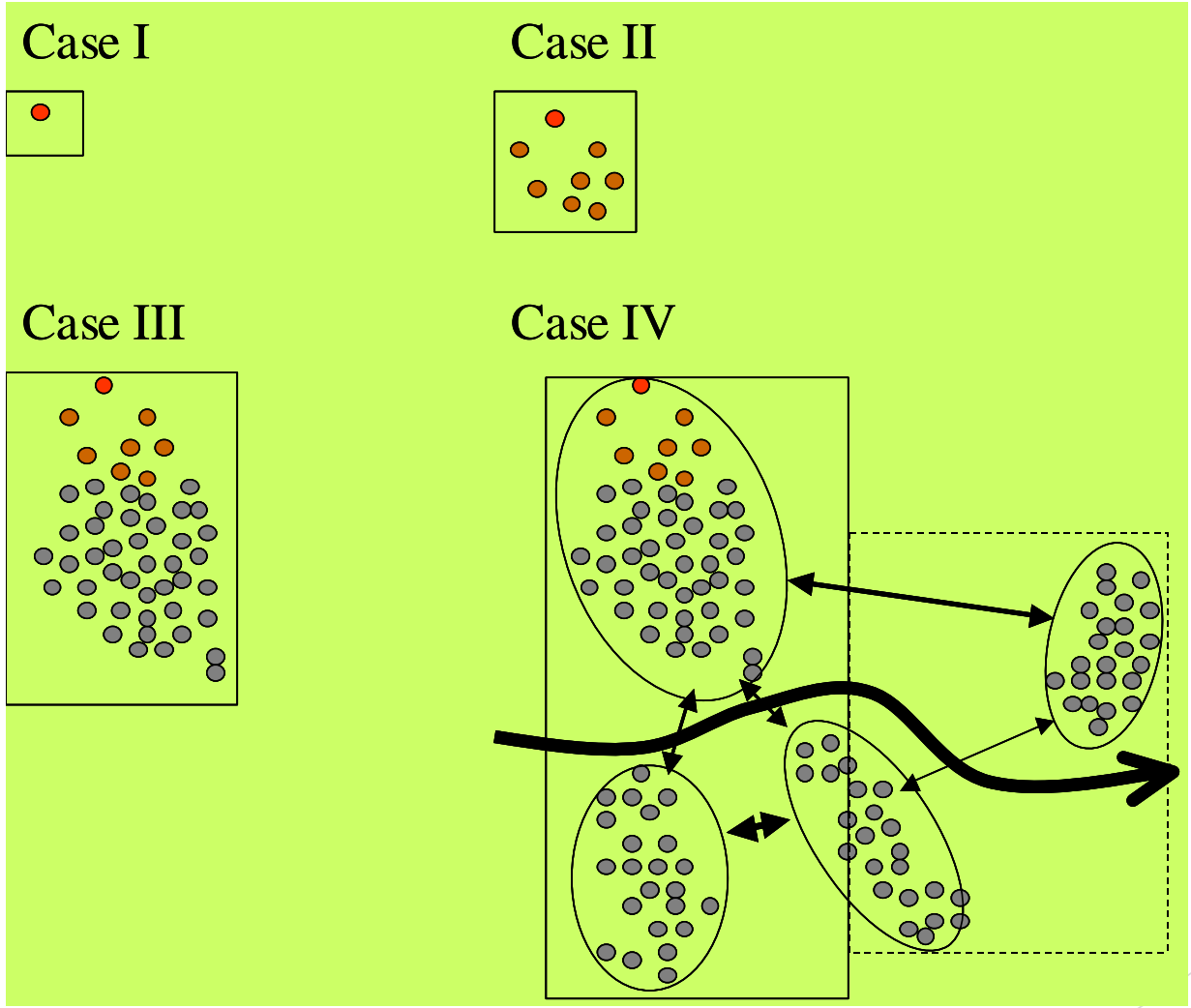
- Landscape features (vegetation cover, food items, physical components, etc.)
- Range in degrees of sophistication
  - Binary
  - Proportional index
    - Qualitative (i.e., not explicitly linked to density)
    - Semi- or Pseudo-quantitative
  - Absolute, Quantitative
    - Multiple regression
    - Factor analyses

