The role of soil microbiology in restoration

Cranfield UNIVERSITY

Professor Jim Harris

Department of Natural Resources

SER Europe Summer School September 2007

www.cranfield.ac.uk

Cranfield UNIVERSITY

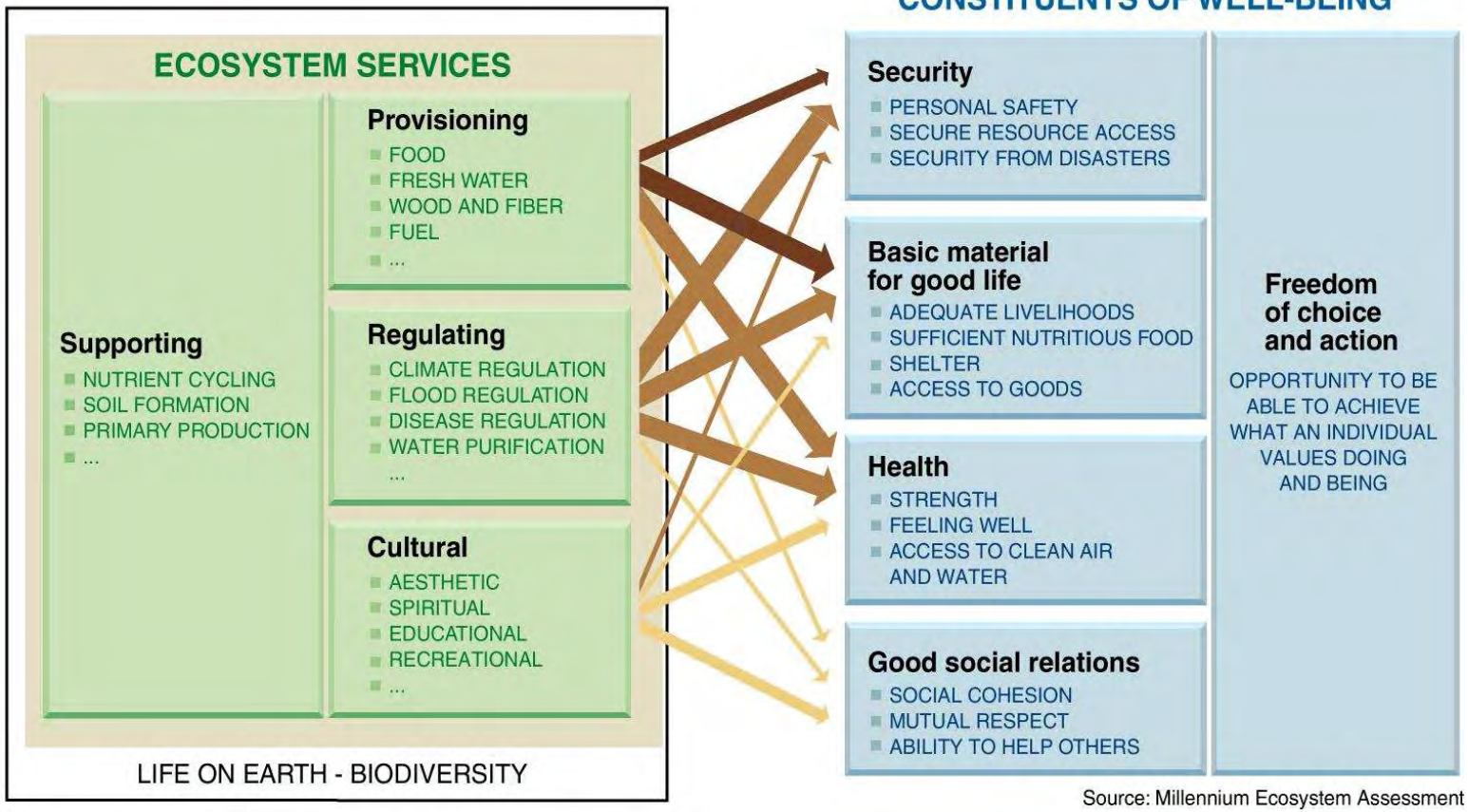
The Millennium Ecosystem Assessment

The Millennium Ecosystem Assessment

Cranfield UNIVERSITY

- 60% of world ecosystem services have been degraded
- Of 24 evaluated ecosystem types, 15 are being damaged
- About a quarter of the Earth's land surface is now cultivated.

Cranfield UNIVERSITY



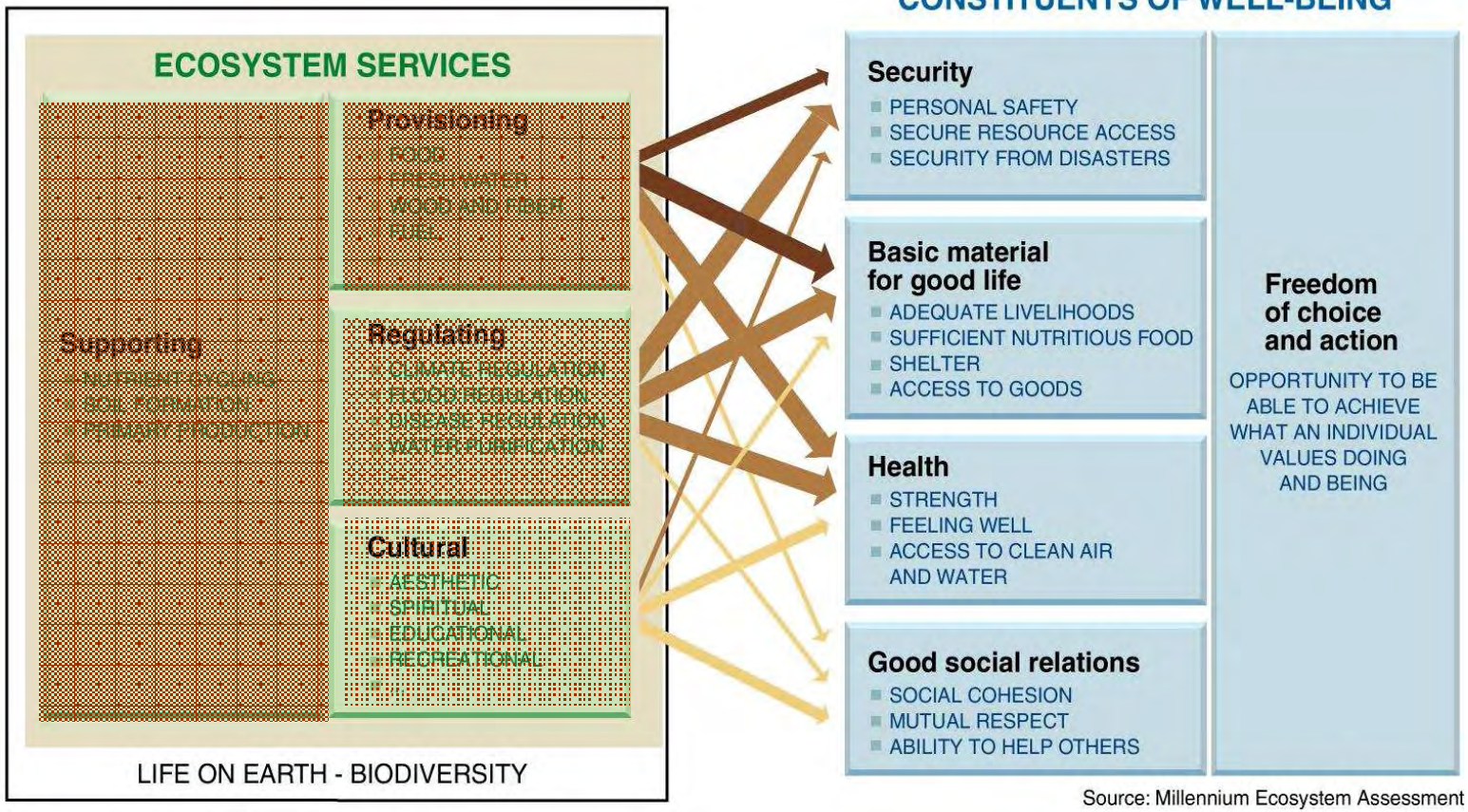
Source: Millennium Ecosystem Assessment

ARROW'S COLOR
Potential for mediation by socioeconomic factors

- Low
- Medium
- High

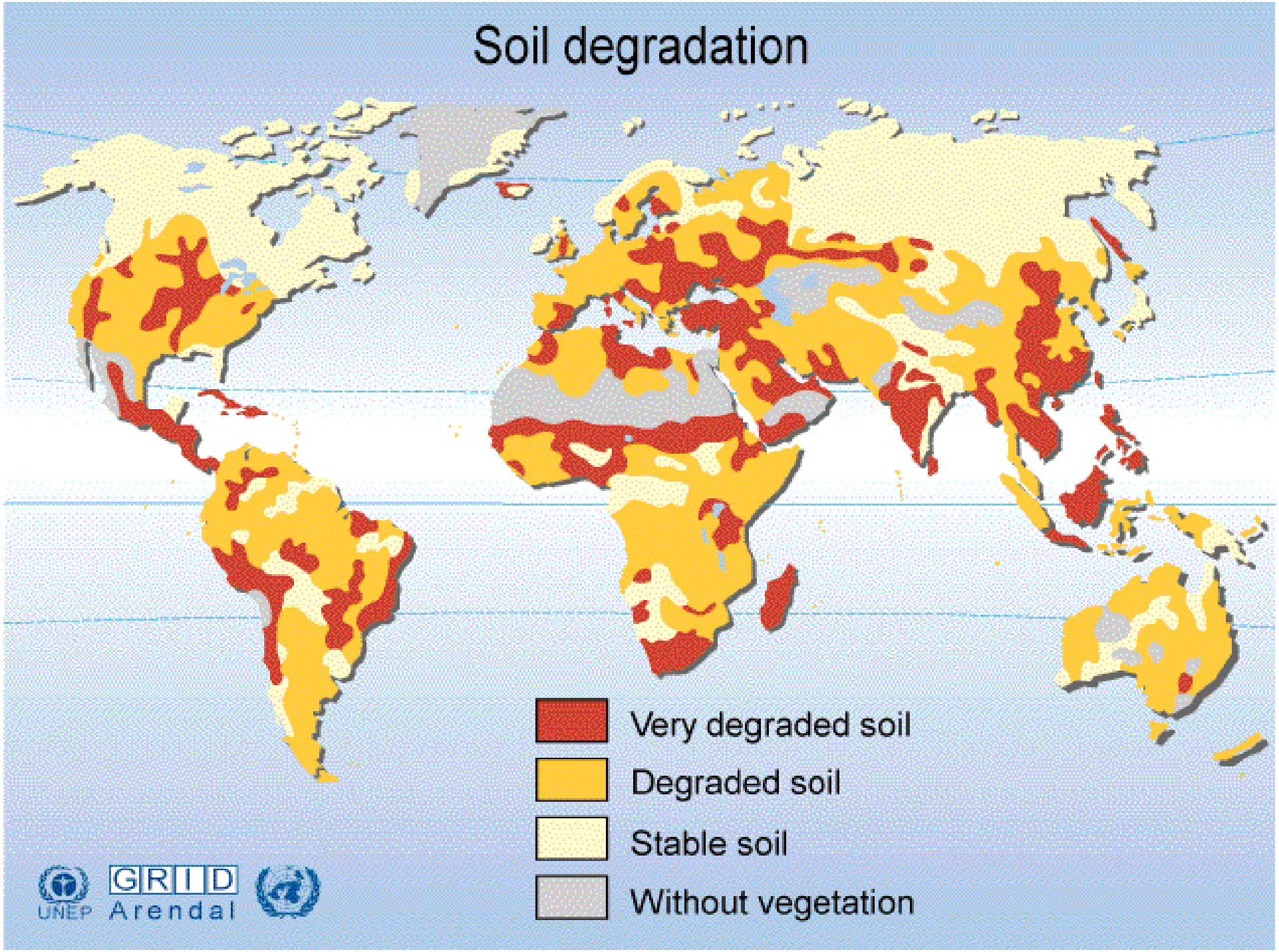
ARROW'S WIDTH
Intensity of linkages between ecosystem services and human well-being

- Weak
- Medium
- Strong



Source: Millennium Ecosystem Assessment

Soil-dependent ecosystem services


Soil degradation
Very degraded soil
Degraded soil
Stable soil
Without vegetation
UNEP
GRID
Arendal

Topsoil
Sub-soil
Overburden

Nine attributes of a restored ecosystem

Cranfield UNIVERSITY

1. Reference ecosystem, characteristic assemblages
2. Indigenous species, some exceptions
3. Functional groups present or available
4. Physical environment appropriate
5. Ecosystem functions normally for successional stage
6. Landscape integration, biotic and abiotic interactions
7. Potential threats eliminated
8. Resilience and integrity
9. Self-sustaining

Criteria for ecological indicators

- Easily measured
- Sensitive
- Respond predictably to stress
- Anticipatory
- Allow for adaptive management intervention
- Integrative
- Have known responses to stress, disturbances and time
- Low variability in response

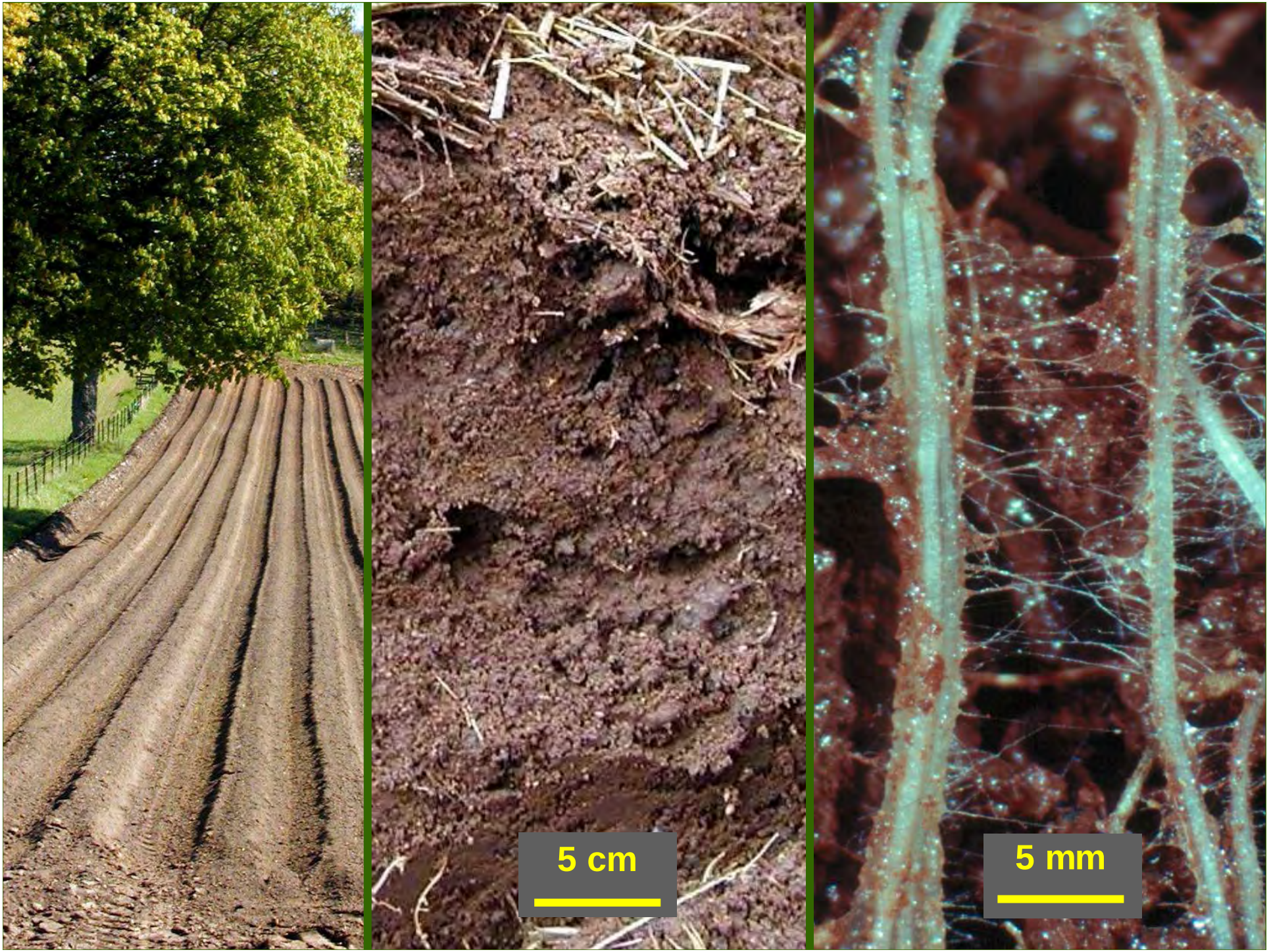
Derived from Dale and Beyeler 2001

A QUICK PRIMER ON LIFE IN EARTH

Cranfield UNIVERSITY

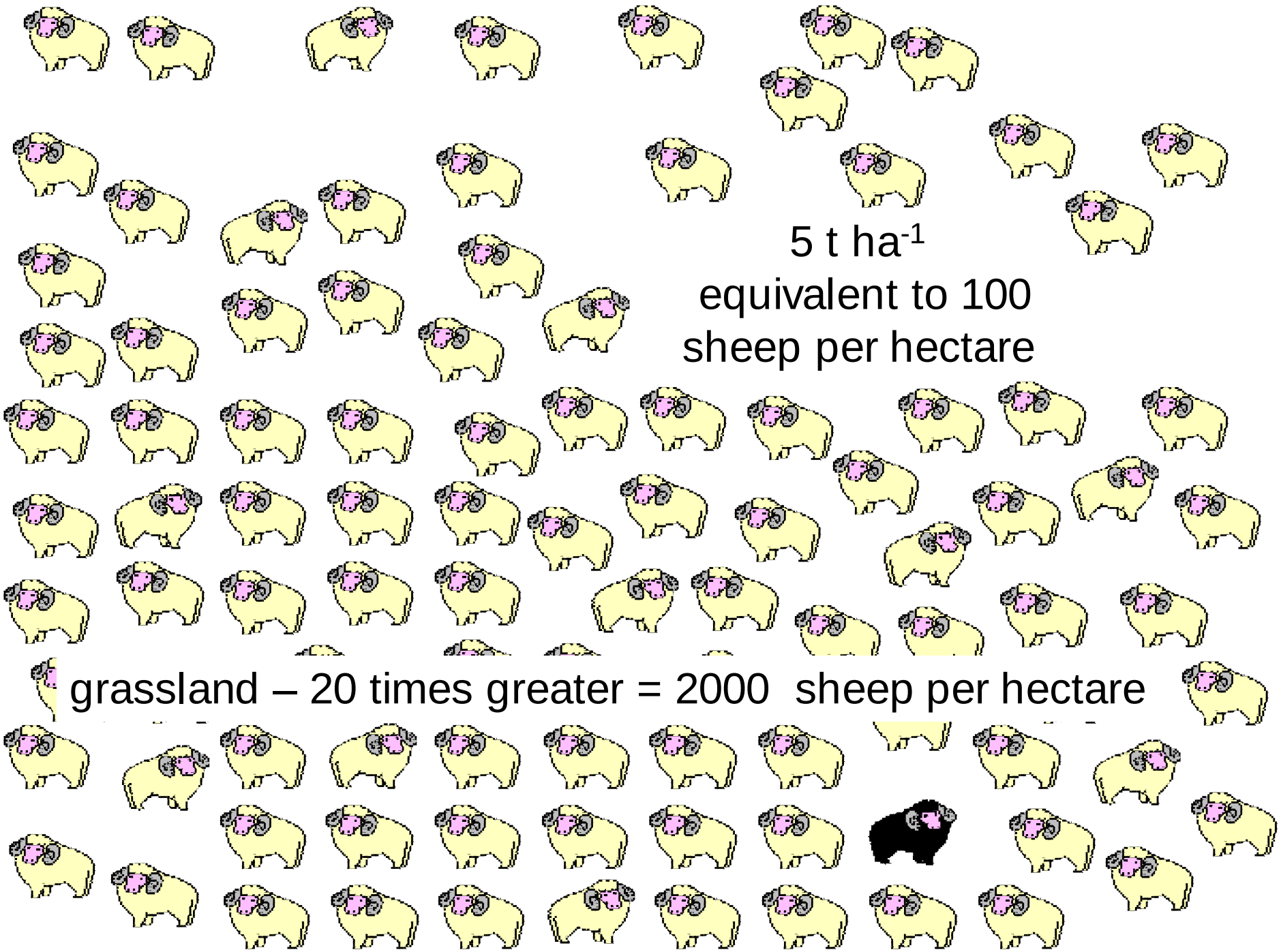
SERVICES PROVIDED BY SOILS

- Primary productivity
  - food and fibre production
  - diverse habitats
- Environmental services
  - filtering
  - buffering
  - transforming
- Biological habitat and biodiversity reserve
- Platform functions
- Landscape and heritage
- Source of raw materials


5 cm
5 mm

SOIL BIOMASS

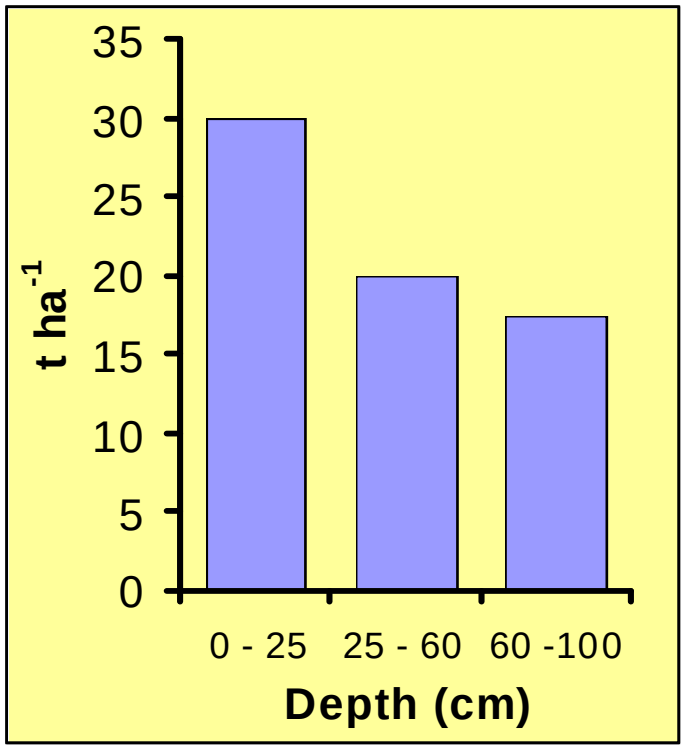
- Handful of arable soil (c. 200g)…..
- ….approximately 0.5 g of fresh biomass (mainly ‘microbial’)


5 t ha-1
equivalent to 100
sheep per hectare
grassland – 20 times greater = 2000 sheep per hectare

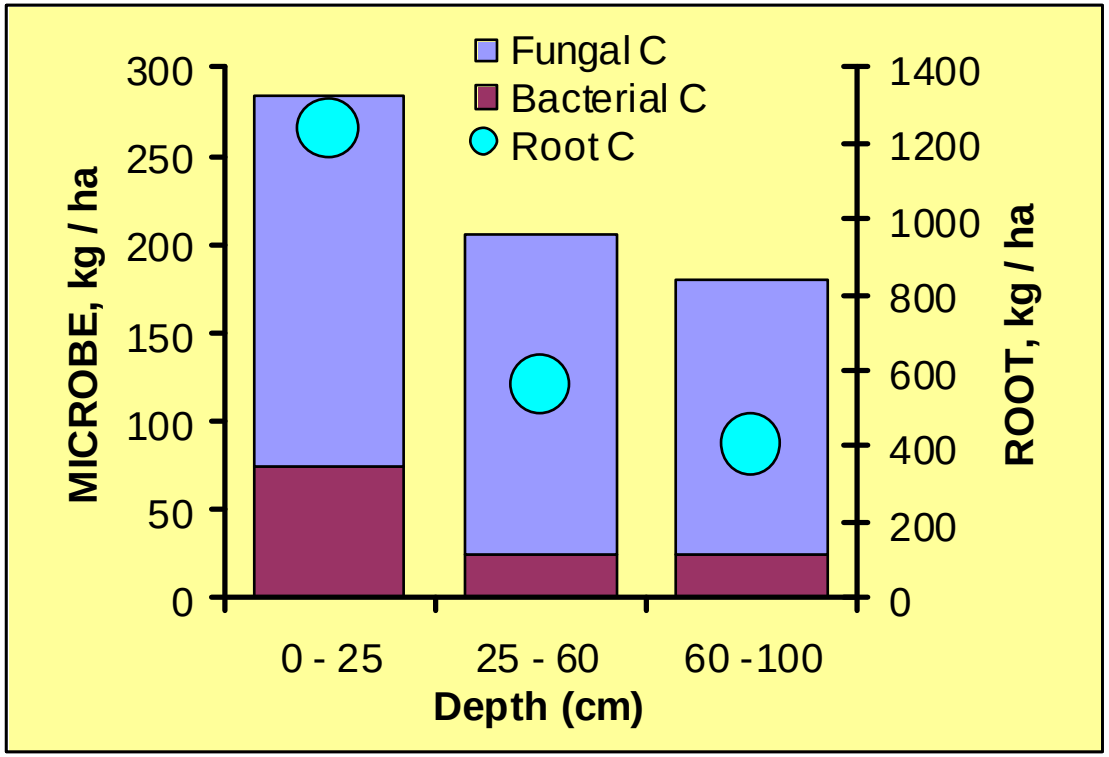
DISTRIBUTION WITHIN SOIL PROFILE

POPLAR PLANTATION (2-YEARS OLD)