Direct versus indirect linkages

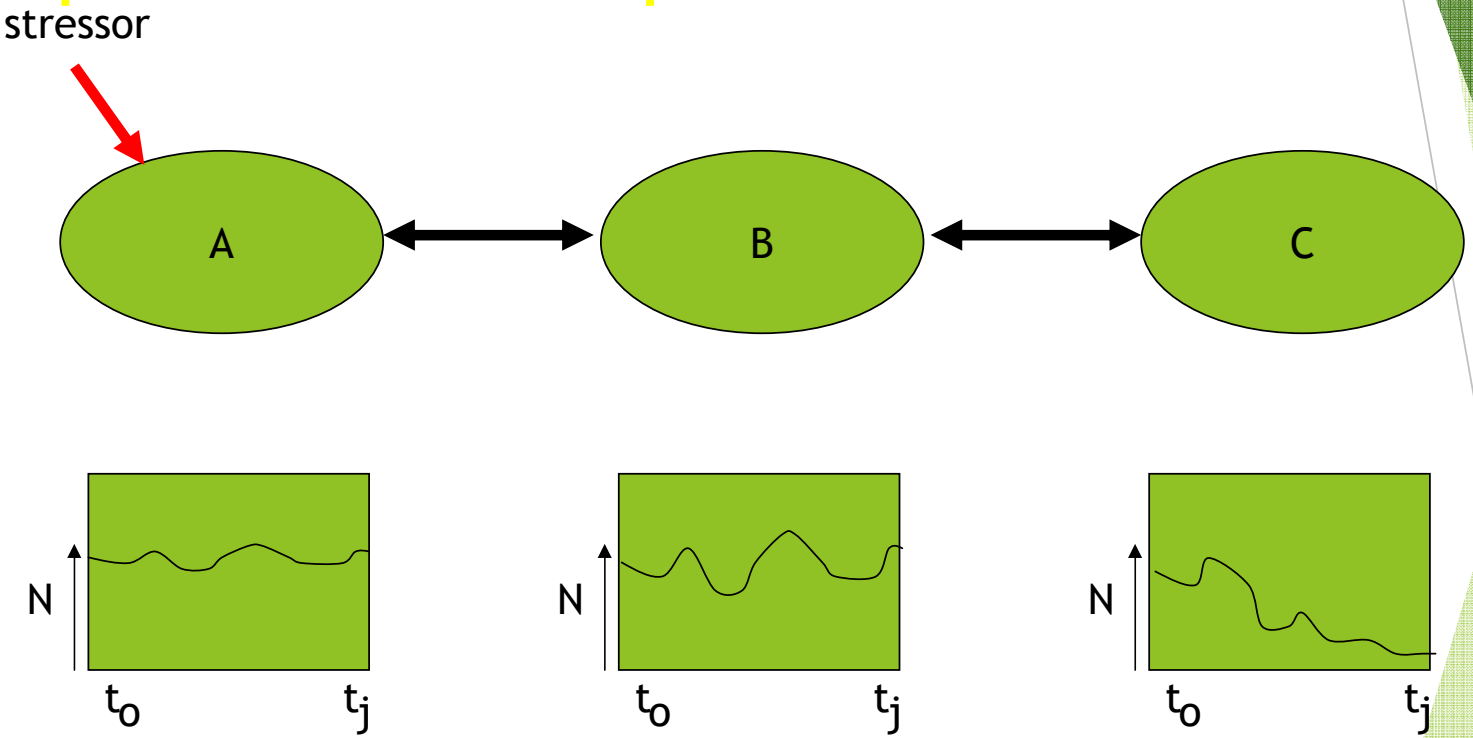
- (A) Stressor goes directly to entity (e.g., direct contact)
- (B) Stressor reaches entity indirectly (e.g., bioaccumulates in food)
- (C) Stressor impacts entity indirectly (e.g., loss of food causes starvation in entity; triggers disease)