TOTAL C

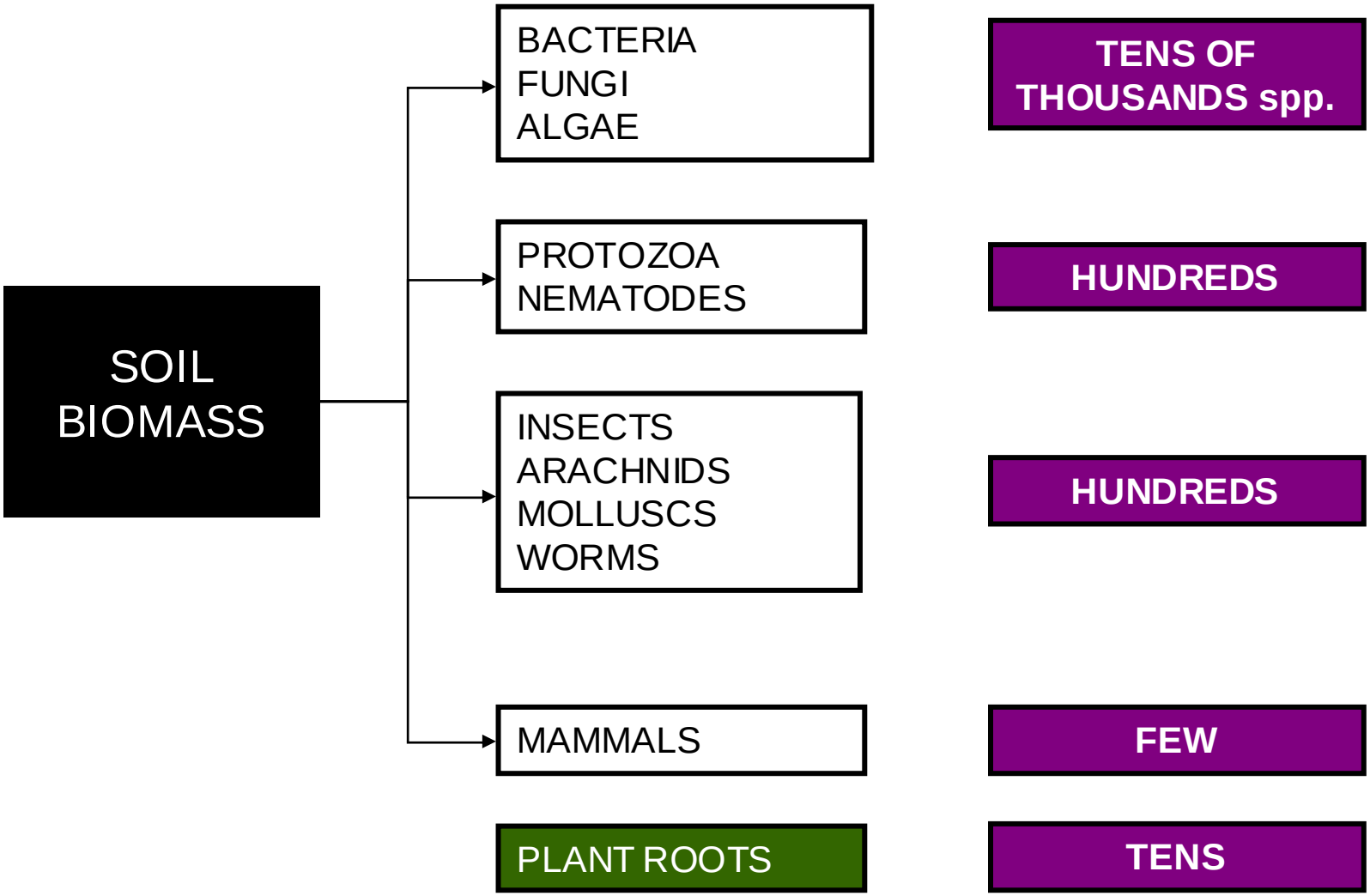


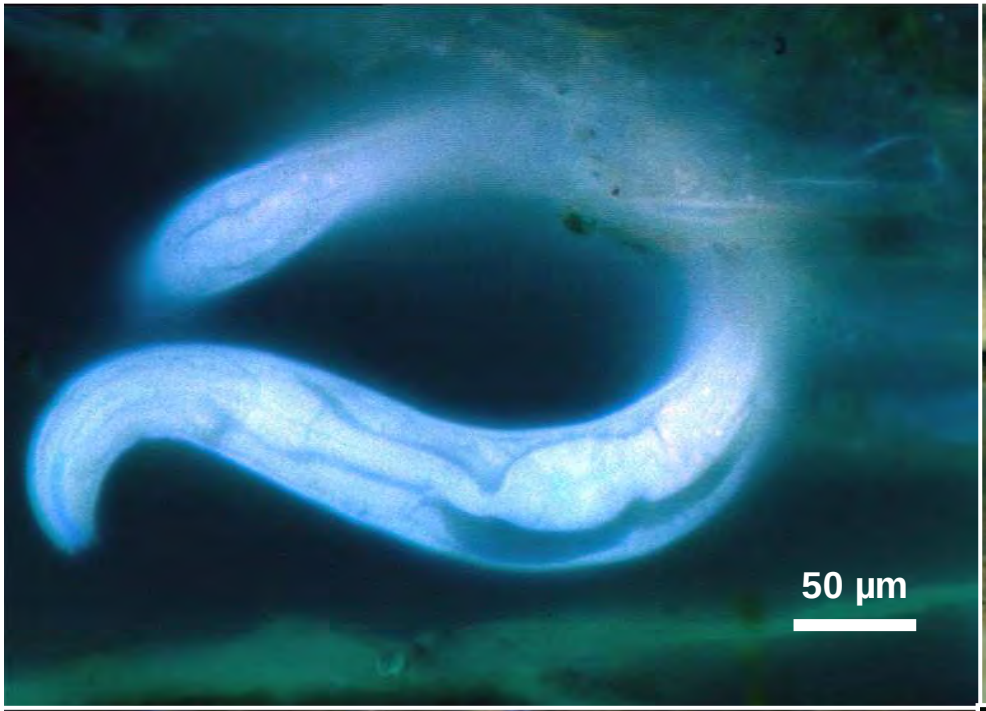
BIOLOGICAL C

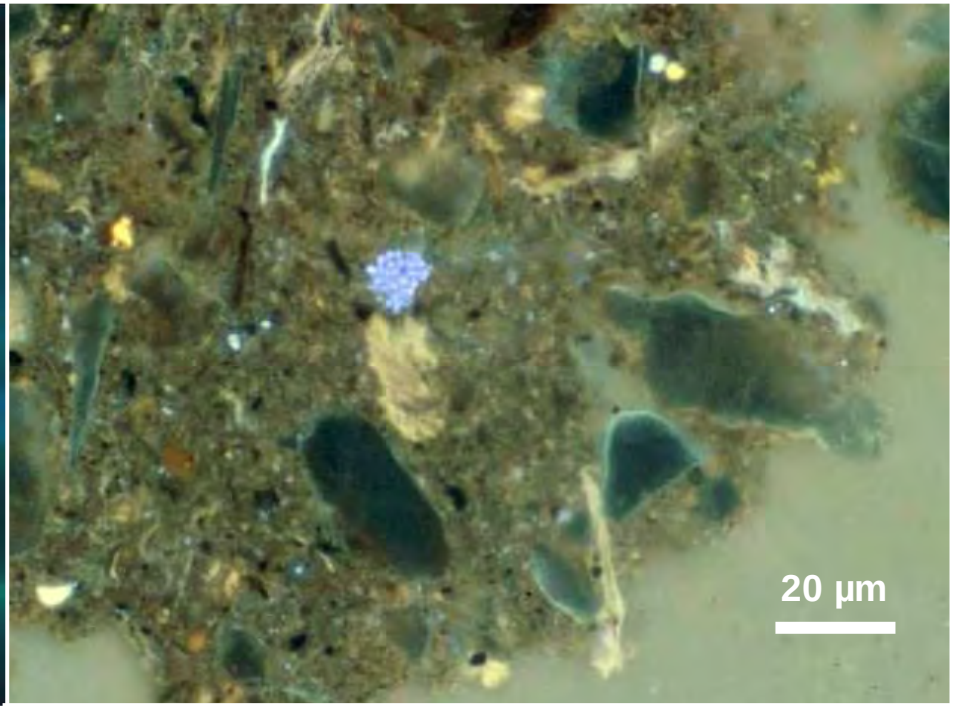


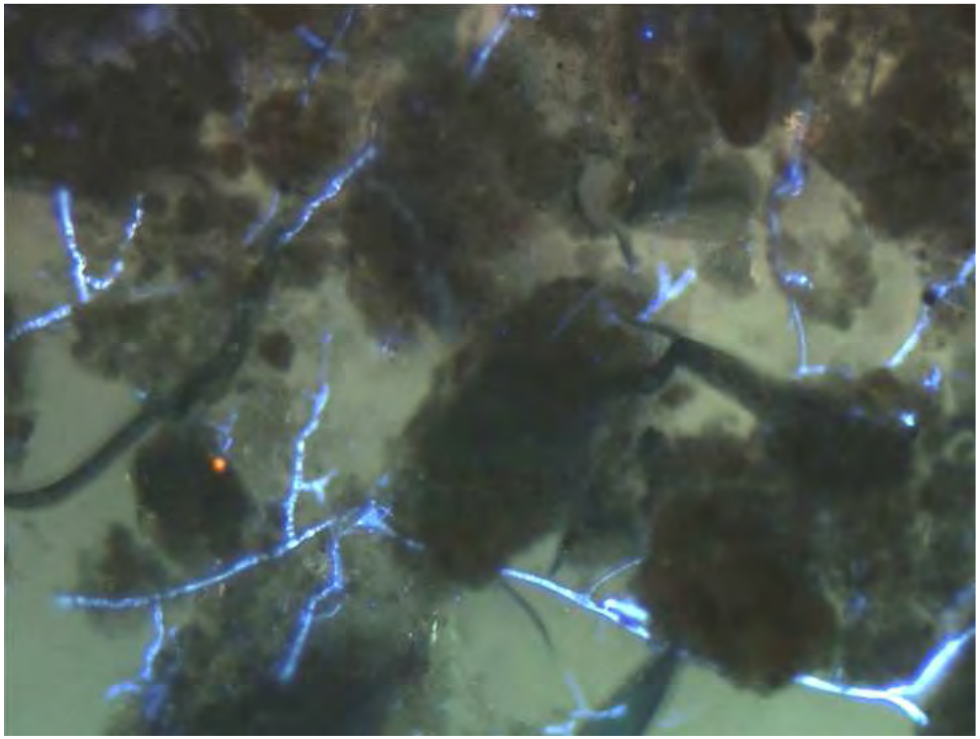
(Horwath, 1993, adapted from Paul and Clark, 199

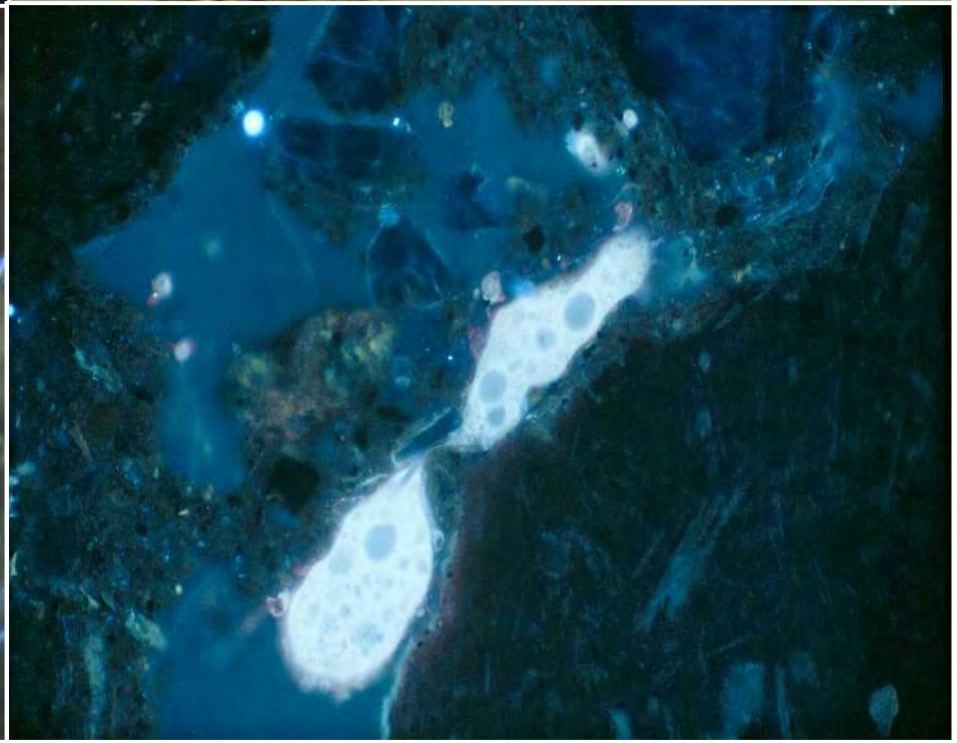
SOIL BIODIVERSITY

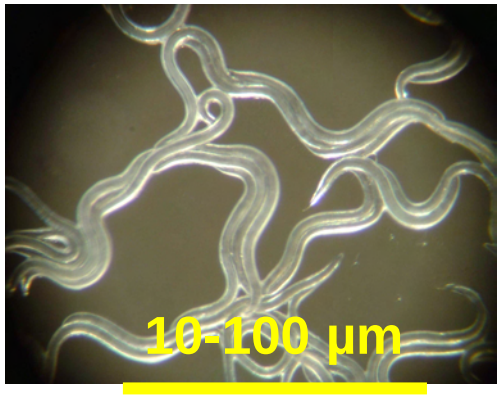


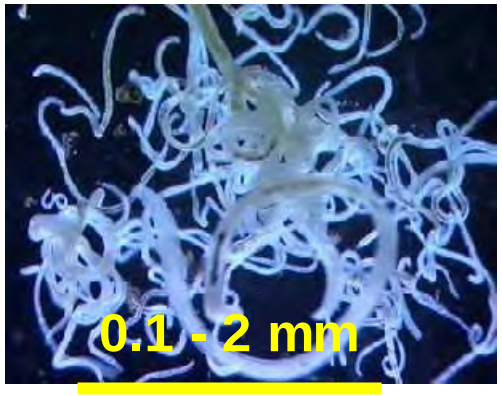

50 µm


20 µm



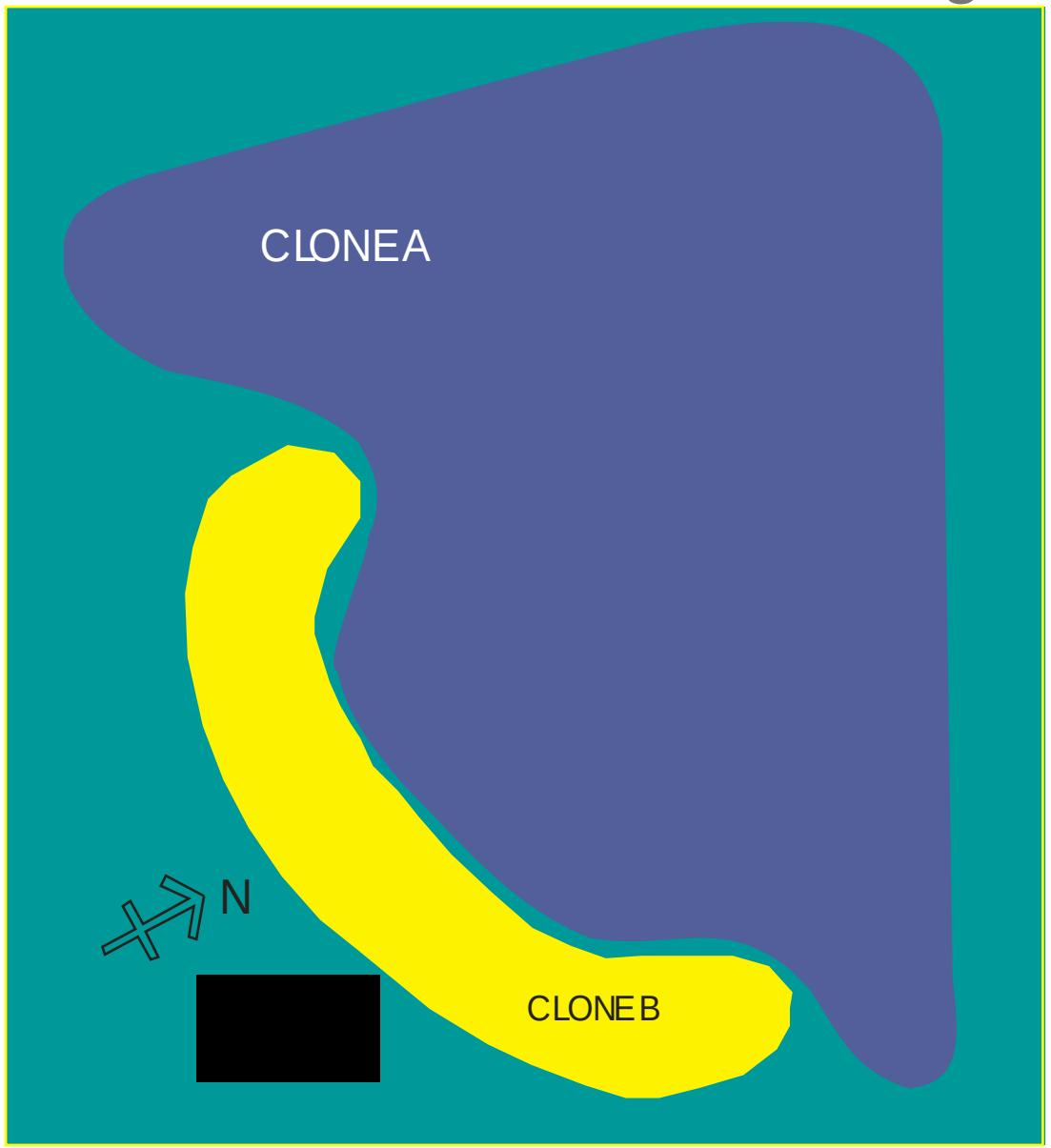


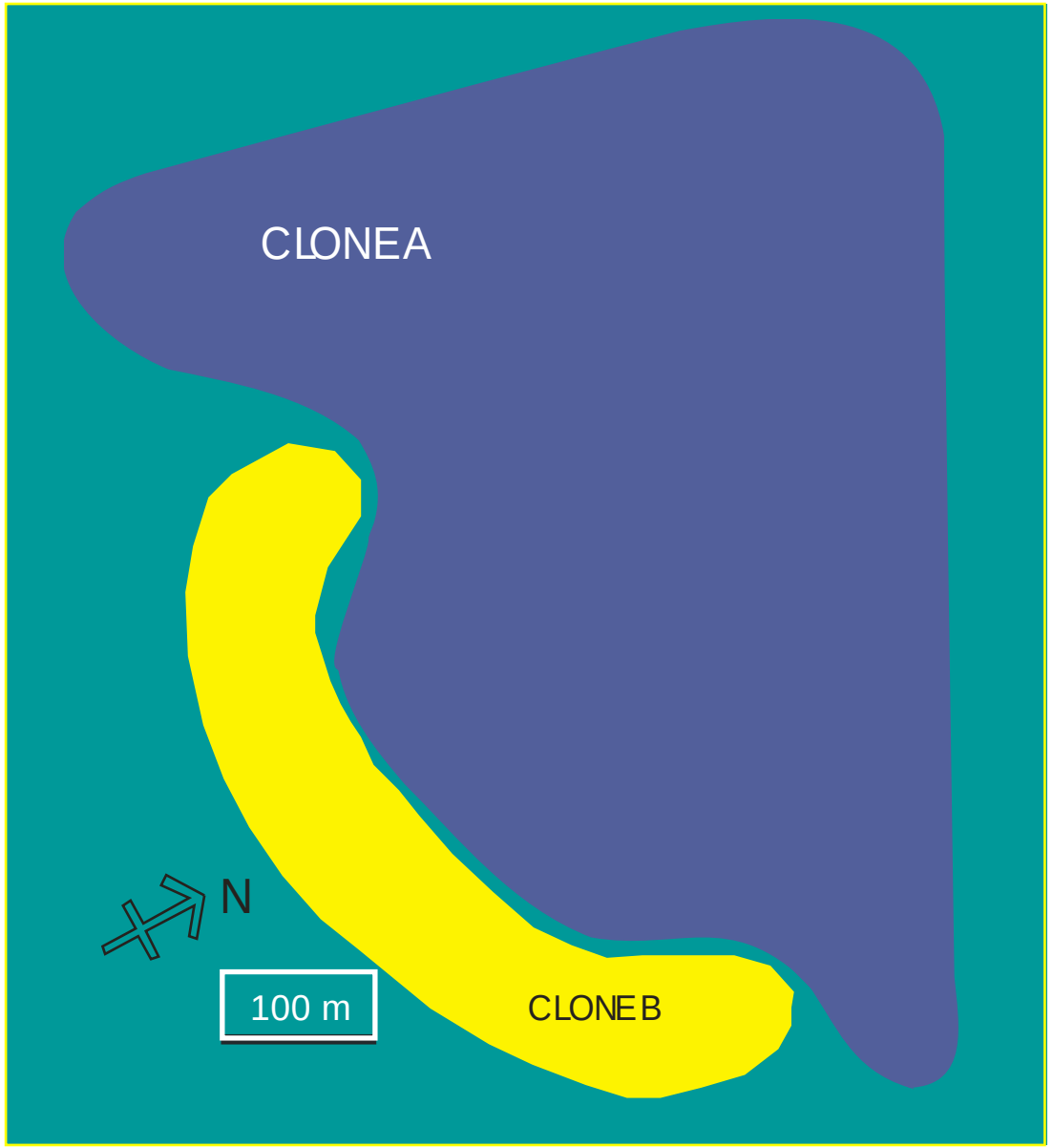

10-100 µm

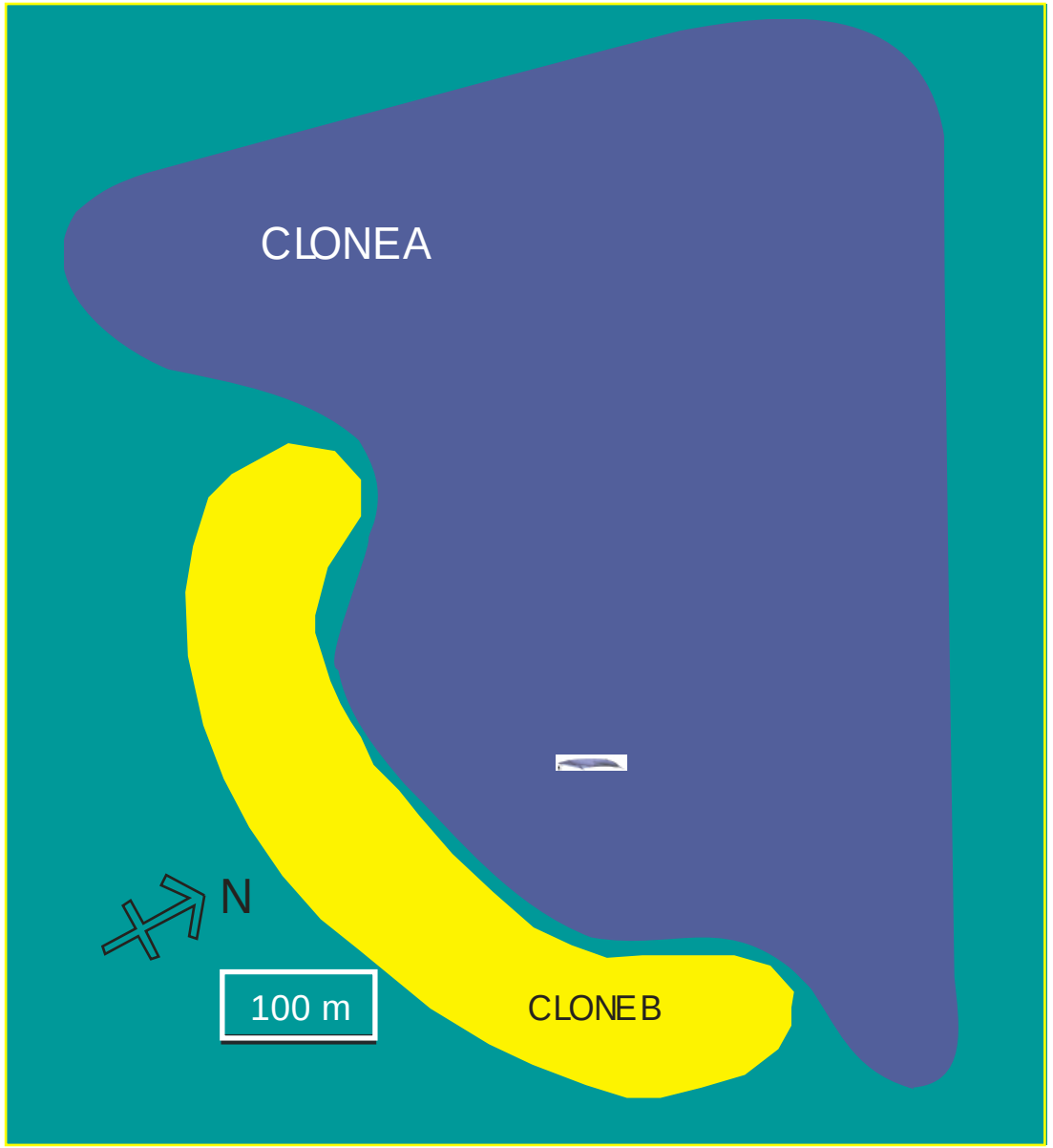

0.1 - 2 mm

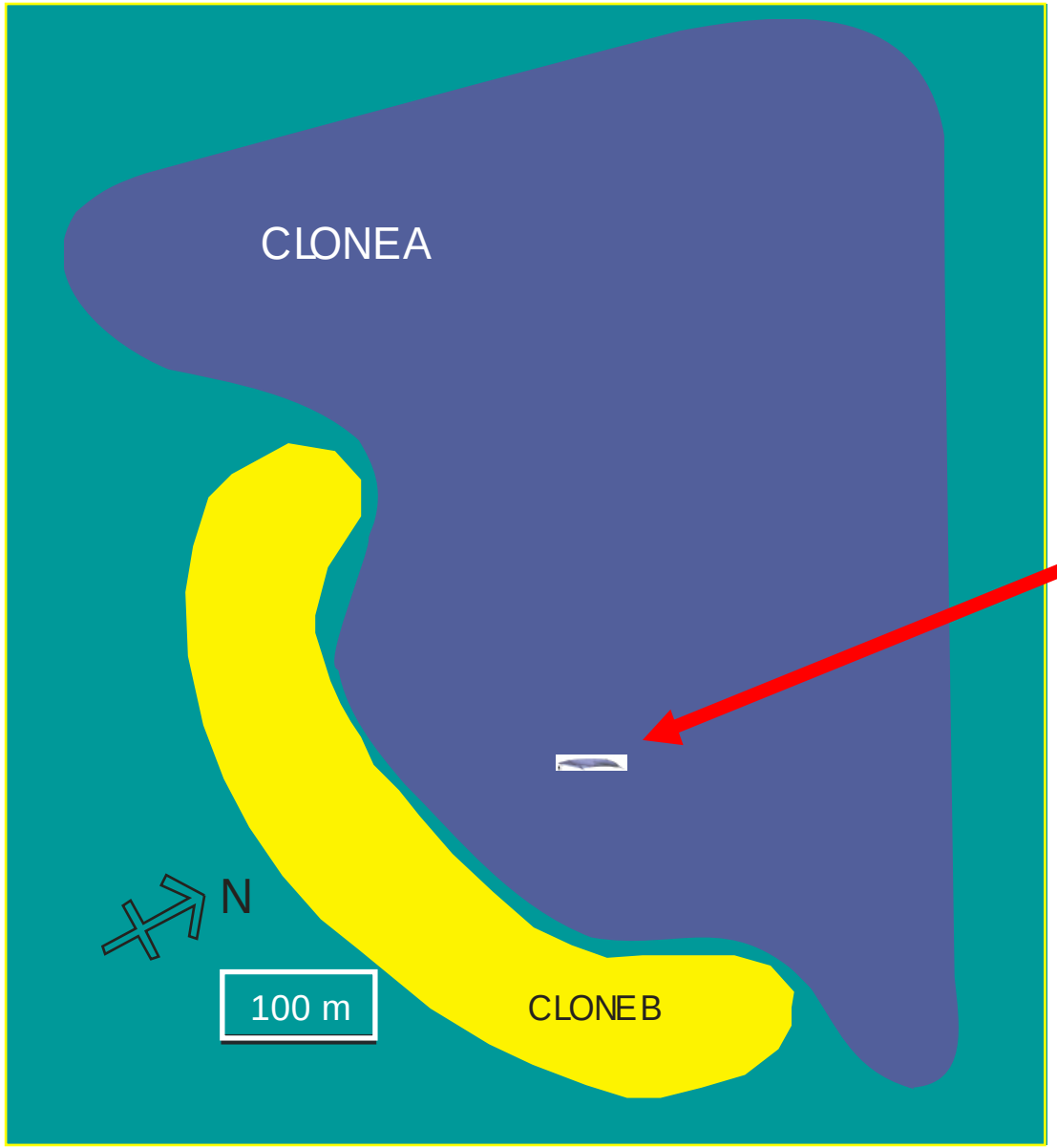
2-20 mm

MAP OF *Armillaria bulbosa* in Michigan forest




CLONE A
N
100 m
CLONE B

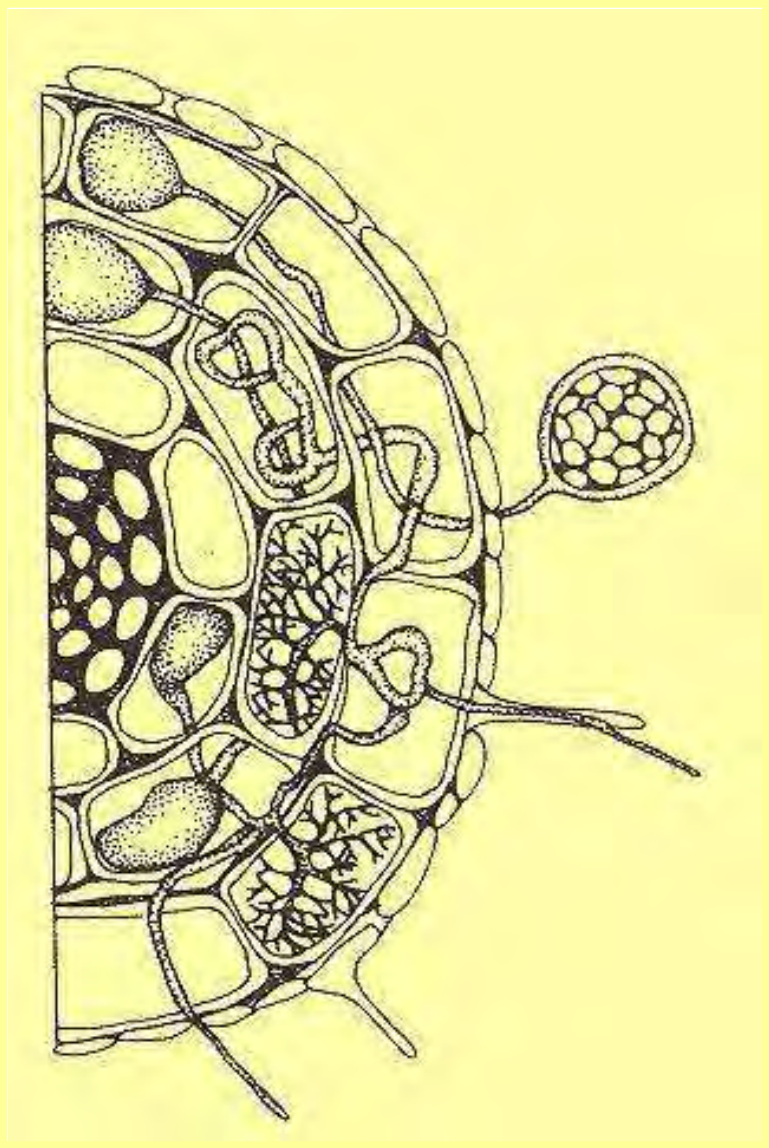

CLONE A
N
100 m
CLONE B

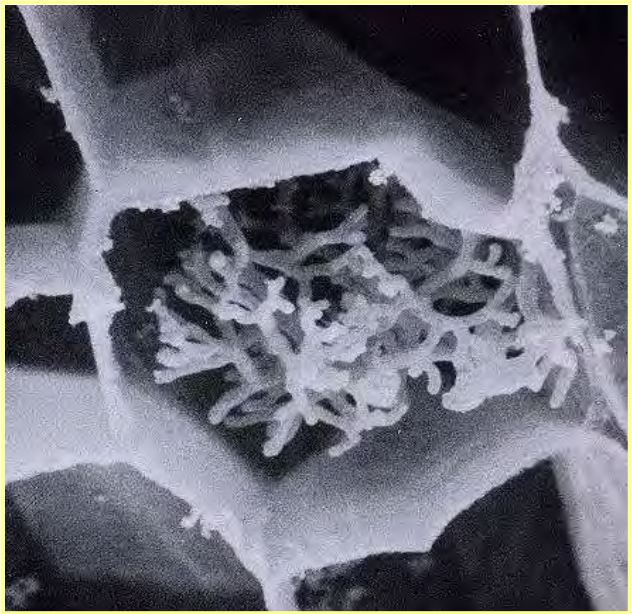


Blue Whale

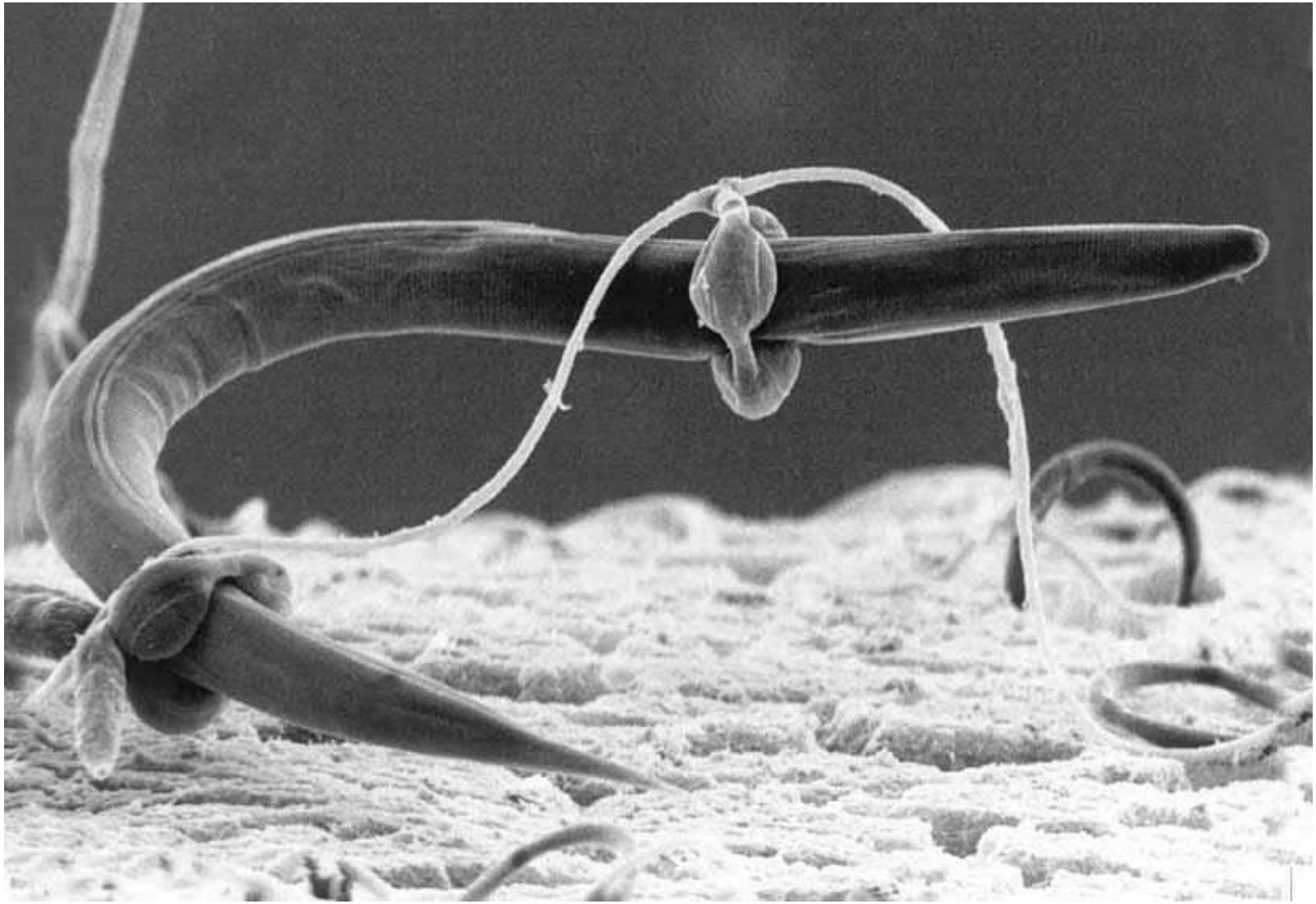
ARBUSCULAR MYCORRHIZAE

Cranfield UNIVERSITY



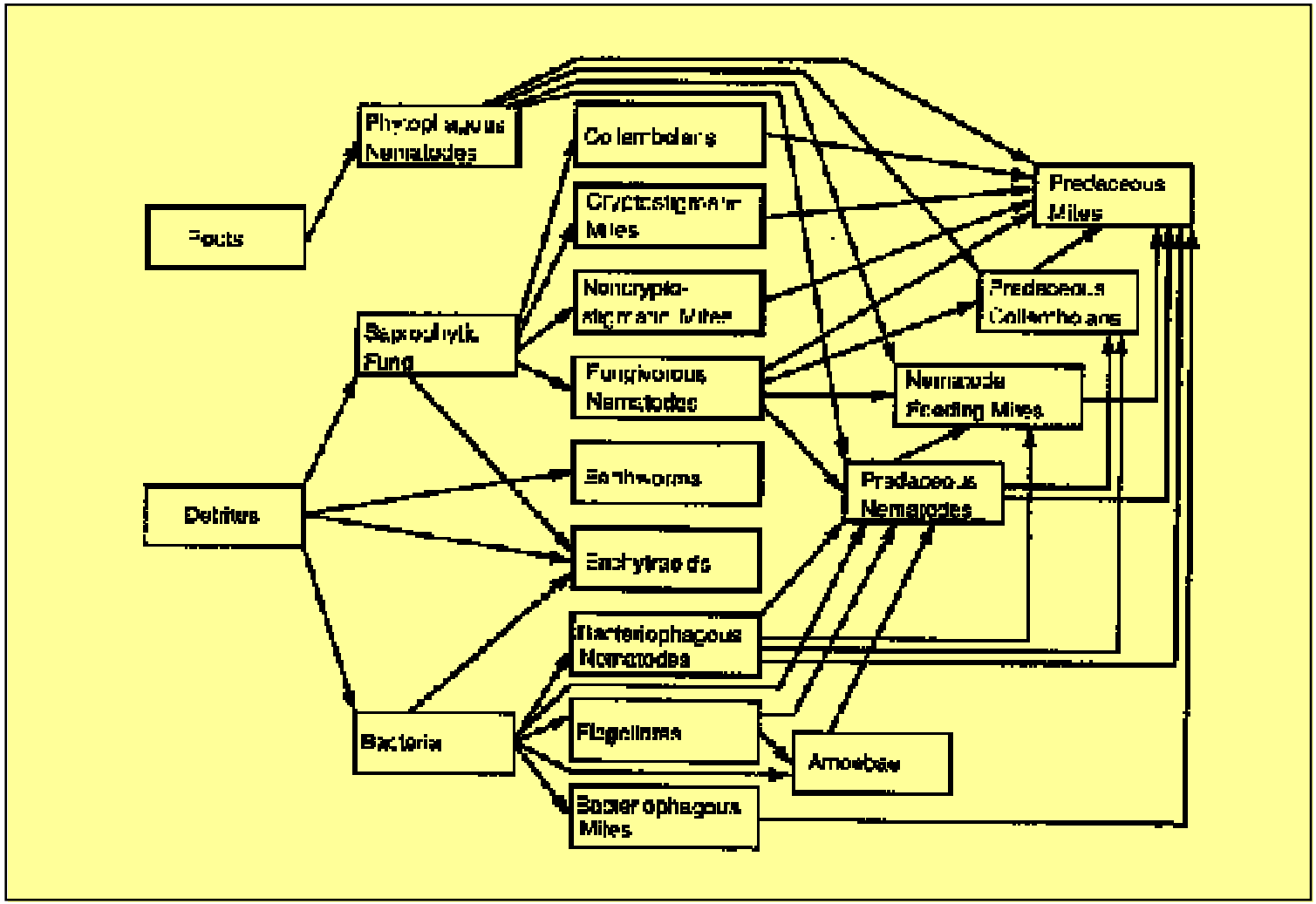


NEMATODE-TRAPPING FUNGI



Arthrobotrys anchonia

EXAMPLE OF SOIL FOOD WEB IN ARABLE SOIL



de Ruiter, Moore et al. 1993; Journal of Applied Ecology 30, 95-106

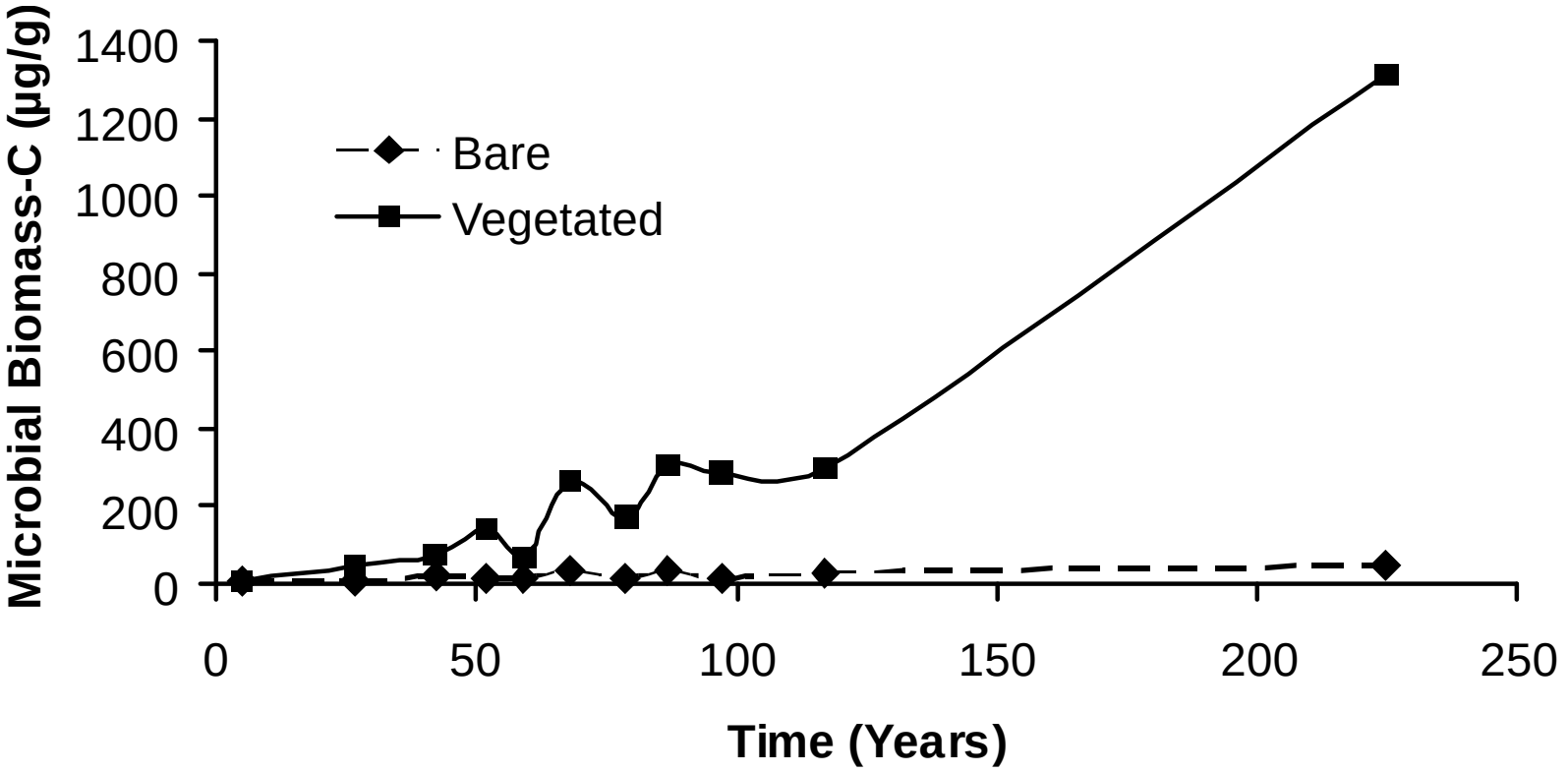
What can we measure?