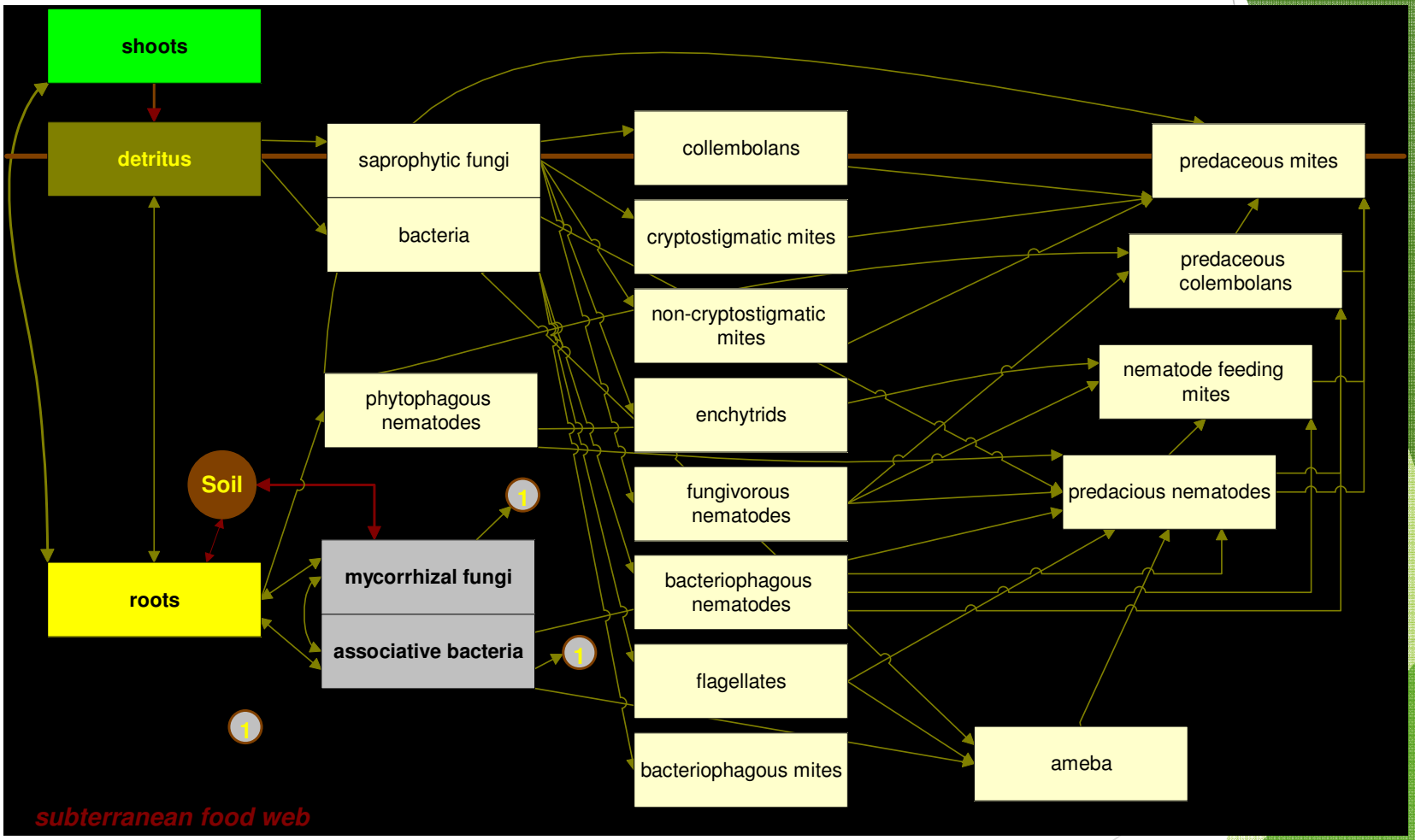
Metapopulations-level considerations

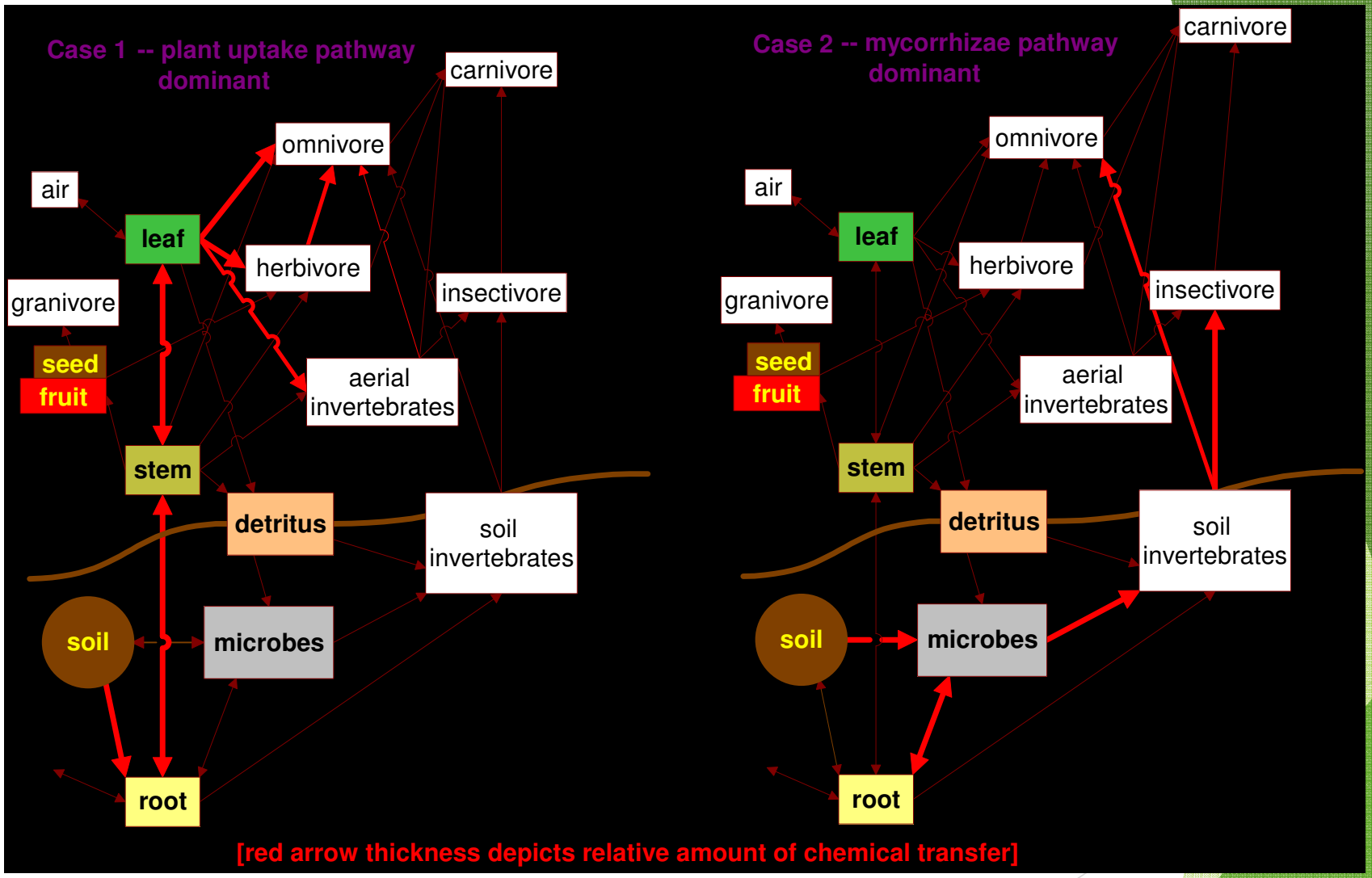


Metapopulation Consequences



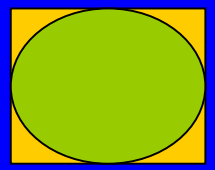
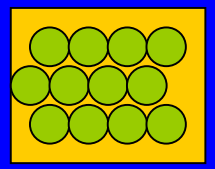
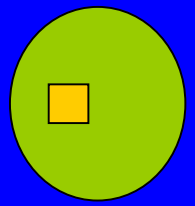
Adapted from:
Spromberg, J. A., B. M. Johns and W. G. Landis. 1998. Environ. Toxicol. Chem. 17:1640-1649
Macovsky, Louis-A Test of the Action at a Distance Hypothesis using Insect Metapopulations (Dr. Landis-Huxley College). 1999


shoots
detritus
saprophytic fungi
bacteria
phytophagous nematodes
Soil
roots
mycorrhizal fungi
associative bacteria
1
1
1
collembolans
cryptostigmatic mites
non-cryptostigmatic mites
enchytrids
fungivorous nematodes
bacteriophagous nematodes
flagellates
bacteriophagous mites
predaceous mites
predaceous colembolans
nematode feeding mites
predacious nematodes
ameba
subterranean food web