- **Size**
- **Composition**
- **Activity**

Cranfield UNIVERSITY

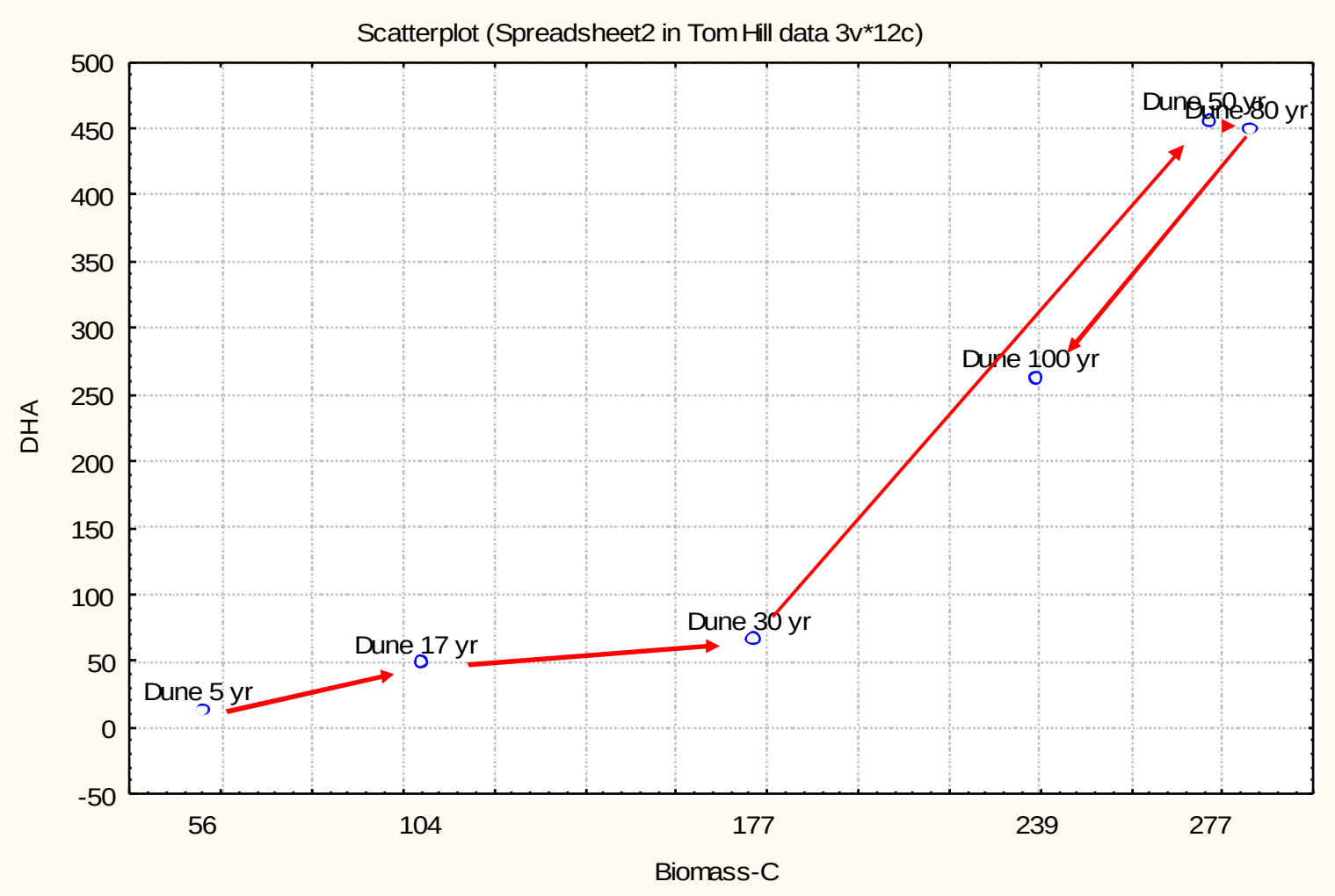
Community Size and Gross Activity

Change in Biomass-C with time

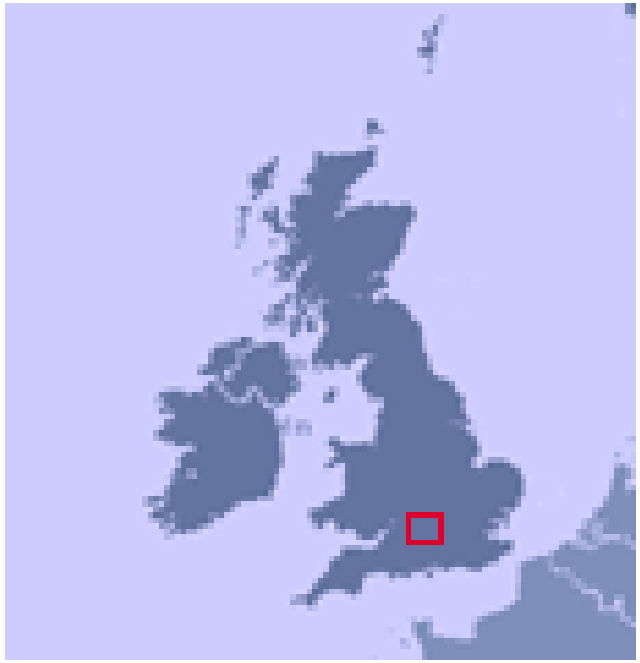


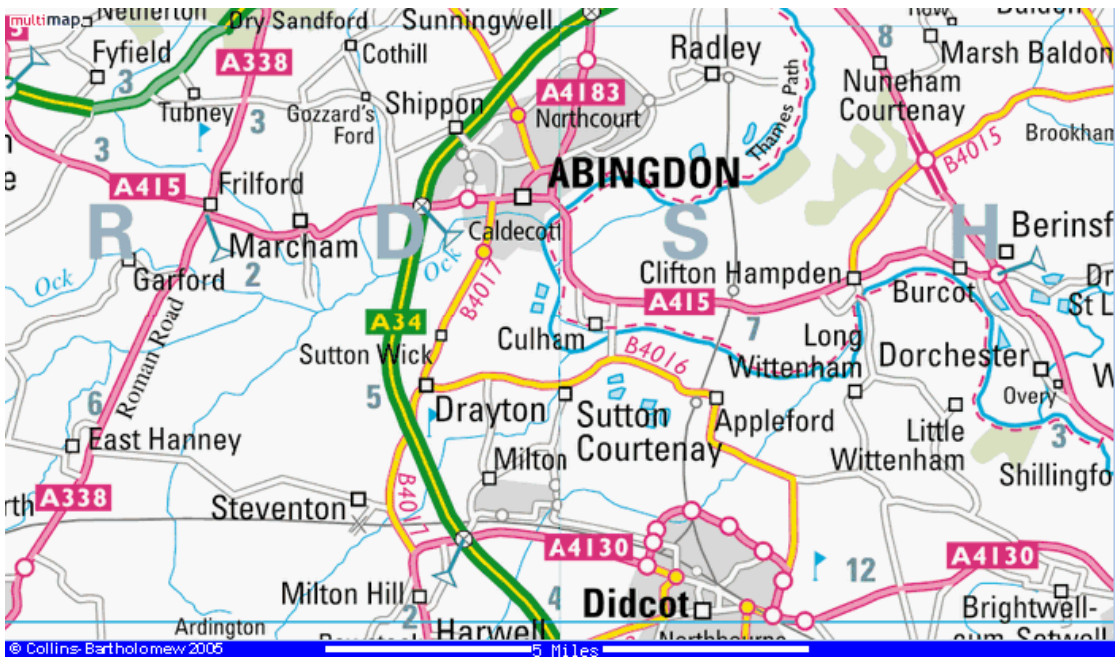
(redrawn from Insam and Domsch, 1989)

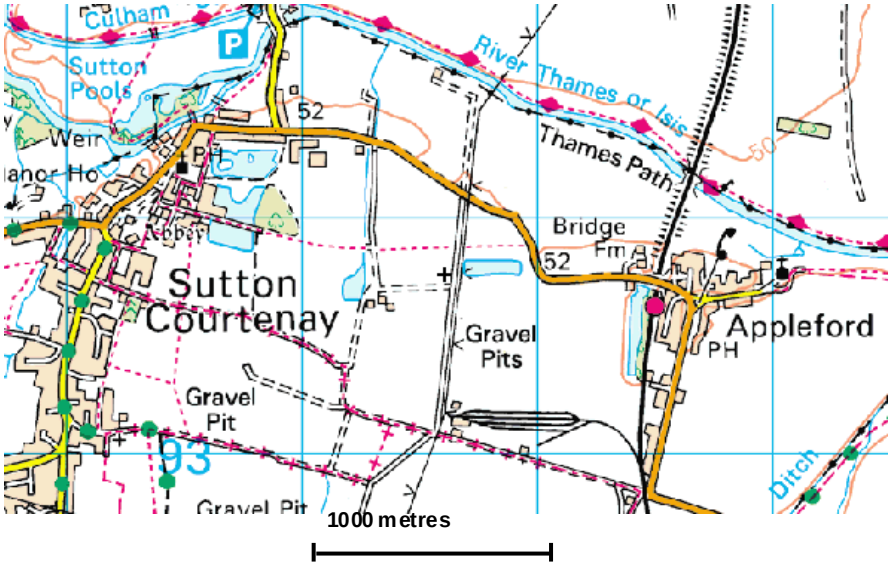
Microbial Community Size and Activity



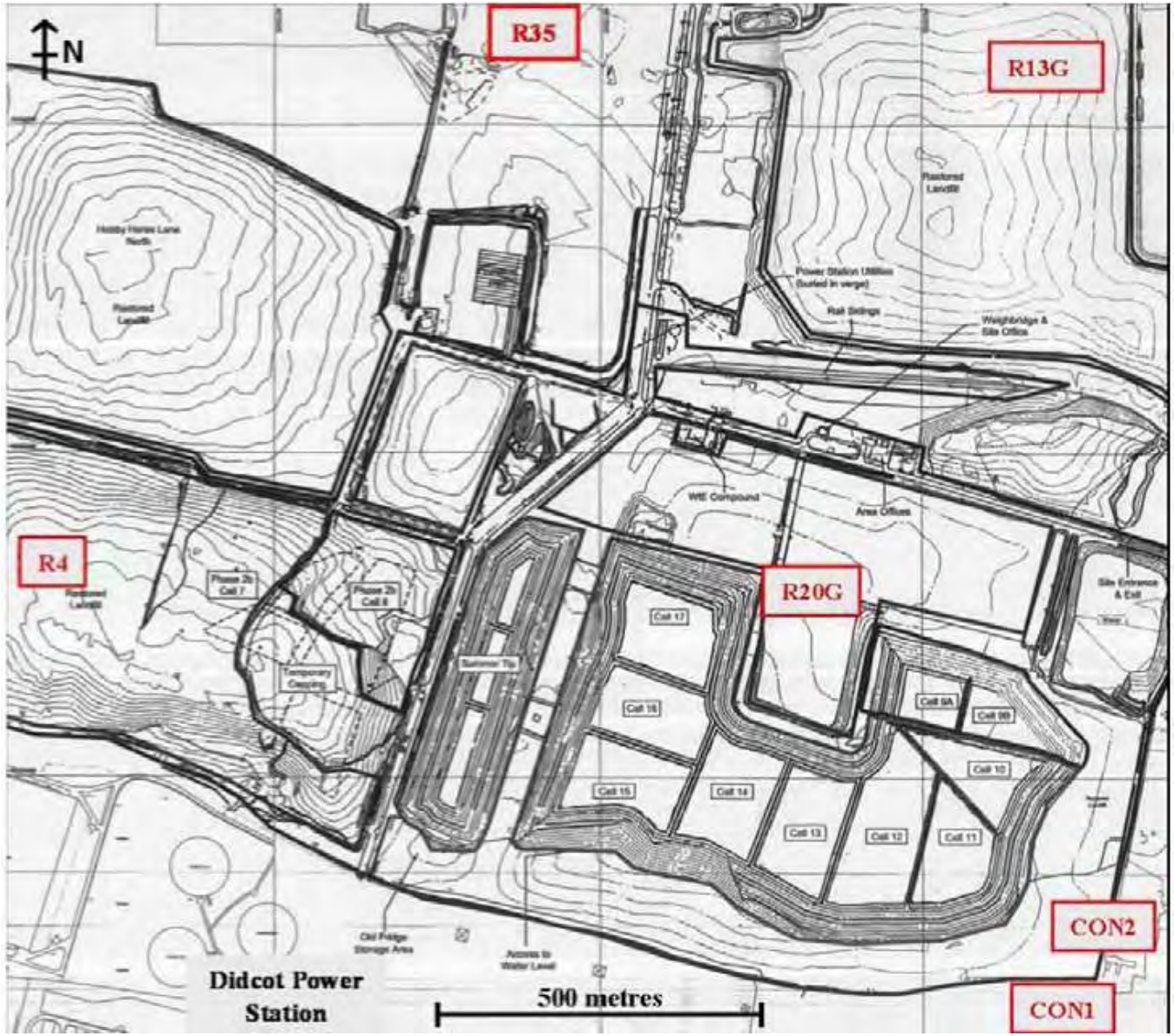
Adapted from Hill, 1995

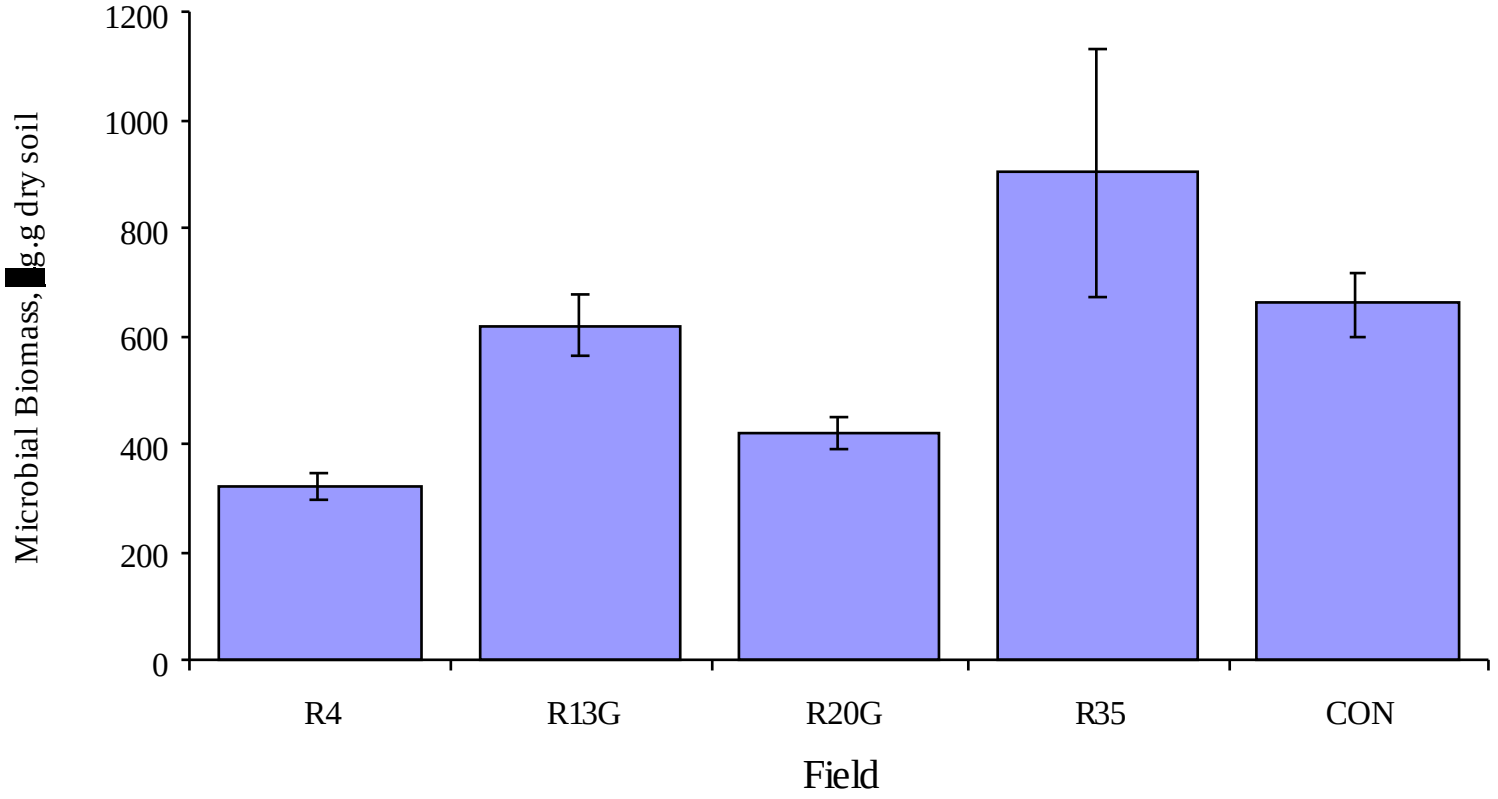




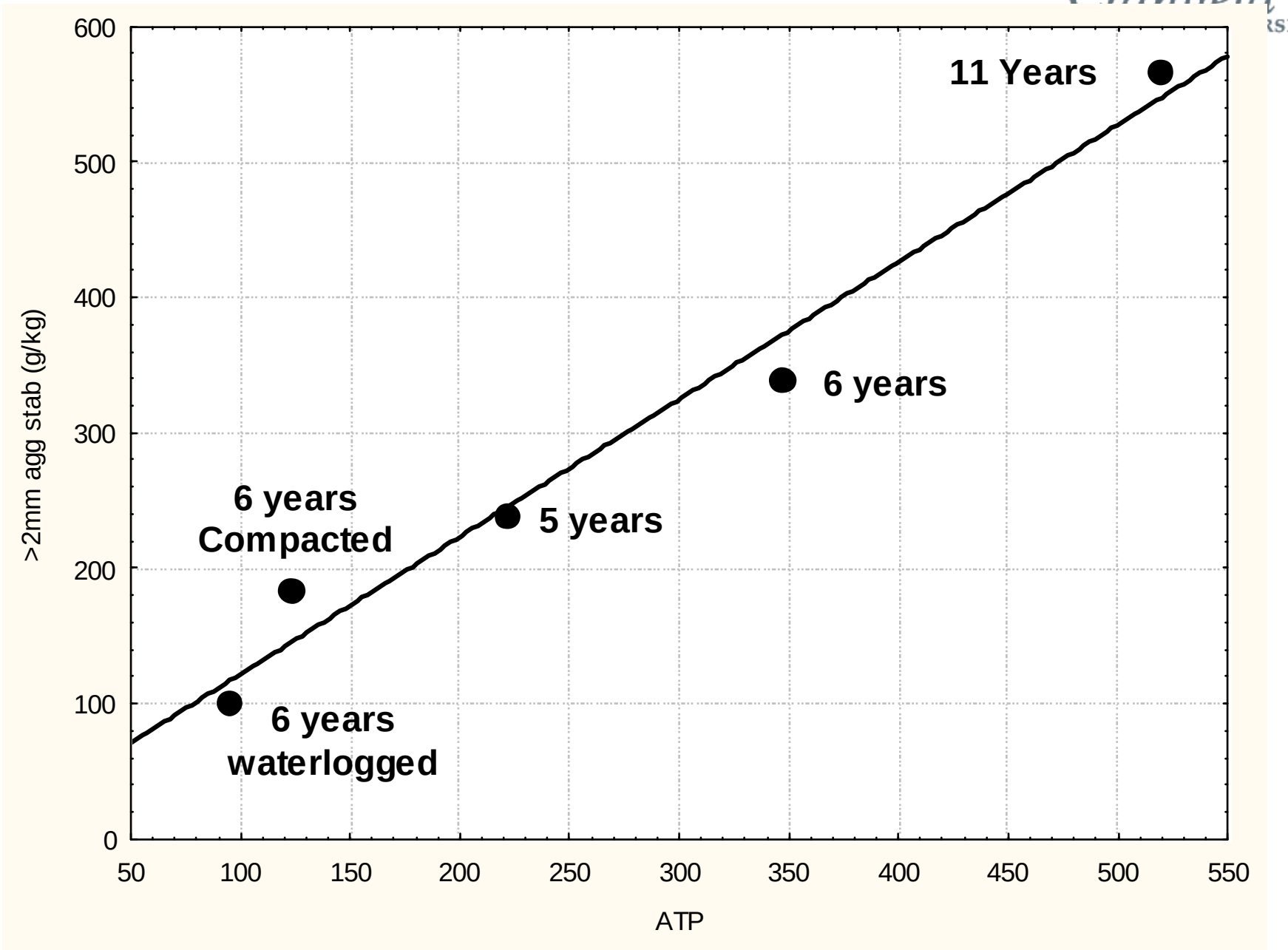


Location of Sutton Courtenay landfill site.

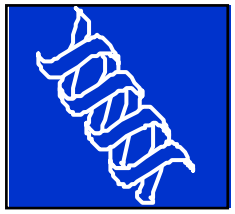

N
R35
R13G
R4
R20G
CON2
CON1
Didcot Power Station
500 metres



Microbial Biomass results from each sample area. The bars show standard error (n=3).

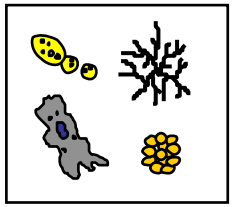

>2mm agg stab (g/kg)
600
500
400
300
200
100
0
50
100
150
200
250
300
350
400
450
500
550
ATP
11 Years
6 years
5 years
6 years
Compacted
6 years
waterlogged

CHARACTERISING BIODIVERSITY



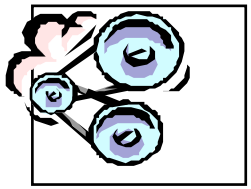
GENOTYPIC

- fundamental information – the blueprint



PHENOTYPIC

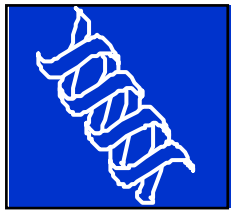
- expressed information – the parts



FUNCTIONAL

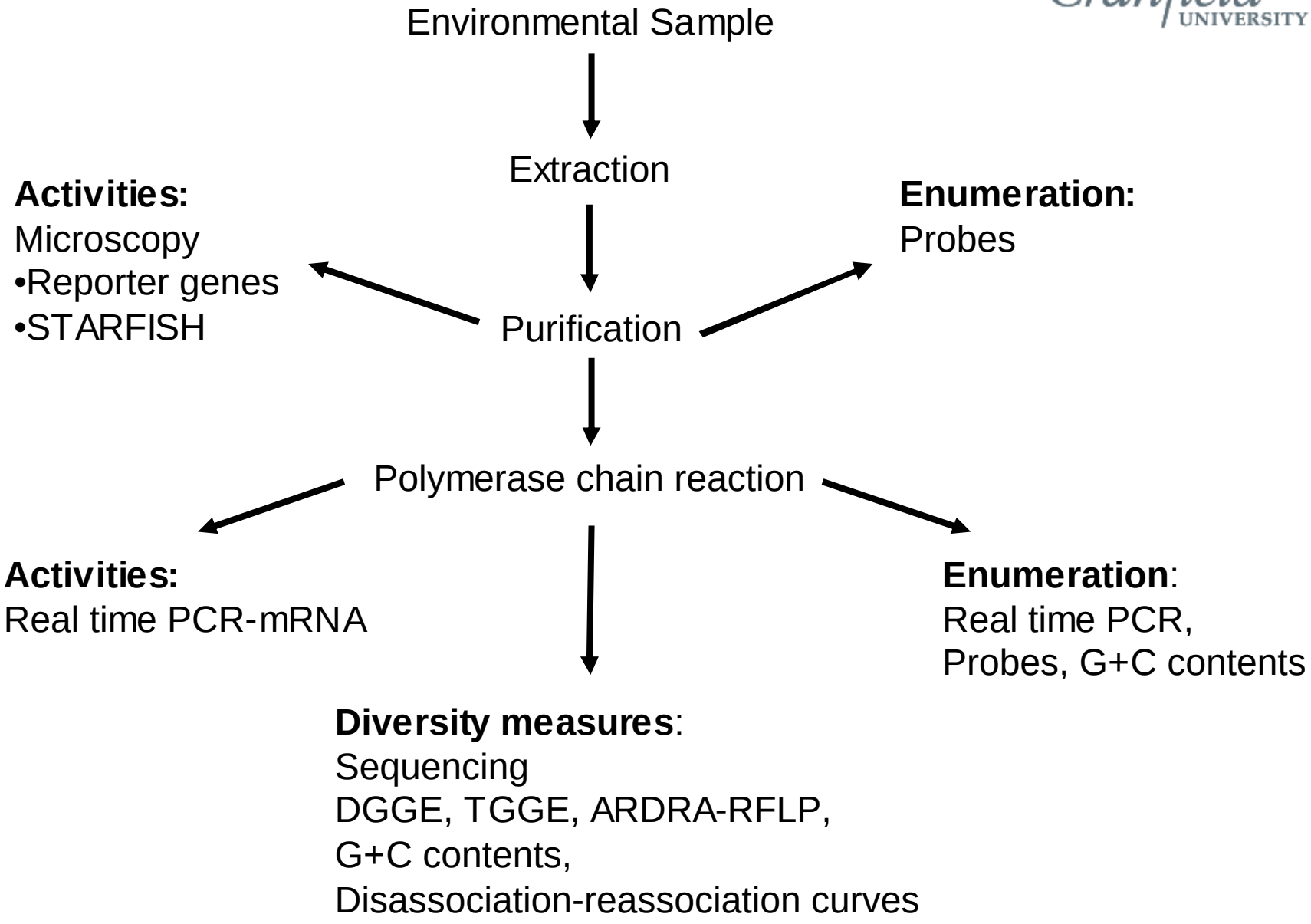
- processes – the working engine

CHARACTERISING BIODIVERSITY



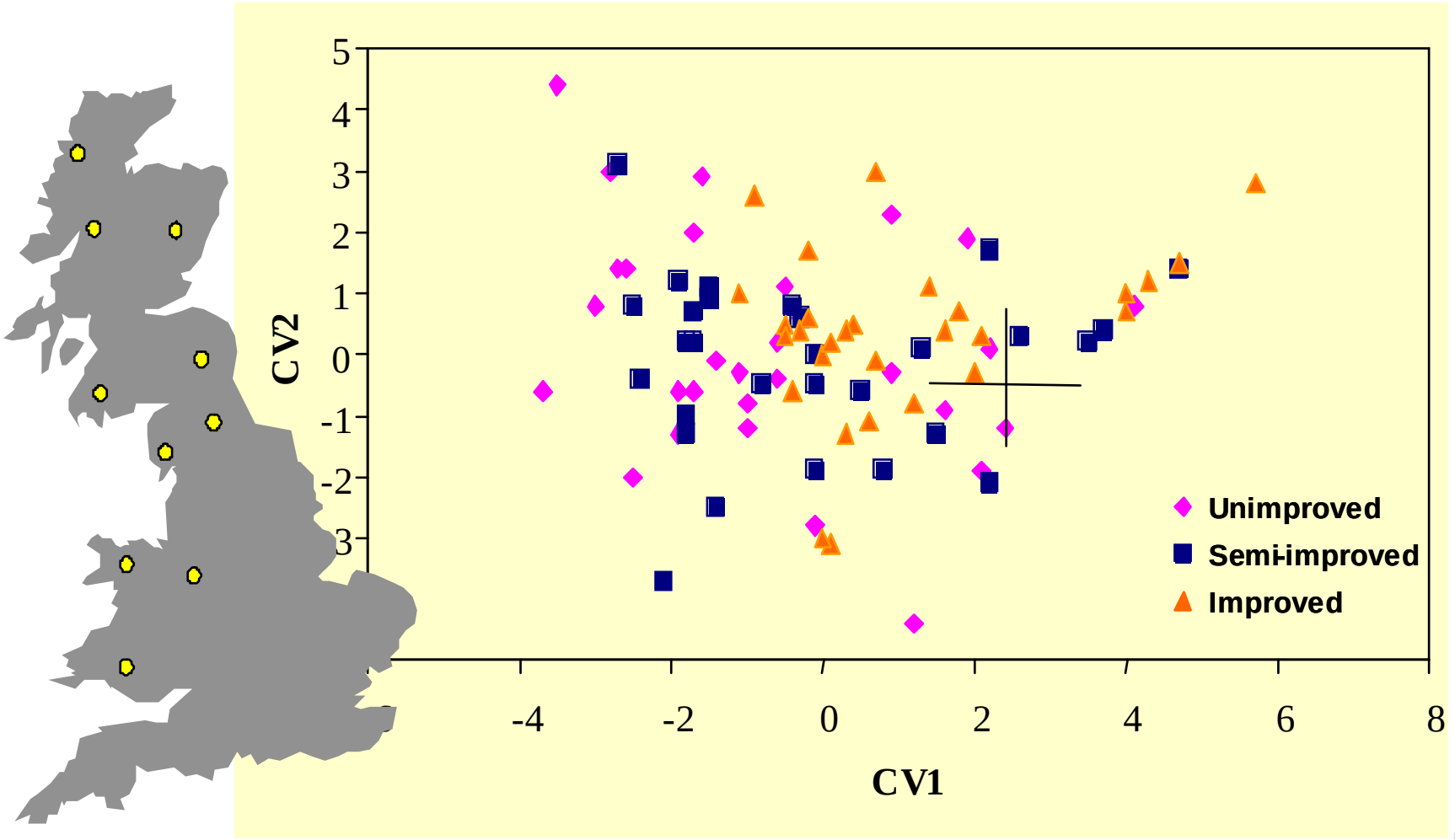
GENOTYPIC

- fundamental information – the blueprint

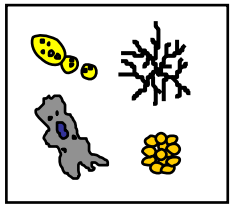

Environmental Sample
Extraction
Purification
Polymerase chain reaction
Activities:
Microscopy
•Reporter genes
•STARFISH
Enumeration:
Probes
Activities:
Real time PCR-mRNA
Enumeration:
Real time PCR,
Probes, G+C contents
Diversity measures:
Sequencing
DGGE, TGGE, ARDRA-RFLP,
G+C contents,
Disassociation-reassociation curves

BROAD-SCALE GENETIC ANALYSIS

- %G+C profiling of soil community DNA in UK upland grasslands

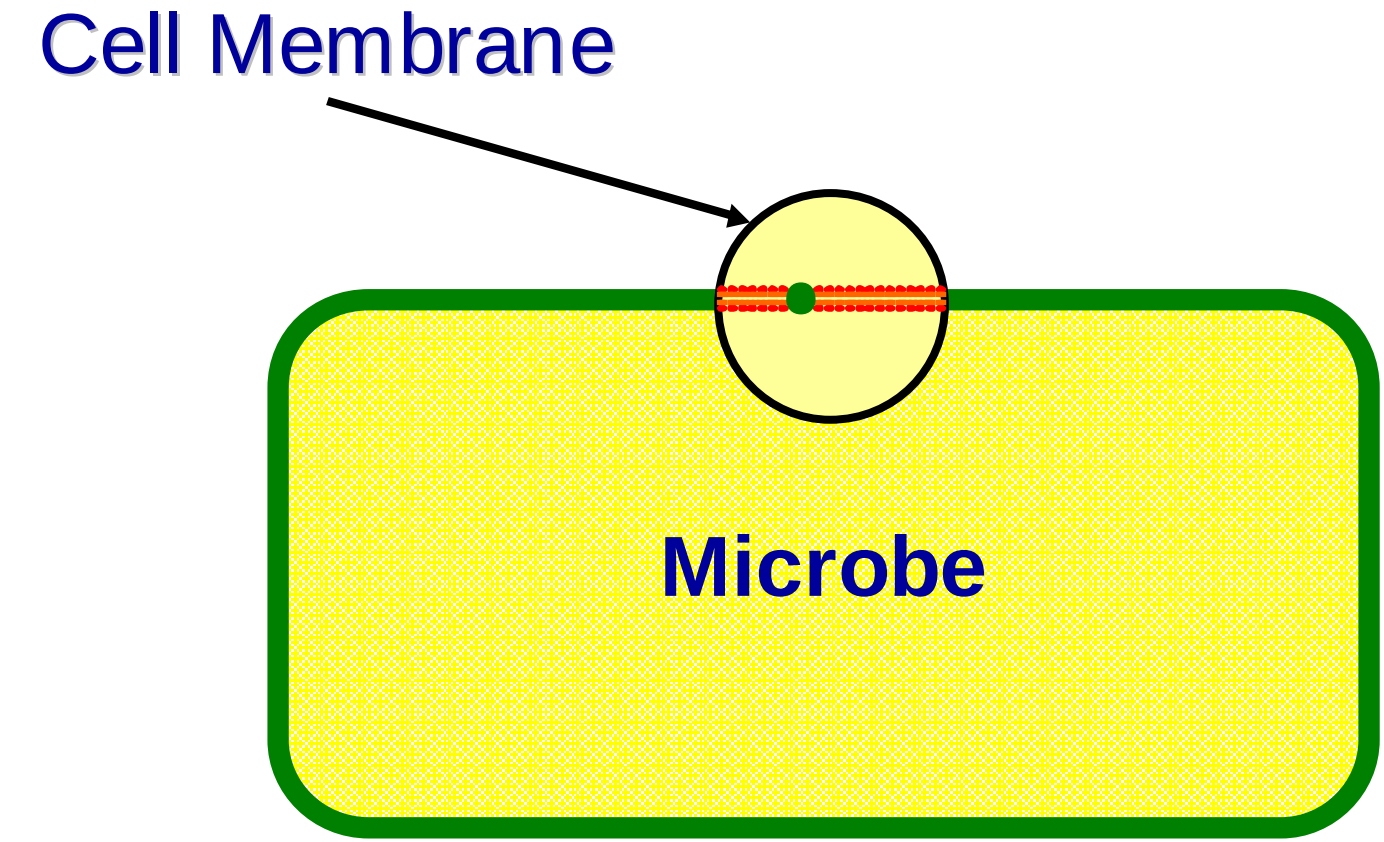


CHARACTERISING BIODIVERSITY

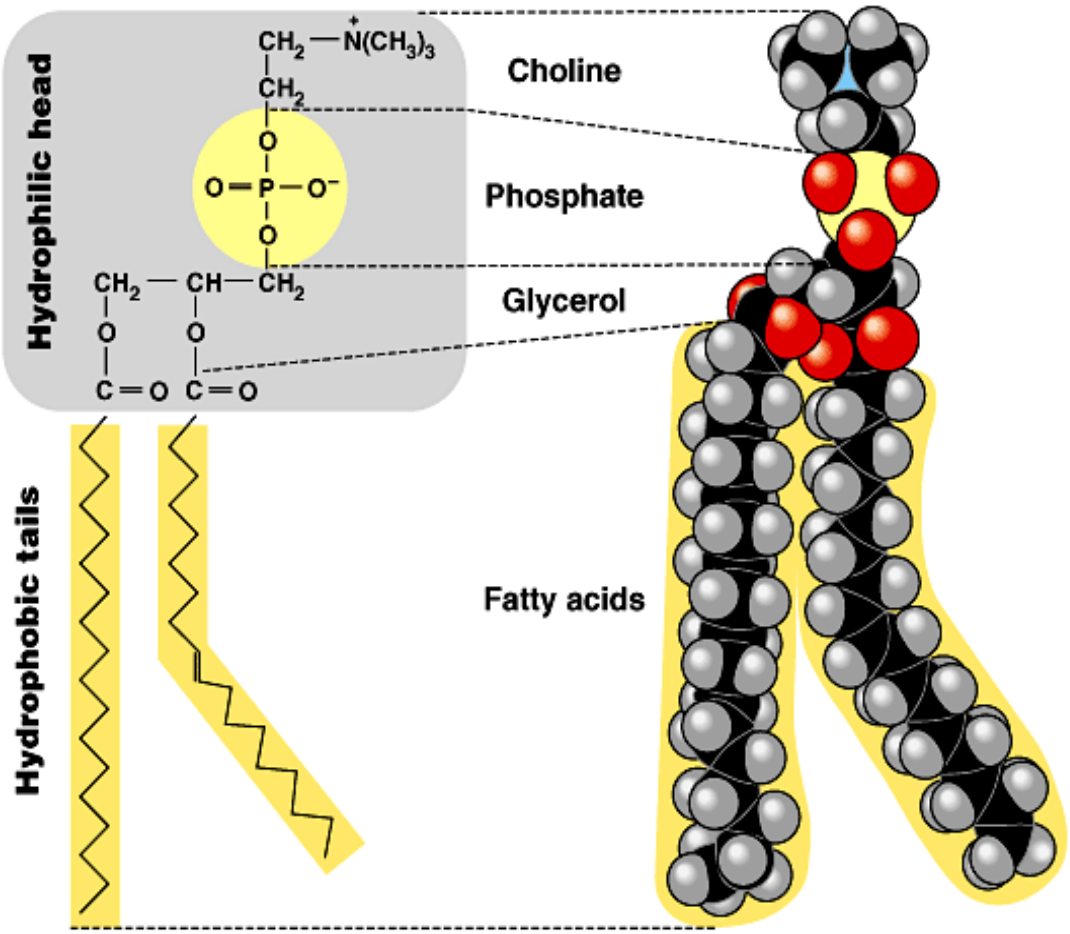


PHENOTYPIC

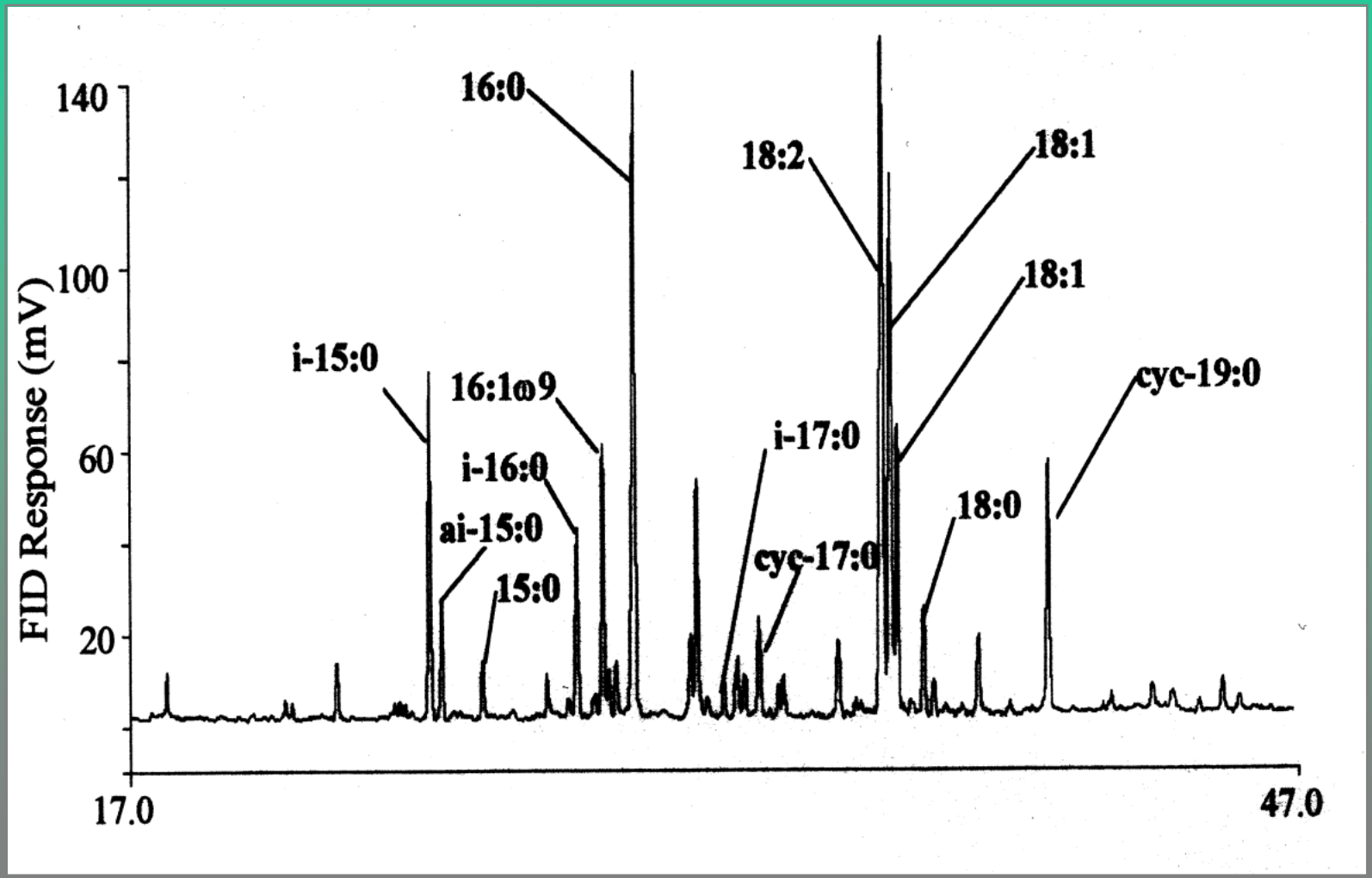
- expressed information – the parts


Cell Membrane
Microbe

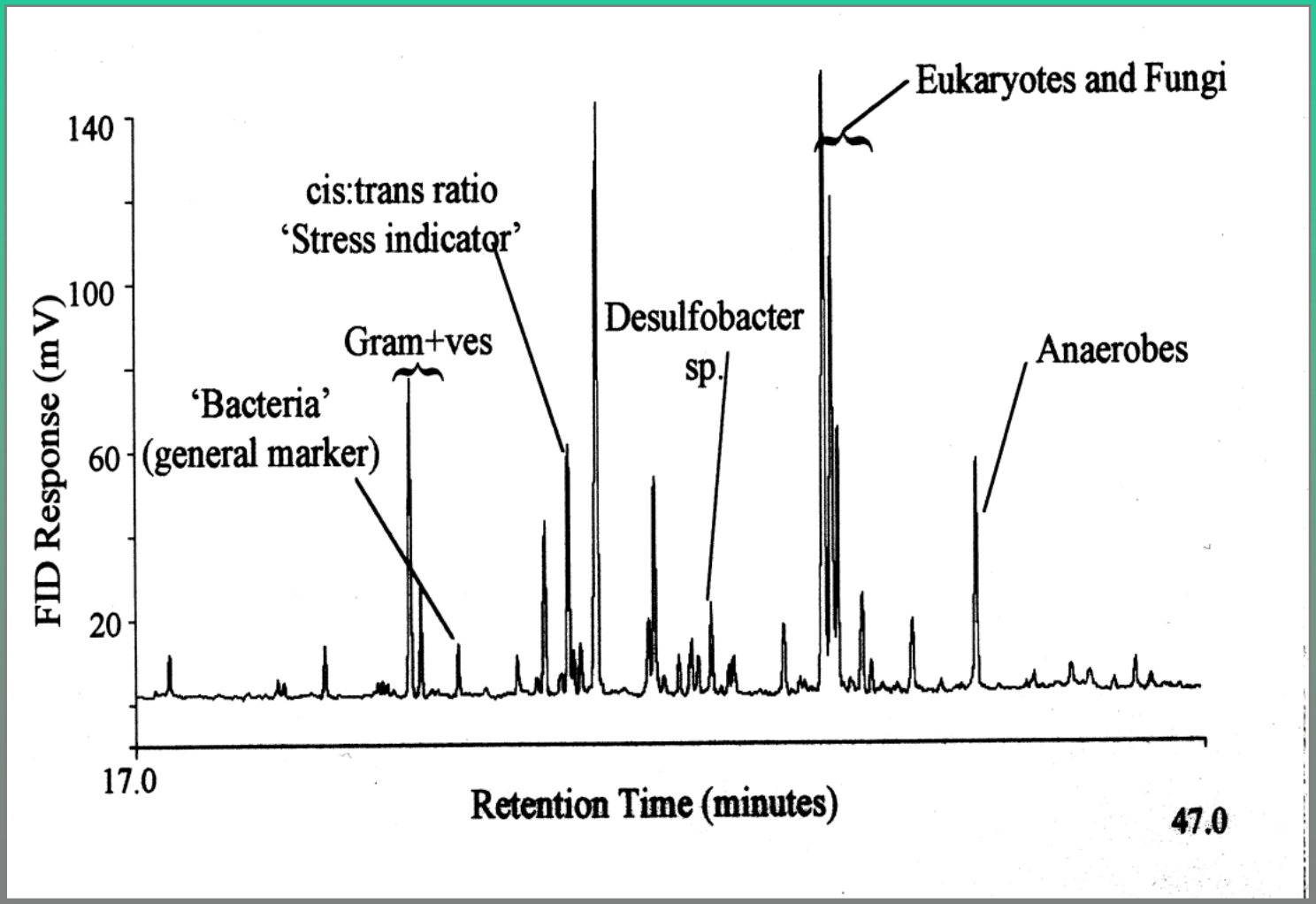
PHOSPHOLIPID FATTY ACIDS



PLFA Profile from a mixed woodland

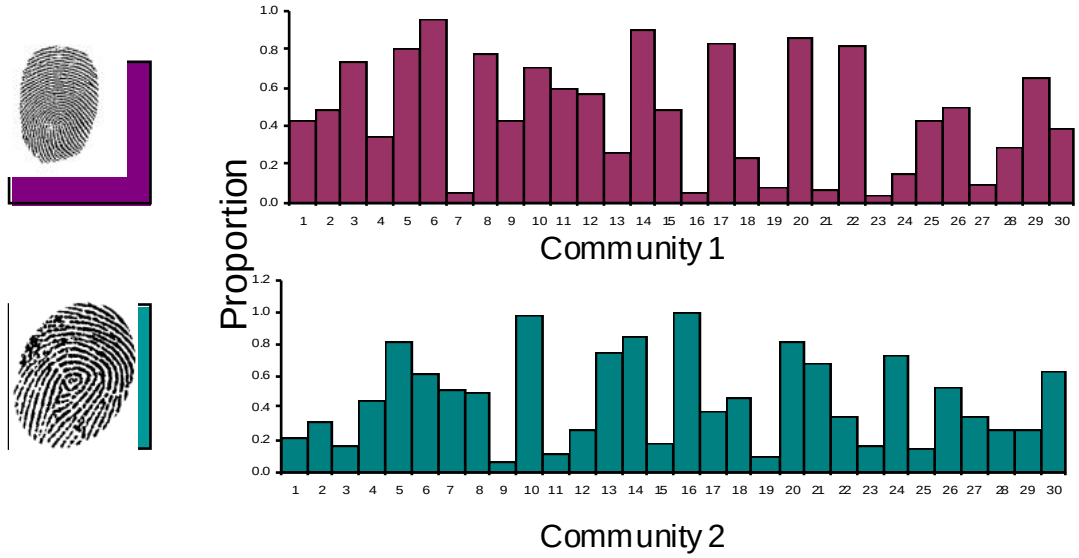


PLFA profiles: Microbial groups

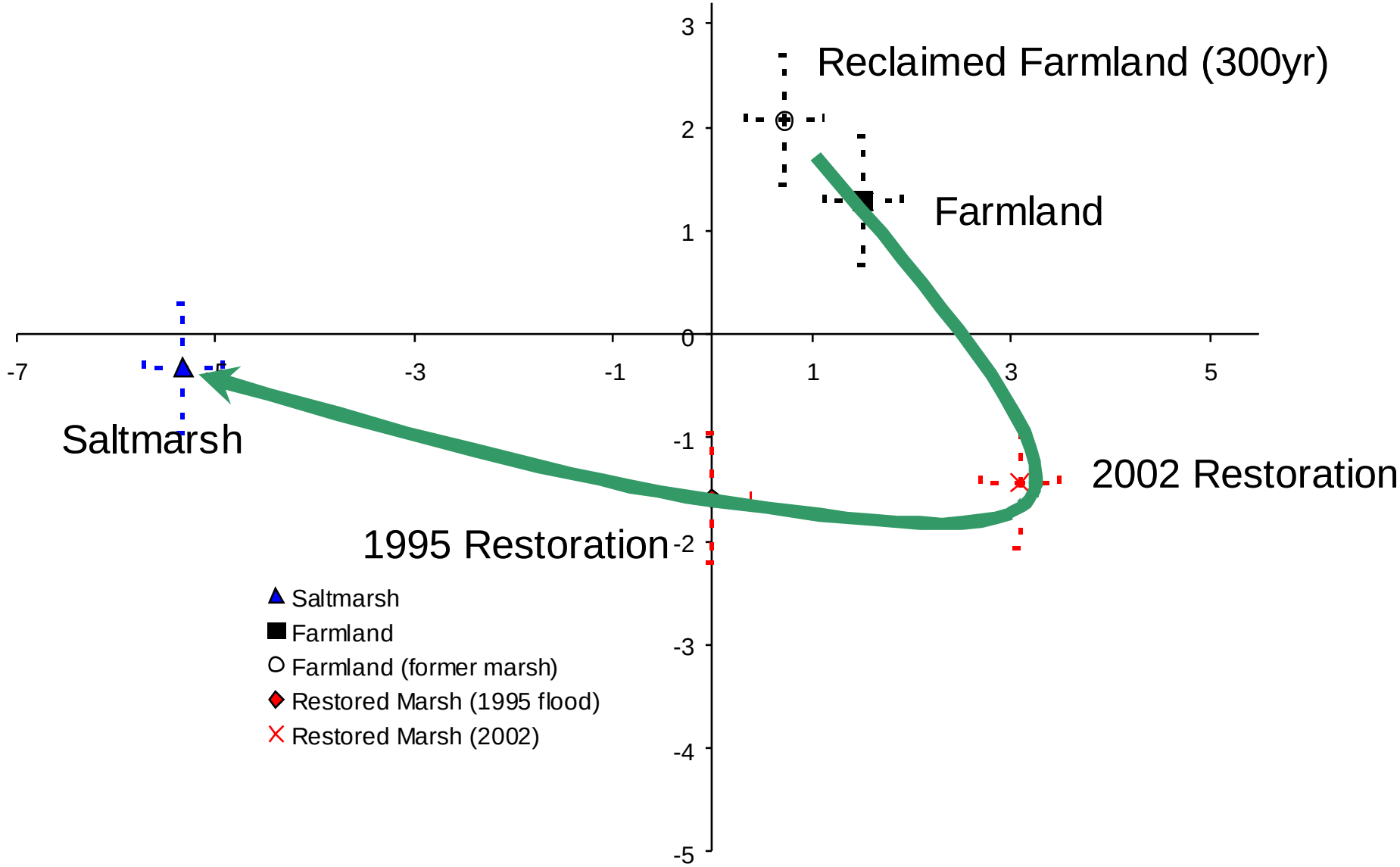


PLFA PHENOTYPIC PROFILING

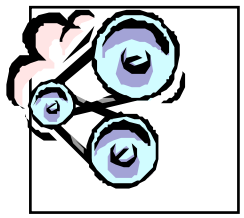
- Appropriateness in context of biodiversity ?
  - relationship to taxonomy is rather loose
  - relationship to environmental context is apparently quite high
  - are number of PLFA's a measure of 'diversity'



Abbots Hall Farm Essex


Reclaimed Farmland (300yr)
Farmland
Saltmarsh
2002 Restoration
1995 Restoration
3
2
1
0
-1
-2
-3
-4
-5
-7
-3
-1
1
3
5
Saltmarsh
Farmland
Farmland (former marsh)
Restored Marsh (1995 flood)
Restored Marsh (2002)