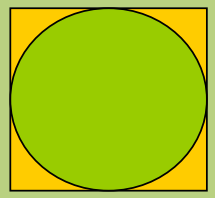
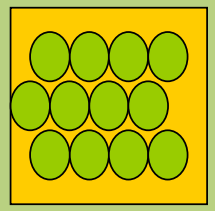
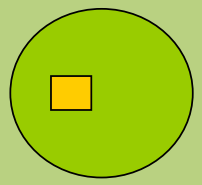

Case 1 -- plant uptake pathway dominant
carnivore
omnivore
air
leaf
herbivore
insectivore
granivore
seed
fruit
aerial invertebrates
stem
detritus
soil invertebrates
soil
microbes
root
Case 2 -- mycorrhizae pathway dominant
carnivore
omnivore
air
leaf
herbivore
insectivore
granivore
seed
fruit
aerial invertebrates
stem
detritus
soil invertebrates
soil
microbes
root
[red arrow thickness depicts relative amount of chemical transfer]

Strategy for Using Spatially-explicit Exposure Assessment

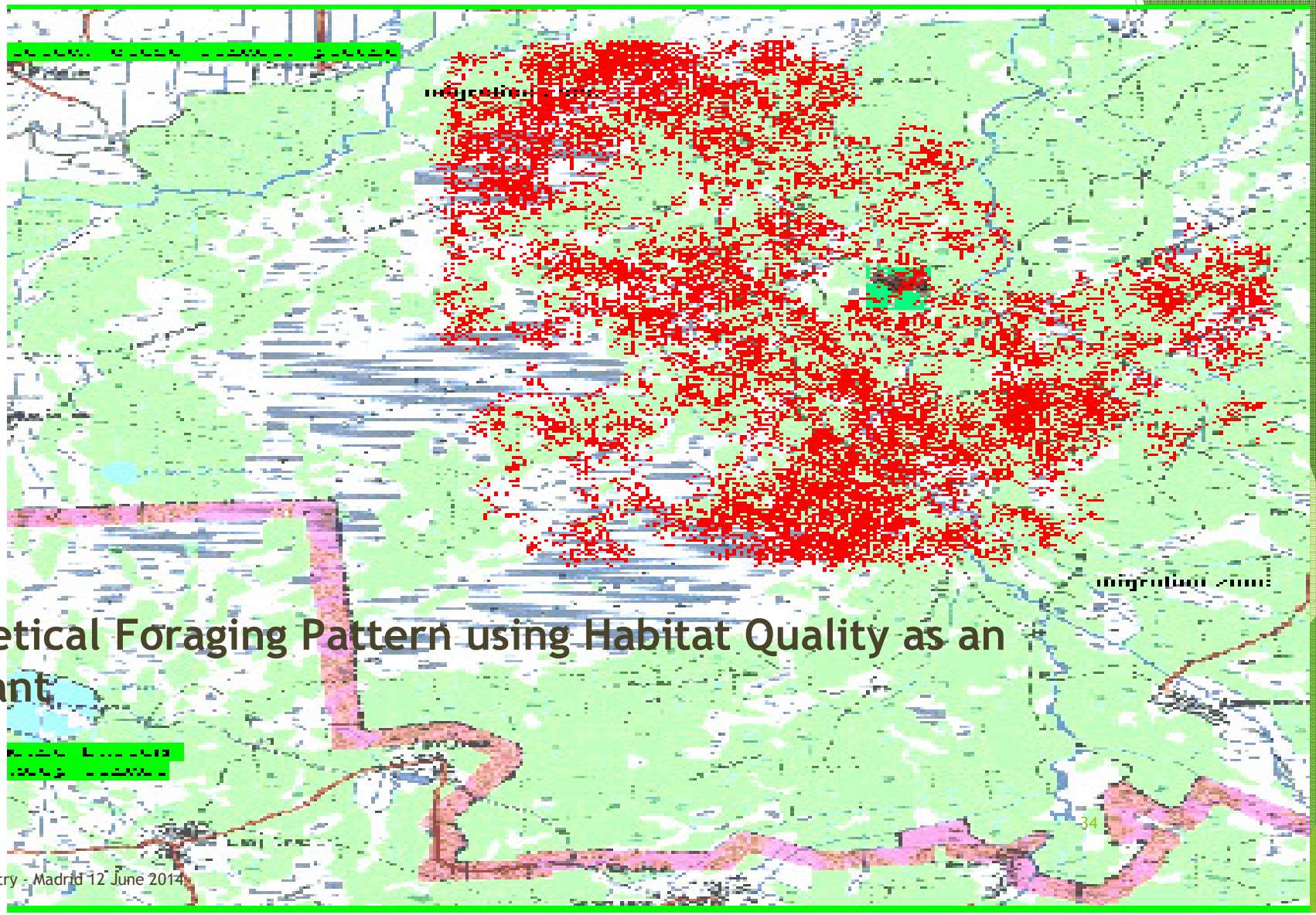
1. Identify scenarios where habitat maybe an important determinant
2. Considerations in selecting assessment species
   - Home/forage range
   - Available habitat suitability models
   - Reasonable knowledge of dietary preferences (e.g., EPA exposure handbook)
   - Expected to frequent the area (wildlife distribution information such as breeding bird survey)
3. Use habitat quality to weight exposure estimates
4. Develop a comprehensive workplan
   - staged from reconnaissance through definitive stages
   - connected to remediation goals and post-remediation monitoring effort