CHARACTERISING BIODIVERSITY



FUNCTIONAL

- processes – the working engine

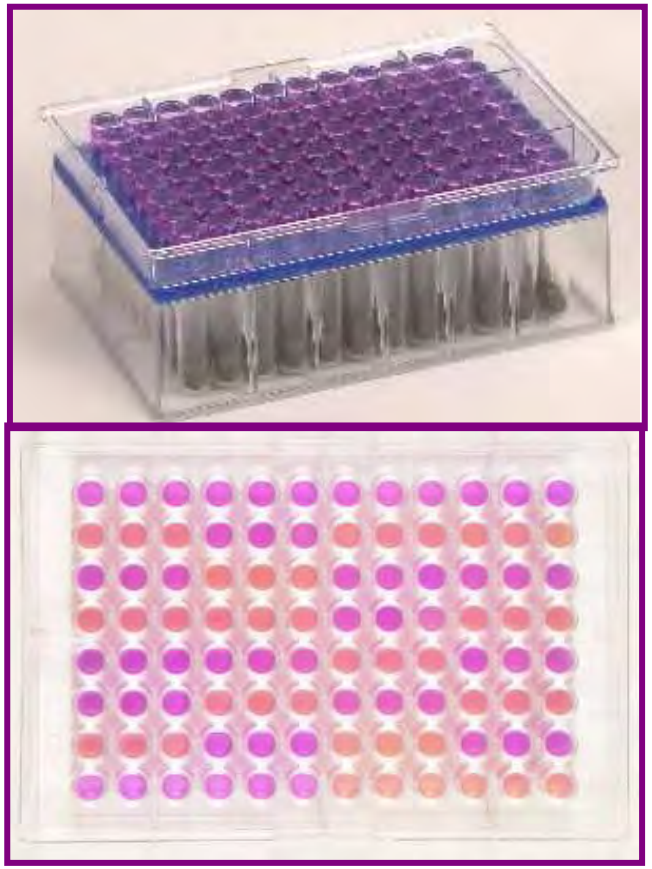
FUNCTIONAL PROFILING

- High-throughput systems:
  - enzyme profiling
    - fluorimetric systems (umbelliferones, MUF)
  - substrate utilisation profiling

Carbon is the currency of the soil economy

Cranfield UNIVERSITY

Multiple Substrate Induced Respiration

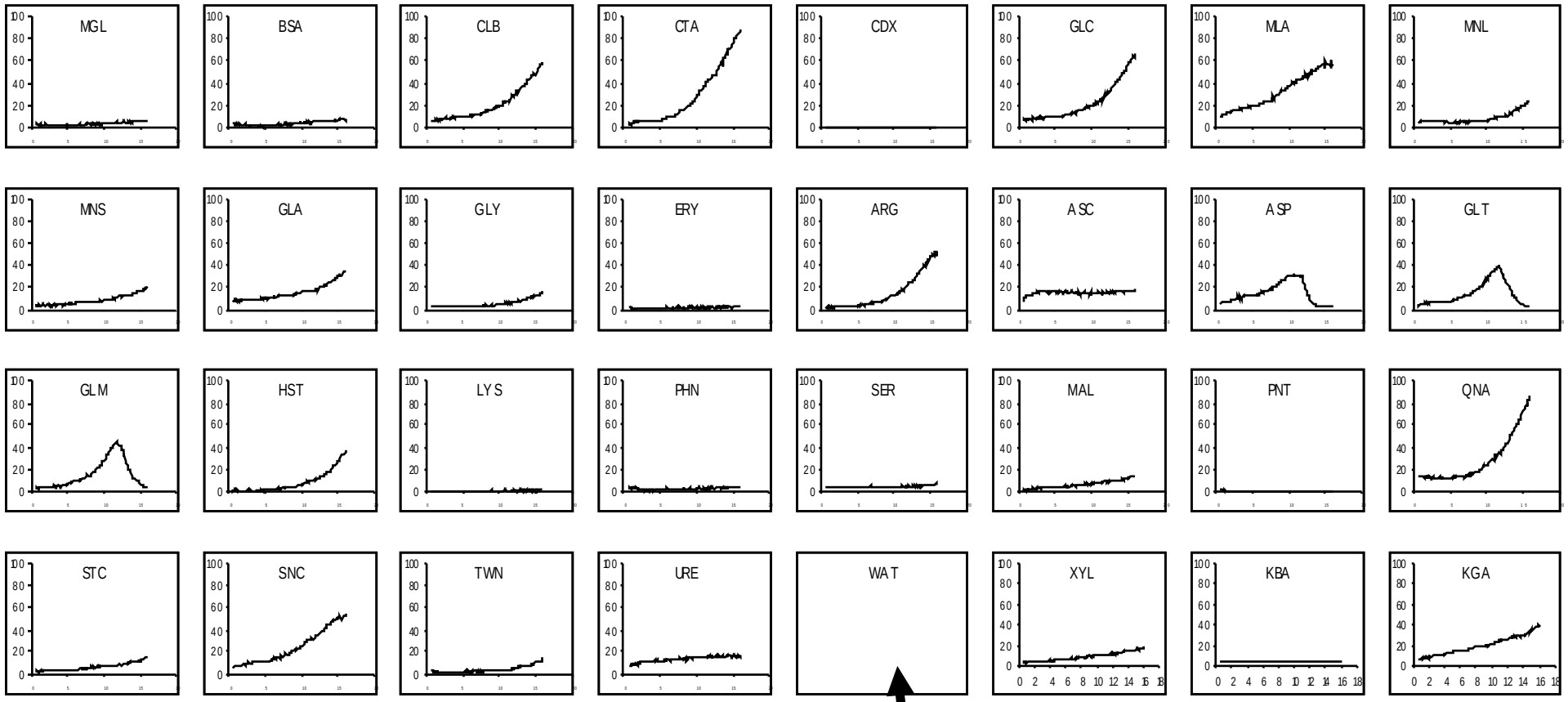


96-channel respirometers:

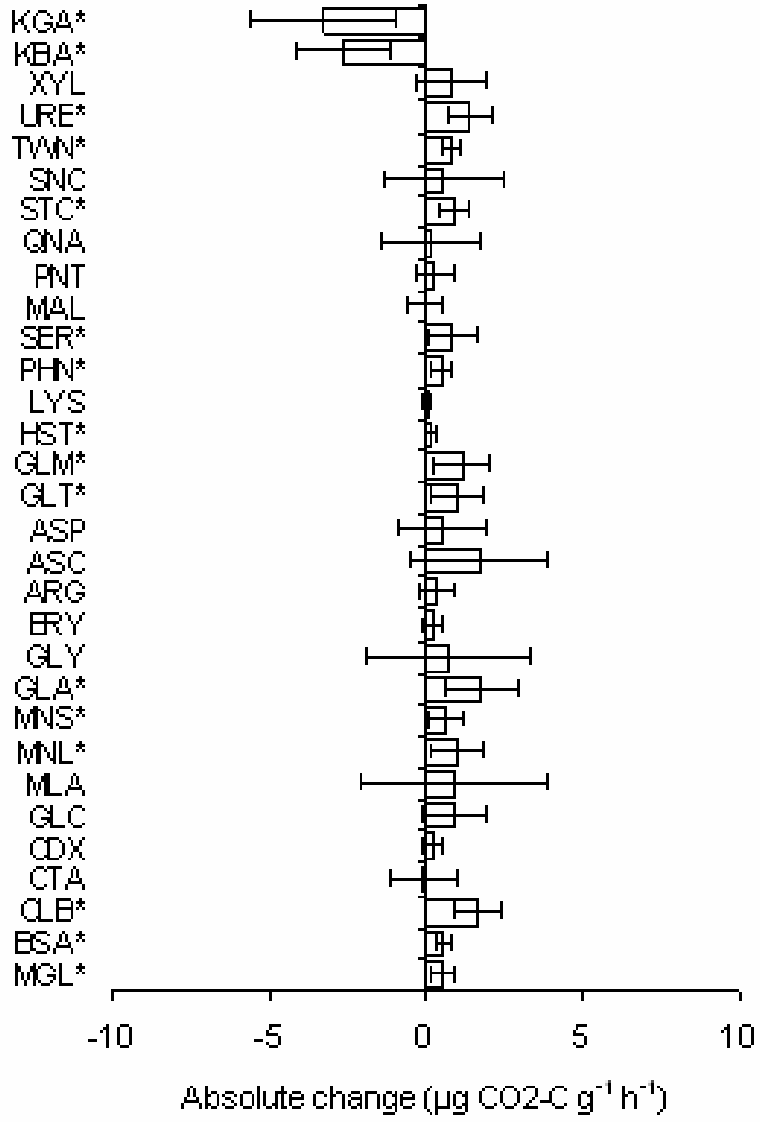
RABIT

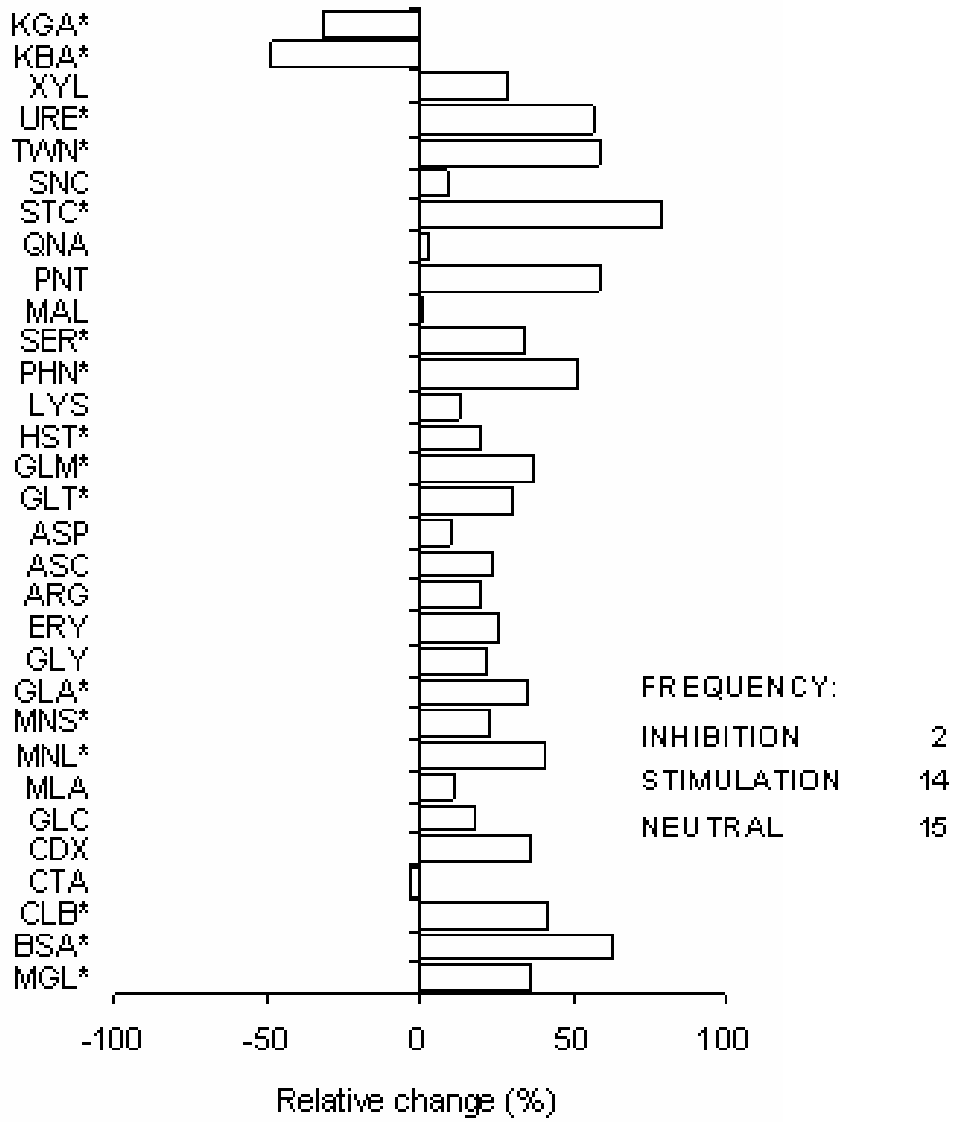
MicroResp™

MSIR OUTPUT: RATE CURVES



Subtract respiration from water controls

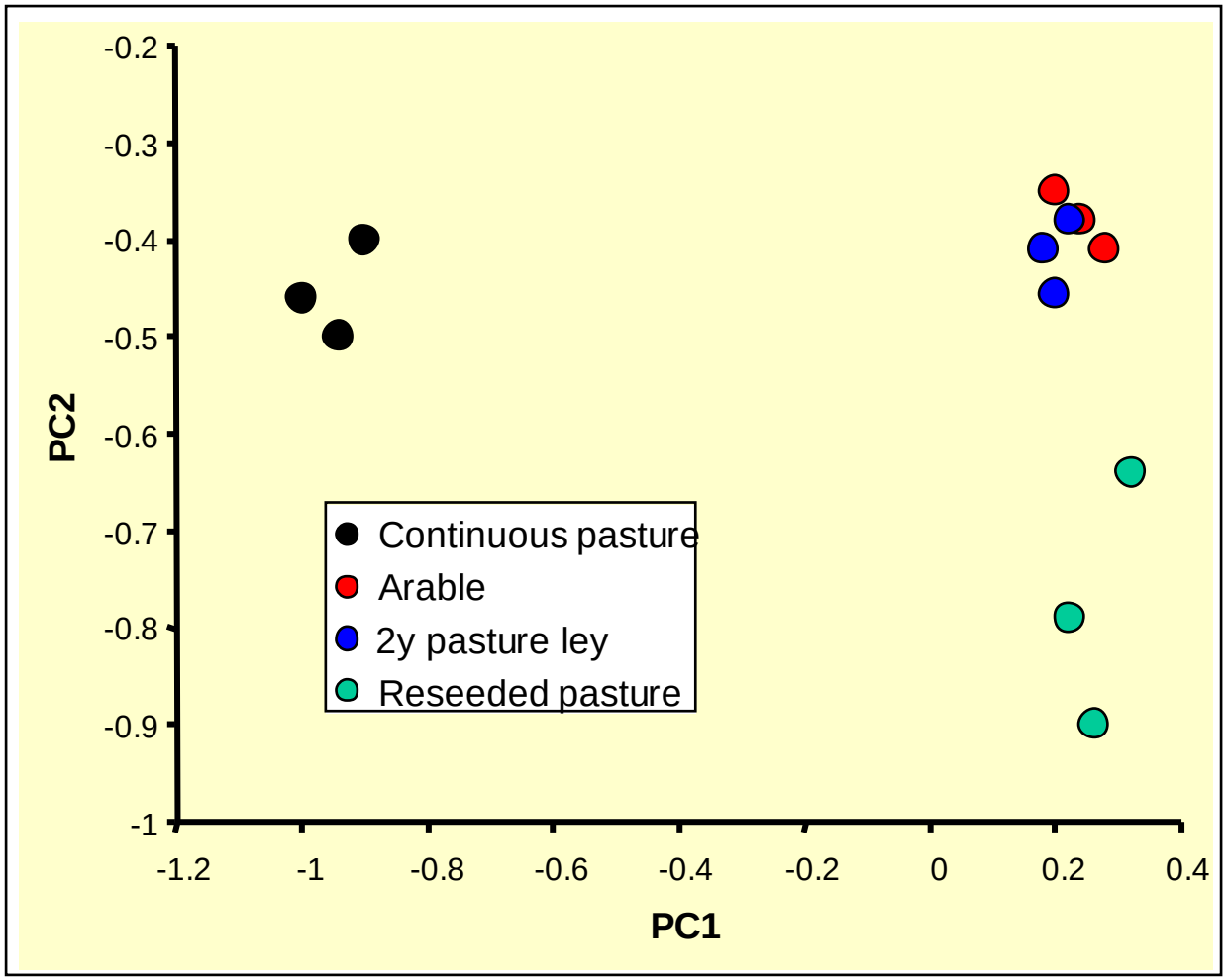

KGA*
KBA*
XYL
URE*
TWN*
SNC
STC*
QNA
PNT
MAL
SER*
PHN*
LYS
HST*
GLM*
GLT*
ASP
ASC
ARG
ERY
GLY
GLA*
MNS*
MNL*
MLA
GLC
CDX
CTA
CLB*
BSA*
MGL*
-10
-5
0
5
10
Absolute change (µg CO2-C g-1 h-1)


KGA*
KBA*
XYL
URE*
TWN*
SNC
STC*
QNA
PNT
MAL
SER*
PHN*
LYS
HST*
GLM*
GLT*
ASP
ASC
ARG
ERY
GLY
GLA*
MNS*
MNL*
MLA
GLC
CDX
CTA
CLB*
BSA*
MGL*
-100
-50
0
50
100
Relative change (%)
FREQUENCY:
INHIBITION 2
STIMULATION 14
NEUTRAL 15

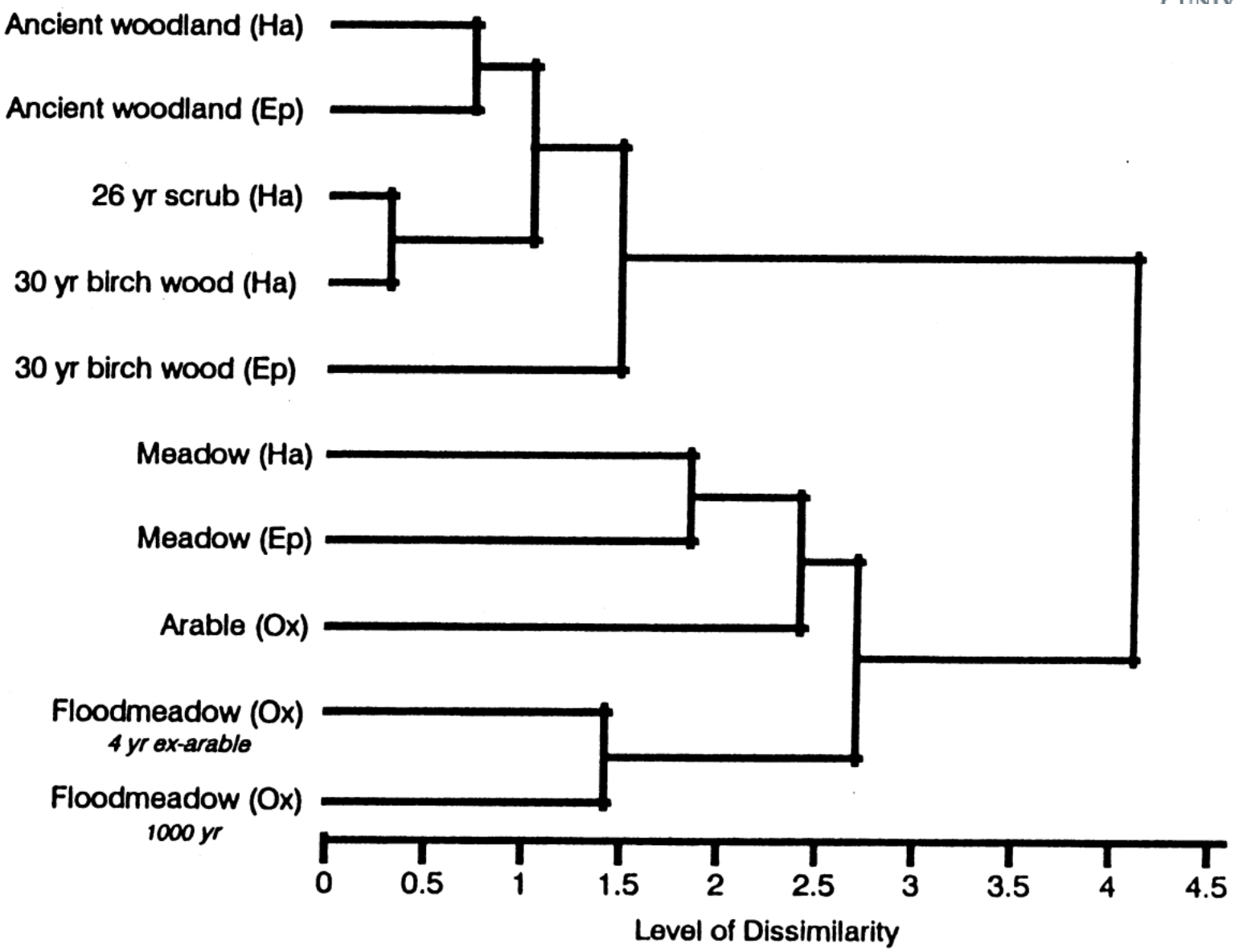
FUNCTIONAL PROFILING: Multiple substrate SIR

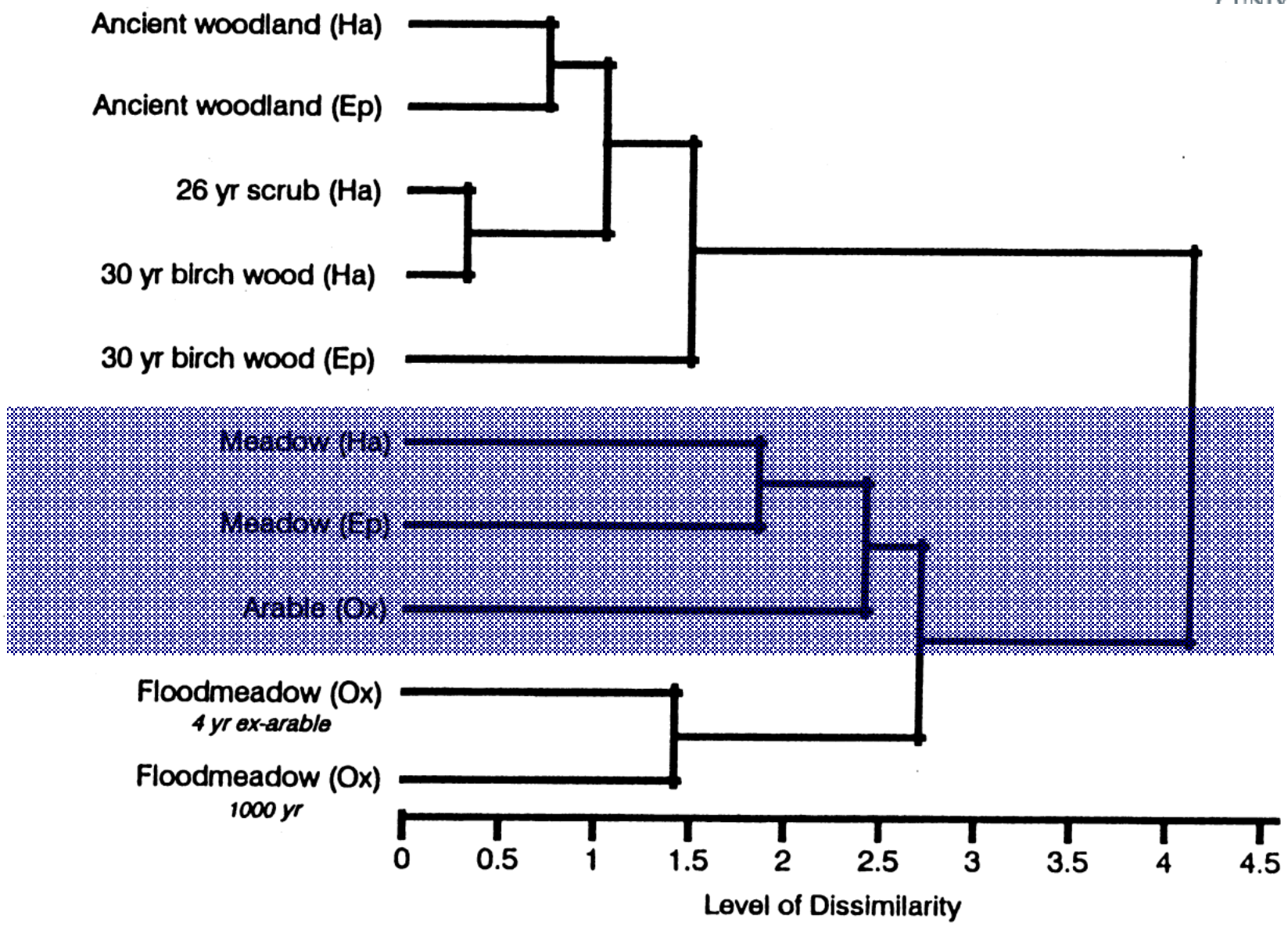
Cranfield UNIVERSITY Silsoe

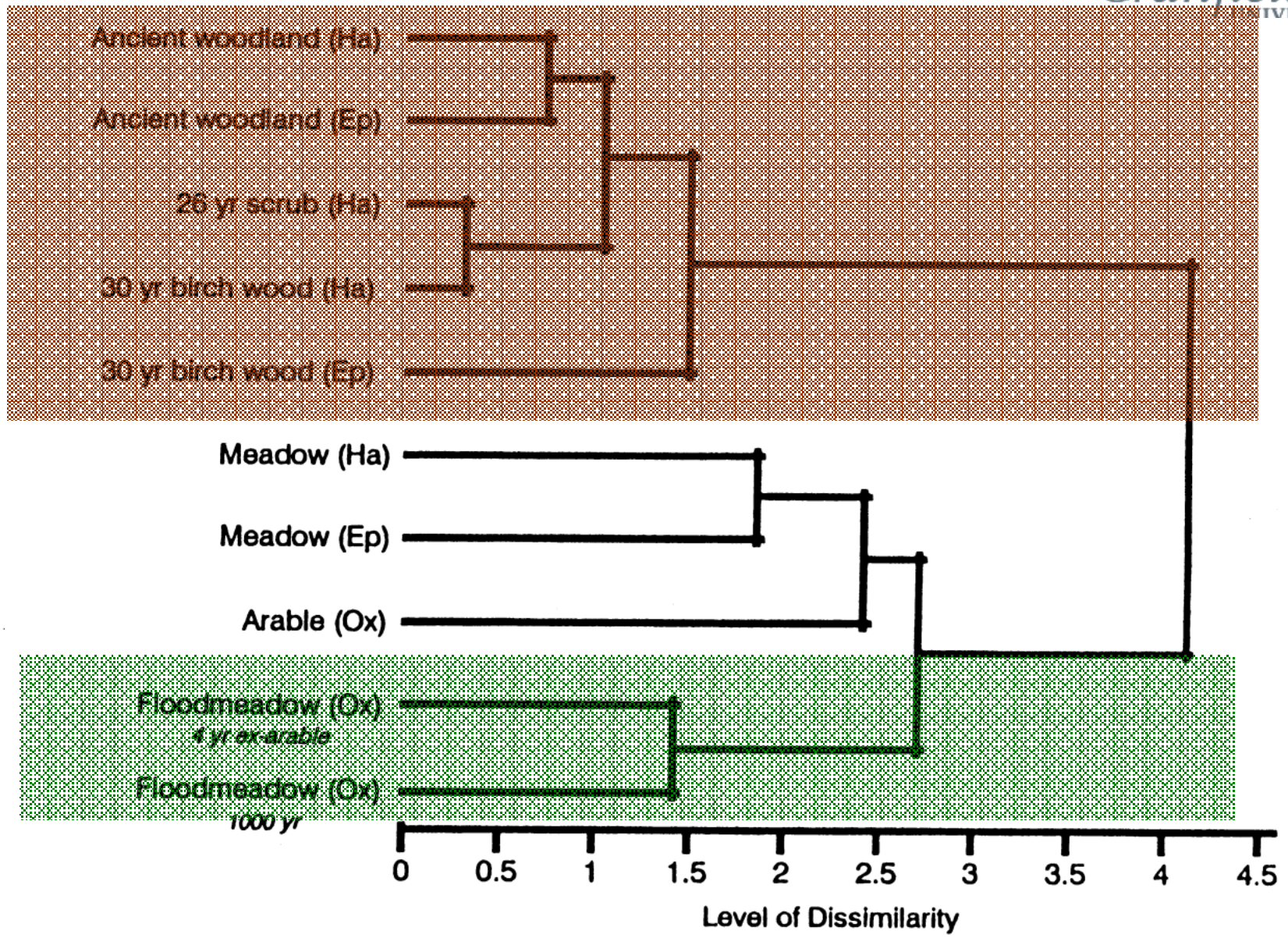
- Effect of agricultural management regimes

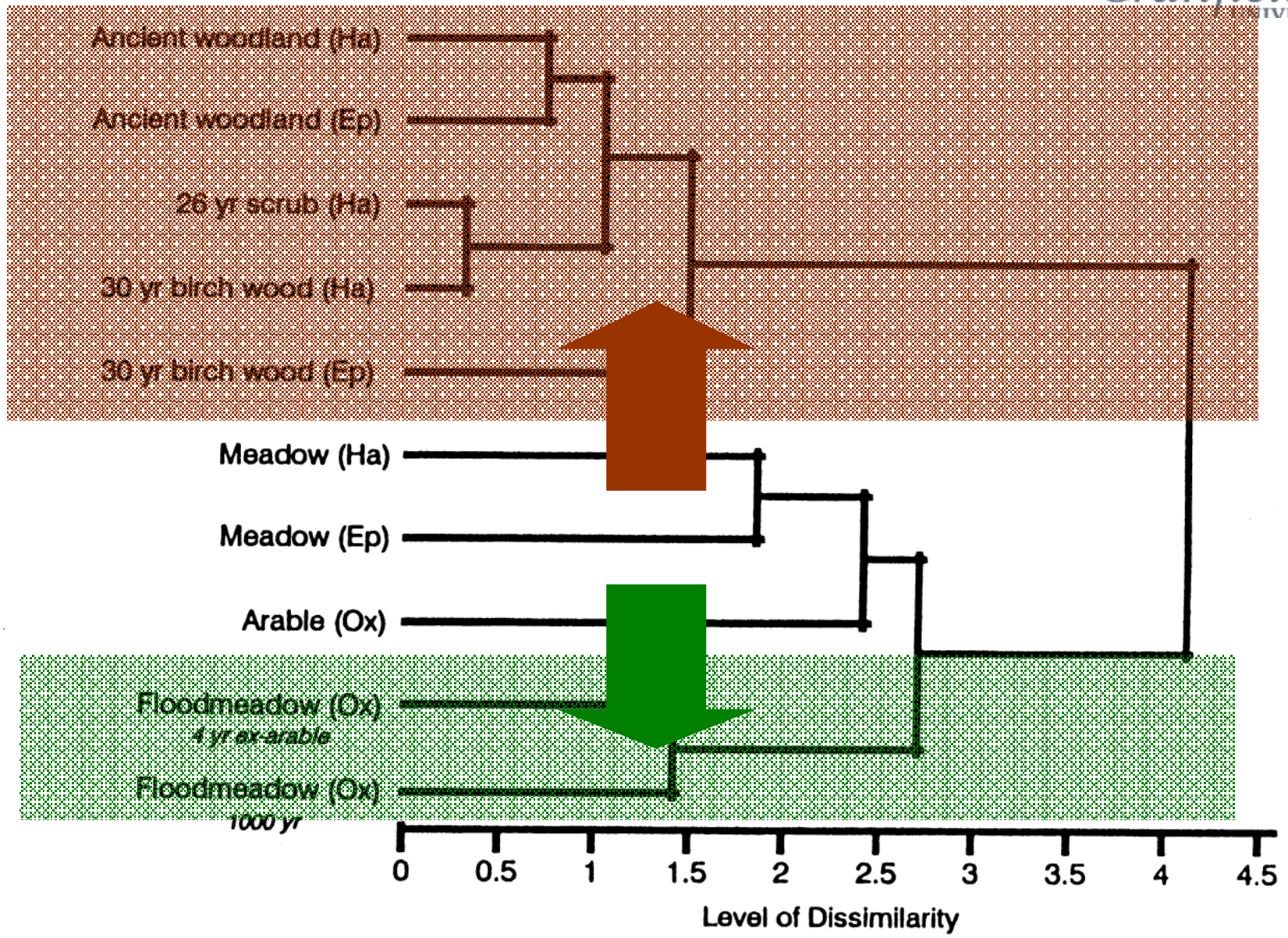


Source: Degens & Harris 1997: Soil Biol Biochem 29:1309-1320


Ancient woodland (Ha)
Ancient woodland (Ep)
26 yr scrub (Ha)
30 yr birch wood (Ha)
30 yr birch wood (Ep)
Meadow (Ha)
Meadow (Ep)
Arable (Ox)
Floodmeadow (Ox)
4 yr ex-arable
Floodmeadow (Ox)
1000 yr
0
0.5
1
1.5
2
2.5
3
3.5
4
4.5
Level of Dissimilarity


Ancient woodland (Ha)
Ancient woodland (Ep)
26 yr scrub (Ha)
30 yr birch wood (Ha)
30 yr birch wood (Ep)
Meadow (Ha)
Meadow (Ep)
Arable (Ox)
Floodmeadow (Ox)
4 yr ex-arable
Floodmeadow (Ox)
1000 yr
0
0.5
1
1.5
2
2.5
3
3.5
4
4.5
Level of Dissimilarity


Ancient woodland (Ha)
Ancient woodland (Ep)
26 yr scrub (Ha)
30 yr birch wood (Ha)
30 yr birch wood (Ep)
Meadow (Ha)
Meadow (Ep)
Arable (Ox)
Floodmeadow (Ox)
4 yr ex-arable
Floodmeadow (Ox)
1000 yr
0
0.5
1
1.5
2
2.5
3
3.5
4
4.5
Level of Dissimilarity

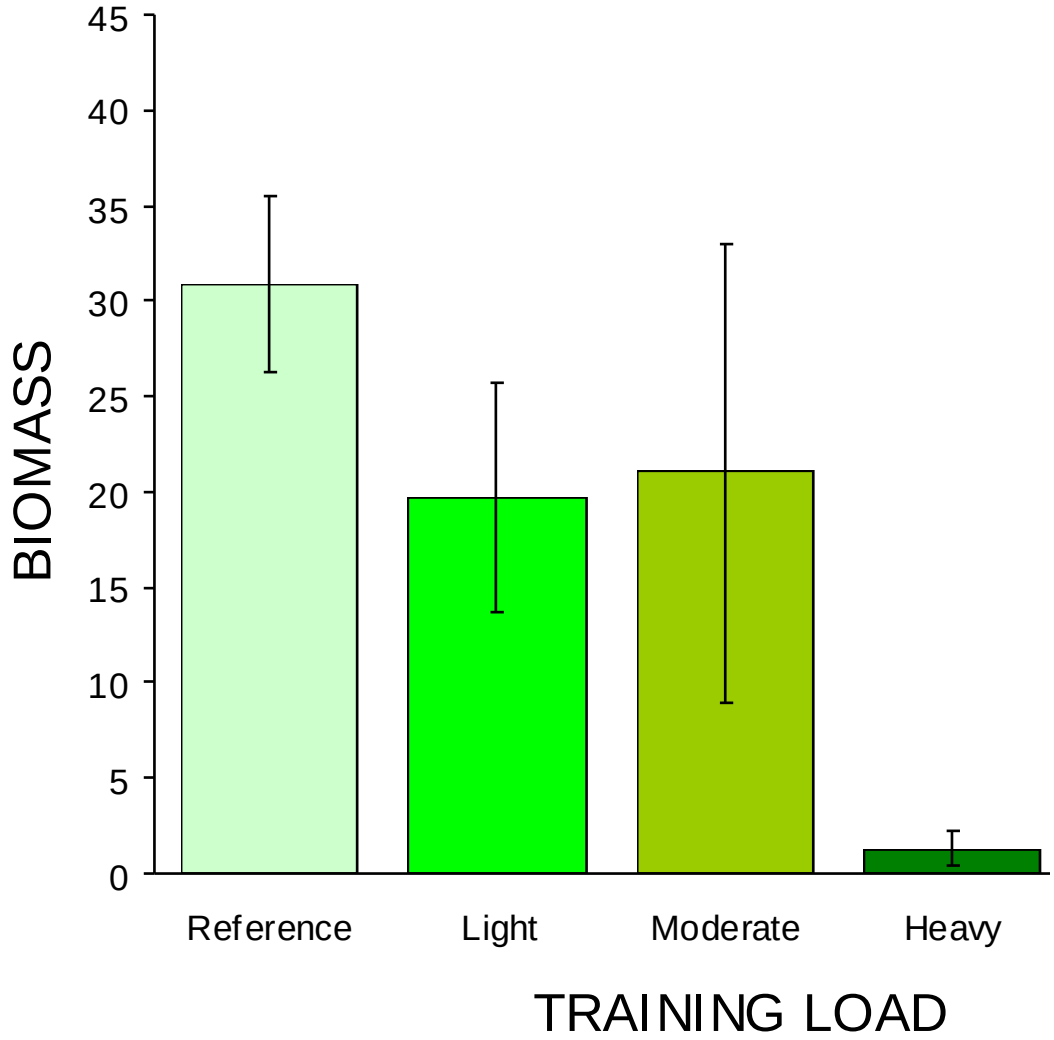

Ancient woodland (Ha)
Ancient woodland (Ep)
26 yr scrub (Ha)
30 yr birch wood (Ha)
30 yr birch wood (Ep)
Meadow (Ha)
Meadow (Ep)
Arable (Ox)
Floodmeadow (Ox)
4 yr ex-arable
Floodmeadow (Ox)
1000 yr
0
0.5
1
1.5
2
2.5
3
3.5
4
4.5
Level of Dissimilarity

MONITORING: TRAINING LOADS

- **BIOLOGICAL STATUS OF SOILS**
  - **microbes provide sensitive indicator**
  - **Approach pioneered in USA**

EFFECT OF MILITARY TRAFFICKING UPON SOIL MICROBIAL BIOMASS

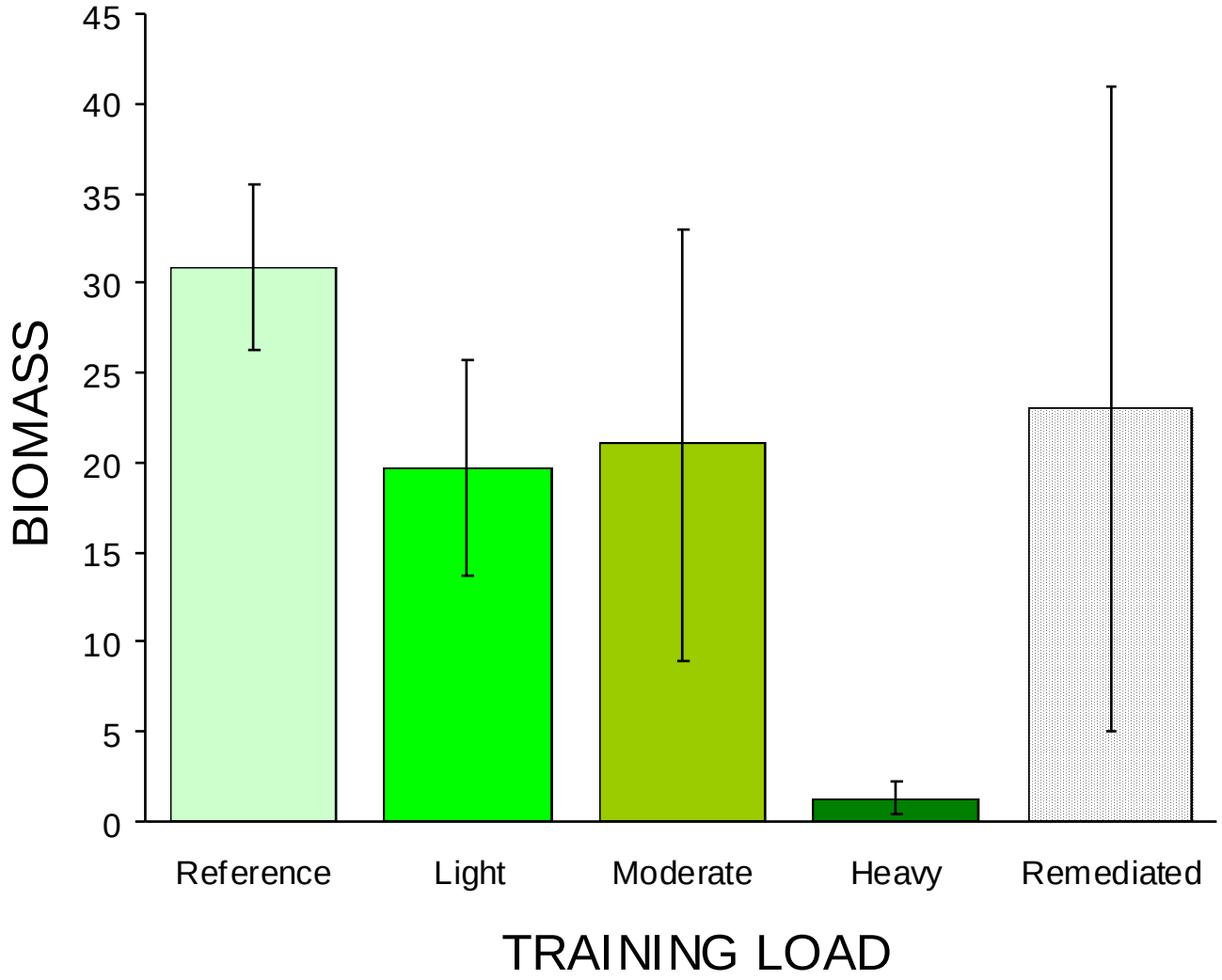
Cranfield UNIVERSITY



Source: Peacock *et al.* (2001) Ecological Indicators 1:113-121

EFFECT OF MILITARY TRAFFICKING UPON SOIL MICROBIAL BIOMASS

Cranfield UNIVERSITY



Source: Peacock *et al.* (2001) Ecological Indicators 1:113-121

Cranfield UNIVERSITY

Salisbury Plain Training Area

BACKGROUND

- Covering approx. 14,000 ha, ATE SP has by far the largest extent of chalk grassland in the UK, and indeed, in north-west Europe
- Chalk grassland is one of the most ecologically diverse wildlife habitats to be found in Britain
- Site of Special Scientific Interest (SSSI) and Special Protection Area (SPA) for birds
- Historical and current land-use of SPTA have resulted in landscapes and wildlife almost unique in the UK

EFFECT OF DISTURBANCE UPON SOIL COMMUNITIES

Cranfield UNIVERSITY

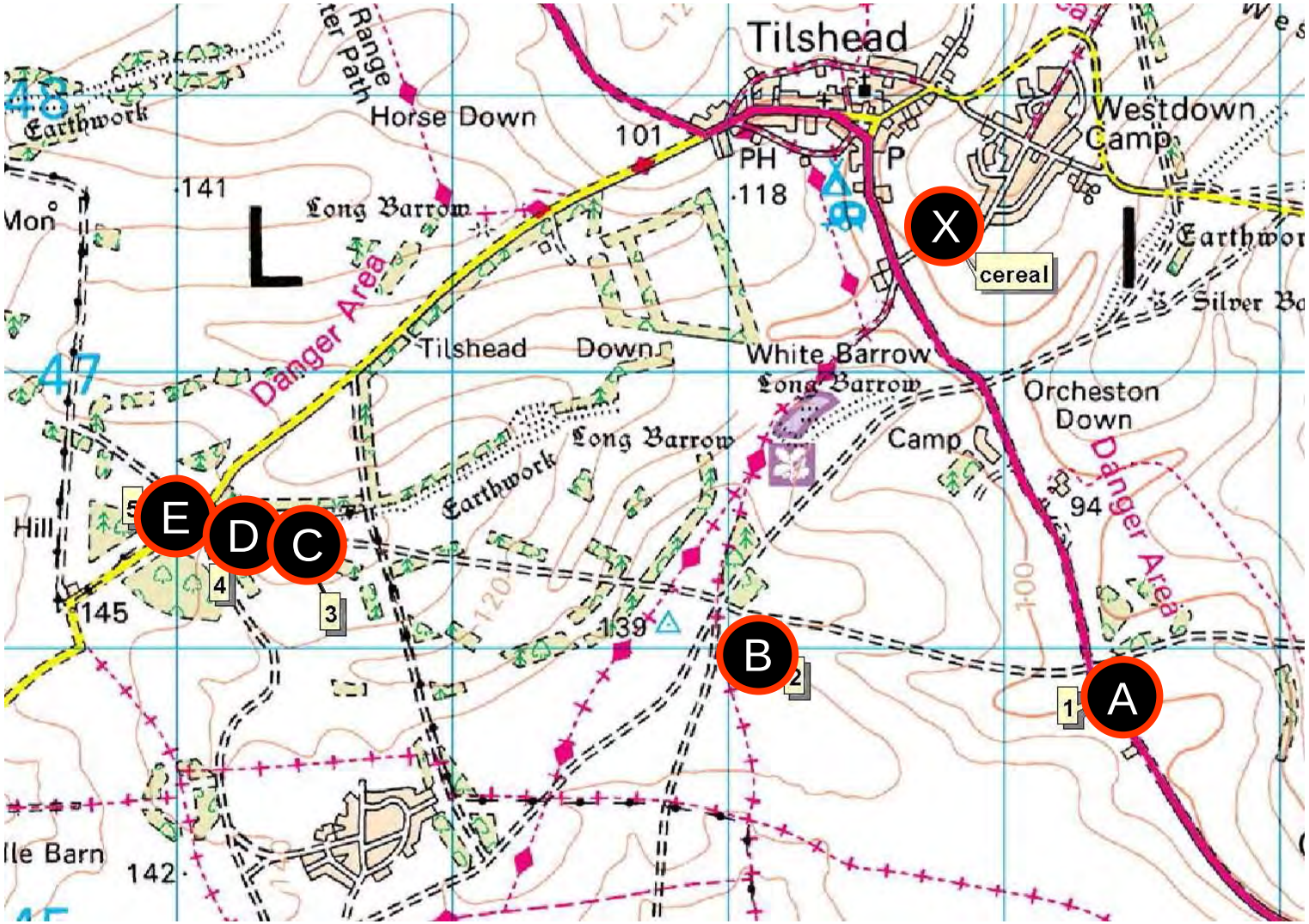
- Cranfield University Development Project
- Case study @ Salisbury Plain
  - **SOILS SAMPLED FROM FIVE CATEGORIES** [March 04]

CODE	DISTURBANCE CATEGORY
A	None
B	Light
C	Medium
D	Heavy
E	Severe
X	Arable field (cereal)

PROPERTIES MEASURED

- **How much is life is there ?**
  - **microbial biomass**
- **Who is there ?**
  - **community structure**
- **Soil chemical properties**