spatial relationship	habitat heterogeneous contamination homogeneous	habitat heterogeneous contamination heterogeneous	habitat homogeneous contamination heterogeneous	habitat homogeneous contamination homogeneous
Type 1 	1) Exposure to organisms is function of site mean contamination level. HSI weighting is not required.	2) Exposure to organism is not a function of site mean contamination level. HSI weighting is necessary.	3) Exposure to organism is function of site mean contamination level. HSI weighting is not required.	4) Exposure to organisms is function of site mean contamination level. HSI weighting is not required.
Type 2 	5) All individuals equally exposed. HSI weighting is not required.	6) All individuals not equally exposed. HSI weighting required to estimate exposure frequencies in population.	7) All individuals not equally exposed. HSI weighting required to estimate frequencies of exposure among population.	8) All individual equally exposed. HSI weighting is not required.
Type 3 	9) Exposure to organisms function of site contamination and relative habitat quality. HSI weighting necessary to estimate exposure frequency to individual.	10) Exposure to organisms function of site contamination and relative habitat quality. HSI weighting necessary to estimate exposure frequency to individual	11) Exposure to organisms function of contamination. HSI weighting is not required.	12) Exposure function of contamination. HSI weighting is not required.

Contingency table illustration relationships of home range (green circle) relative to site size (gold square) -- cases where habitat characterization may be useful in reducing uncertainty of exposure estimates (+) and cases where habitat considerations may be moot (O). (Adapted from Kapustka *et al.*, 2001).

spatial relationship habitat agent	homogeneous homogeneous	homogeneous heterogeneous	heterogeneous heterogeneous	heterogeneous homogeneous
	O	O	+	O
	O	+	+	O
	O	O	+	+

Hypothetical Foraging Pattern using Habitat Quality as an Attractant



conclusions

- Basic measures of landscapes (vegetation, physiognomy) used to parameterize HSI, HEA models.
  - quantify habitat quality by polygons
  - iterative calculations accumulate multiple HSIs for each polygon
  - GIS techniques used to identify zones or nodes of convergence of high-valued habitats
- Scale must be adjusted for each assessment species if one is to avoid the Fallacy of Averages and the Ecological Fallacy
- Traditional Risk estimates modified by HSI values.
- Hierarchical theory should be used to understand context and explore mechanisms
- Ecological problems are best viewed as wicked problems!

¡Buena suerte!