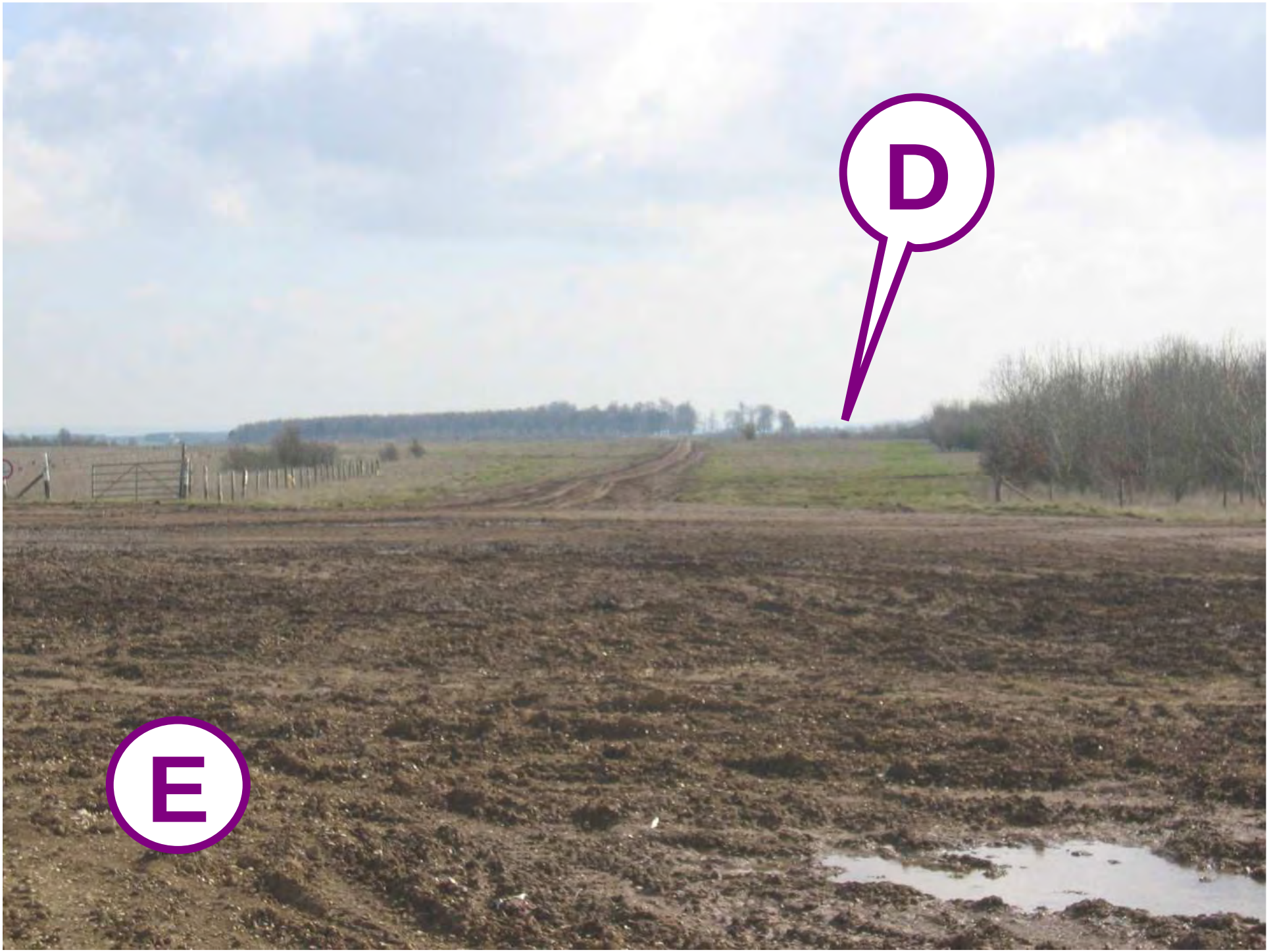
SAMPLING LOCATIONS



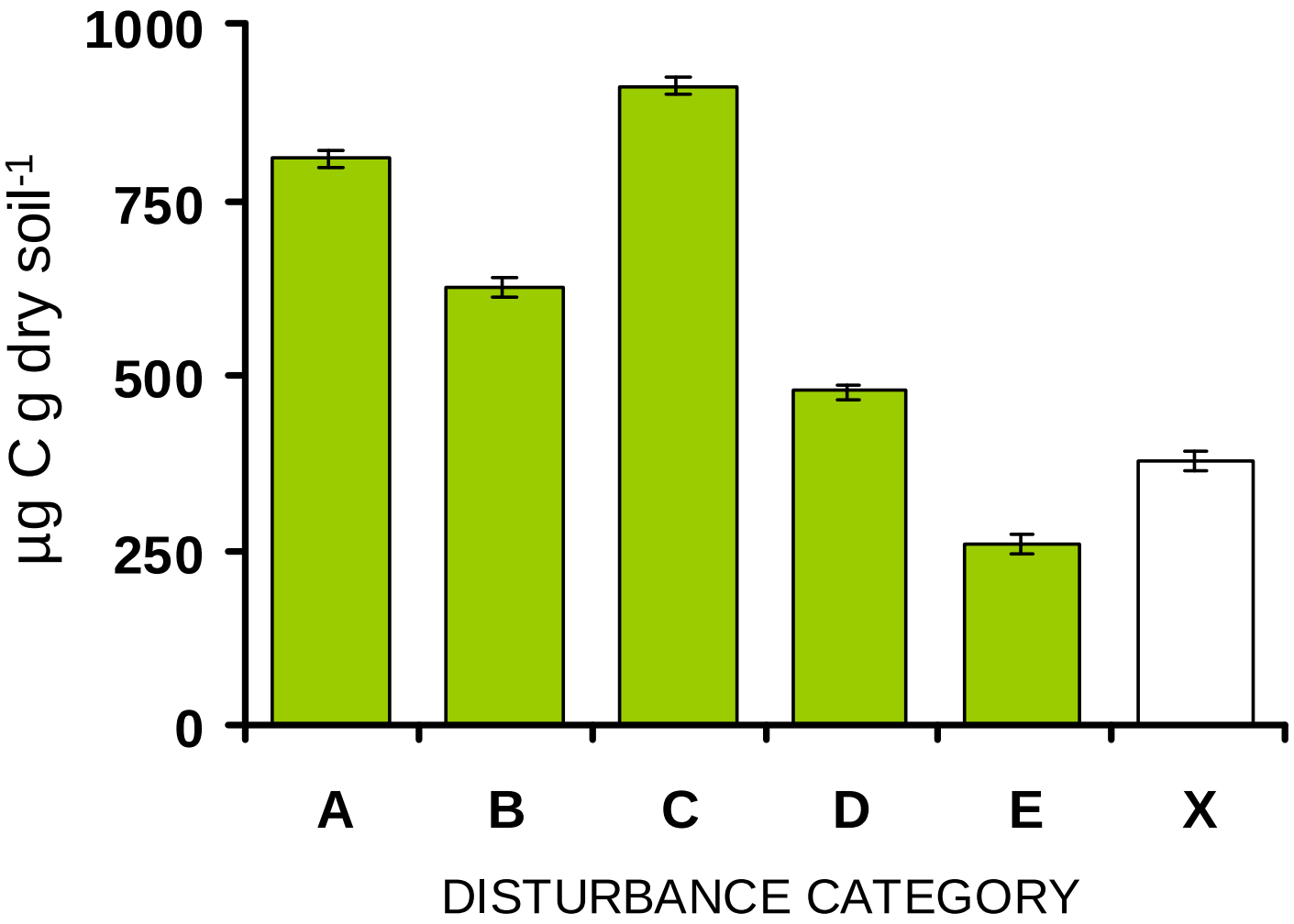
A

B

C


D
E

MICROBIAL BIOMASS



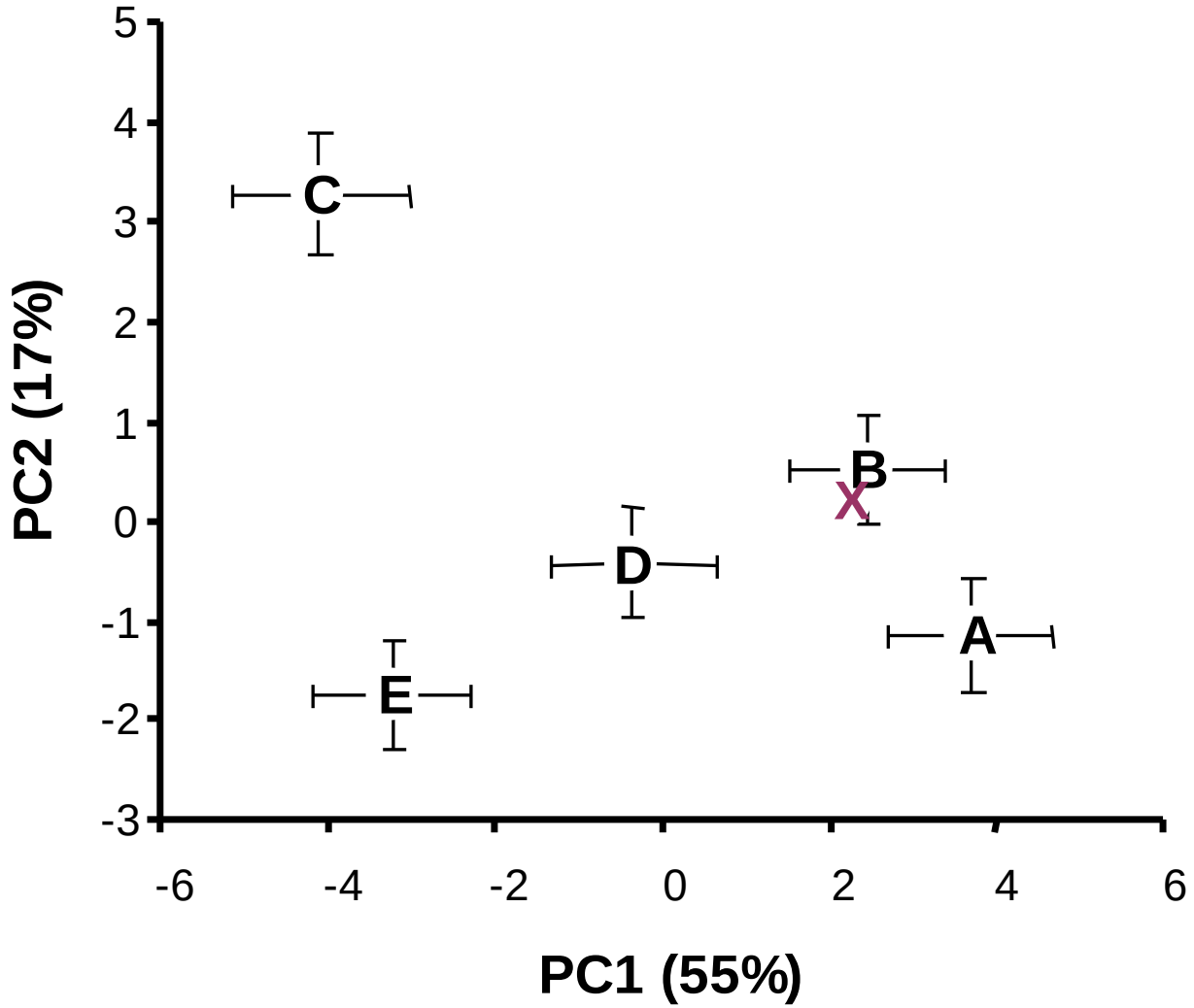
ANALYSIS OF MULTI-VARIATE DATA

Cranfield UNIVERSITY

- Principal component analysis
  - reduces large data sets to a few numbers (Principal Components, PCs) that essentially capture the same information as is contained within the full data set
  - quantify the extent to which the PCs ‘represent’ the entire data set
  - identify which of the properties are most responsible for discriminating between samples

PRINCIPAL COMPONENT ANALYSIS

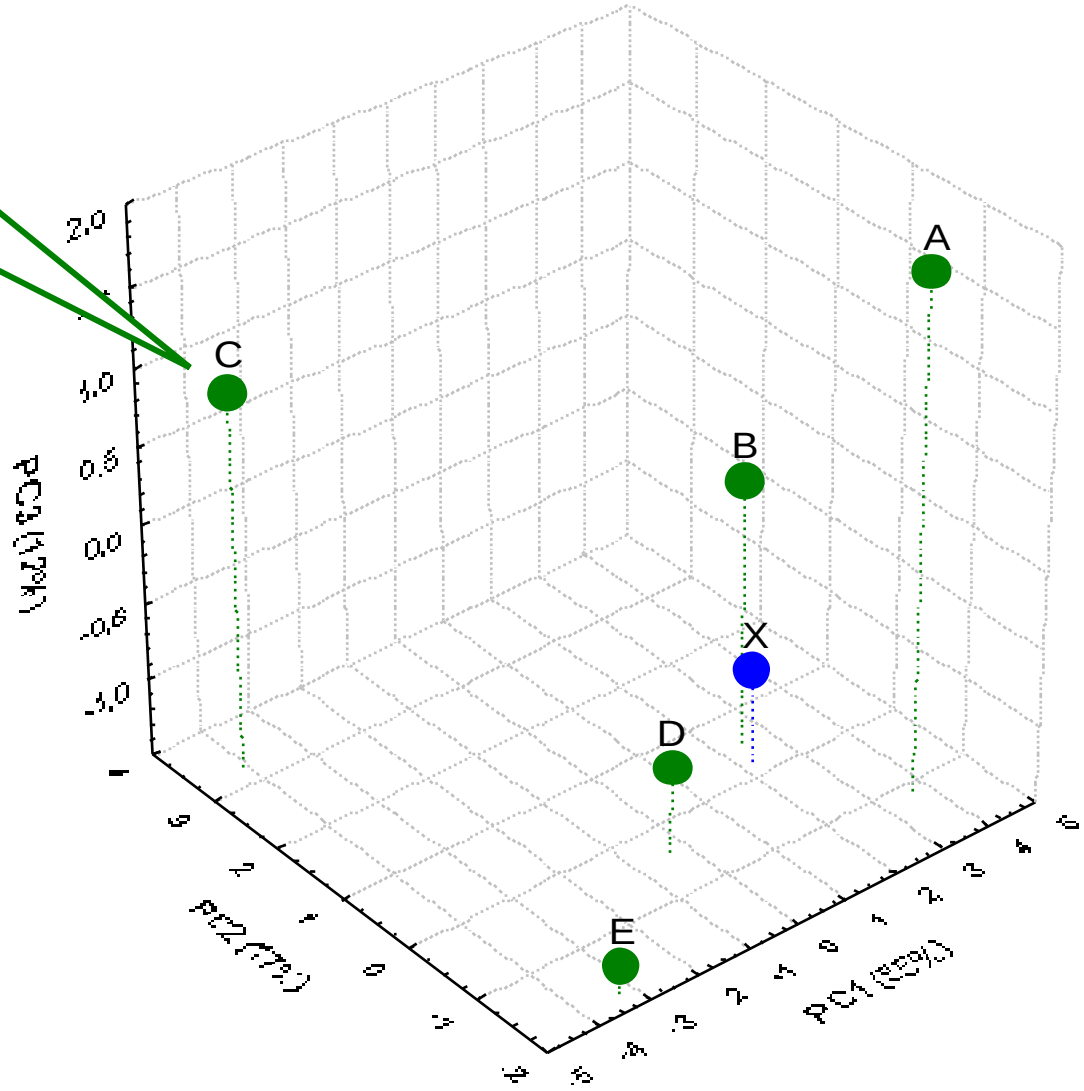
Cranfield UNIVERSITY



PLOT OF FIRST THREE PRINCIPAL COMPONENTS

Cranfield UNIVERSITY

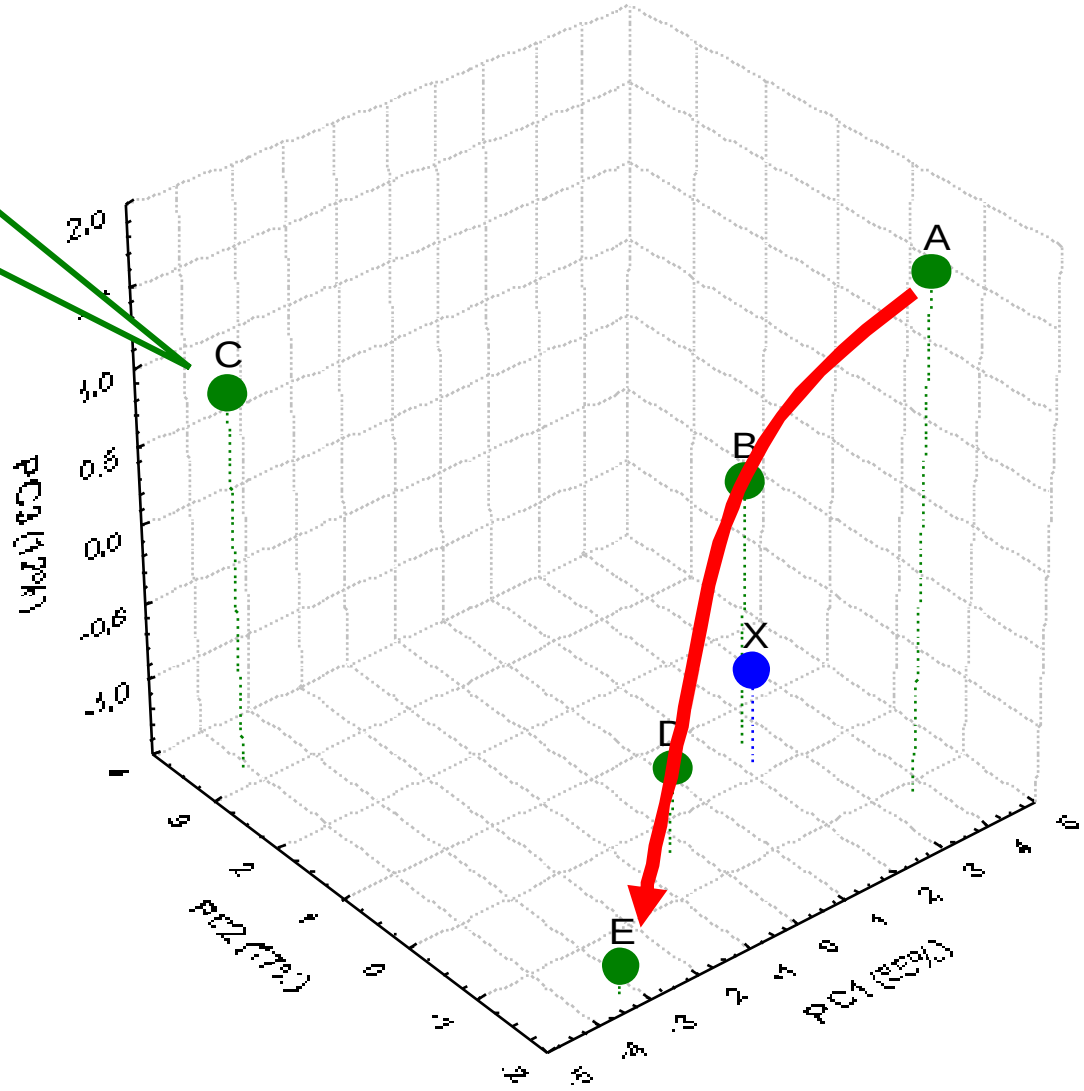
Discrimination mainly due to one PLFA



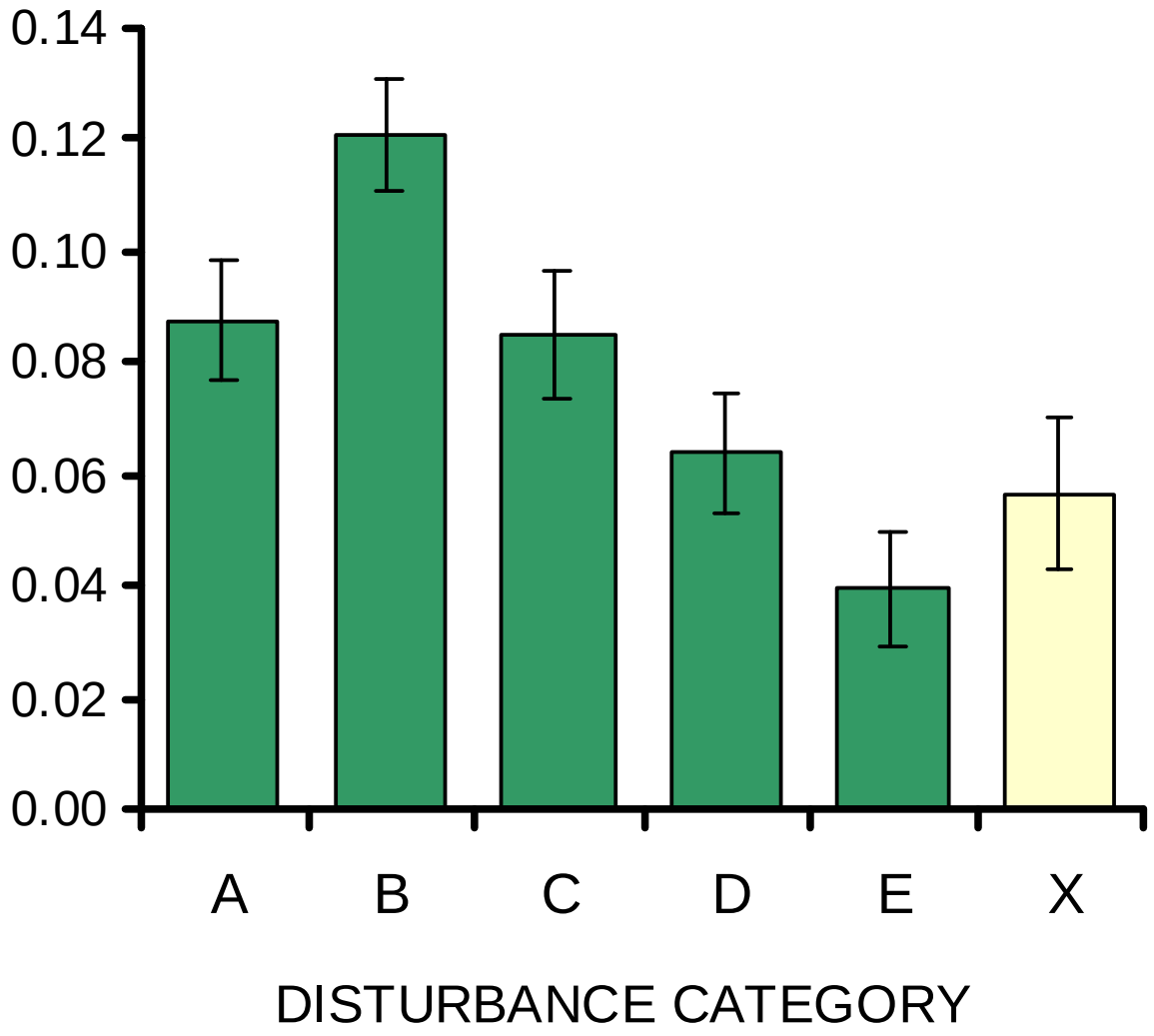
PLOT OF FIRST THREE PRINCIPAL COMPONENTS

Cranfield UNIVERSITY

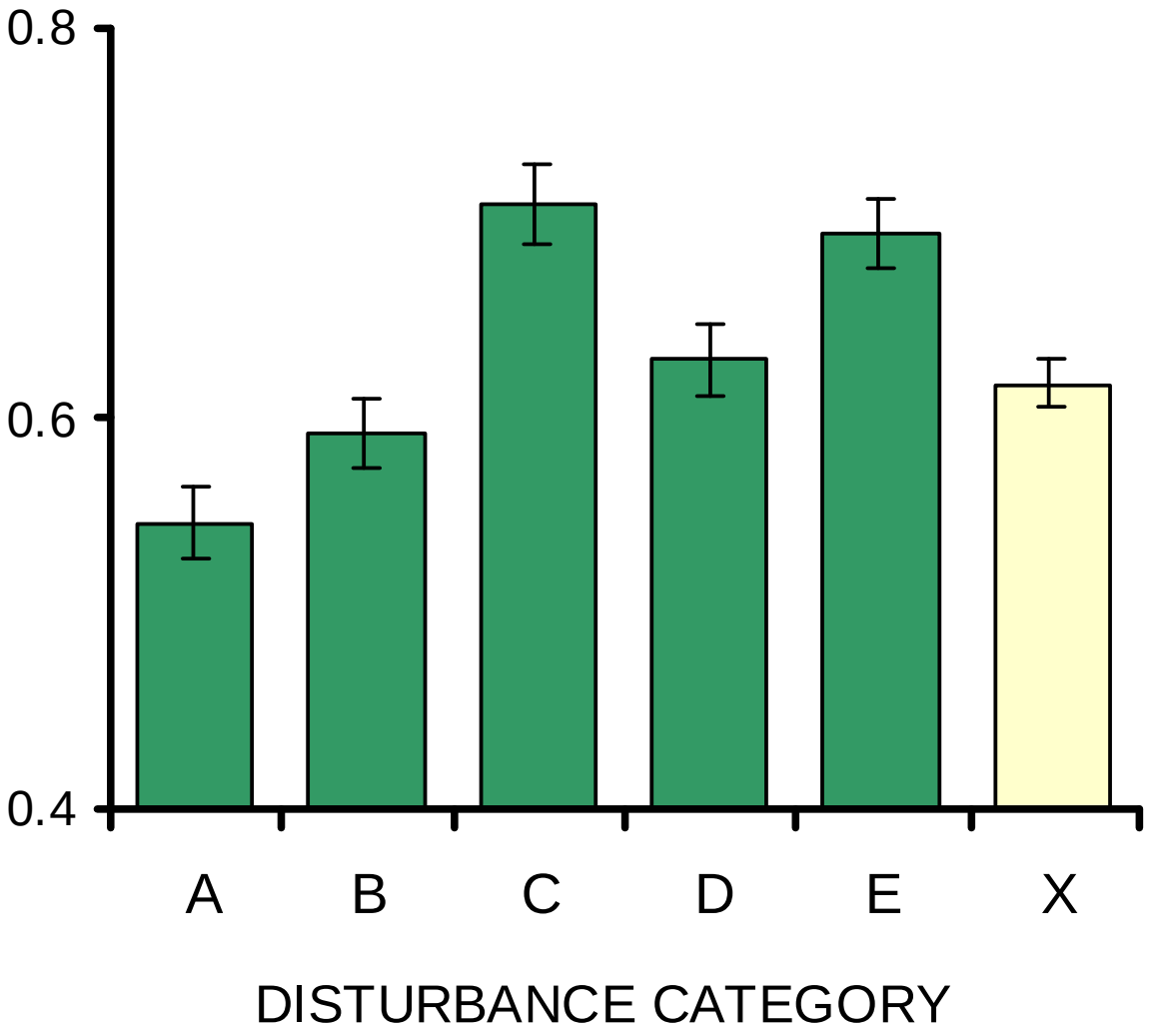
Discrimination mainly due to one PLFA



FUNGAL:BACTERIAL RATIO



“STRESS” RATIO



SALISBURY PLAIN CASE STUDY

Cranfield UNIVERSITY

- Training load influences microbial biomass in a consistent manner
  - greater disturbance → smaller biomass
- Microbial community structure shows distinct trajectory in relation to training load
  - relatively few PLFAs lead to discrimination
- Sample site C – why different ?

DECISION TREE ANALYSIS

Cranfield UNIVERSITY

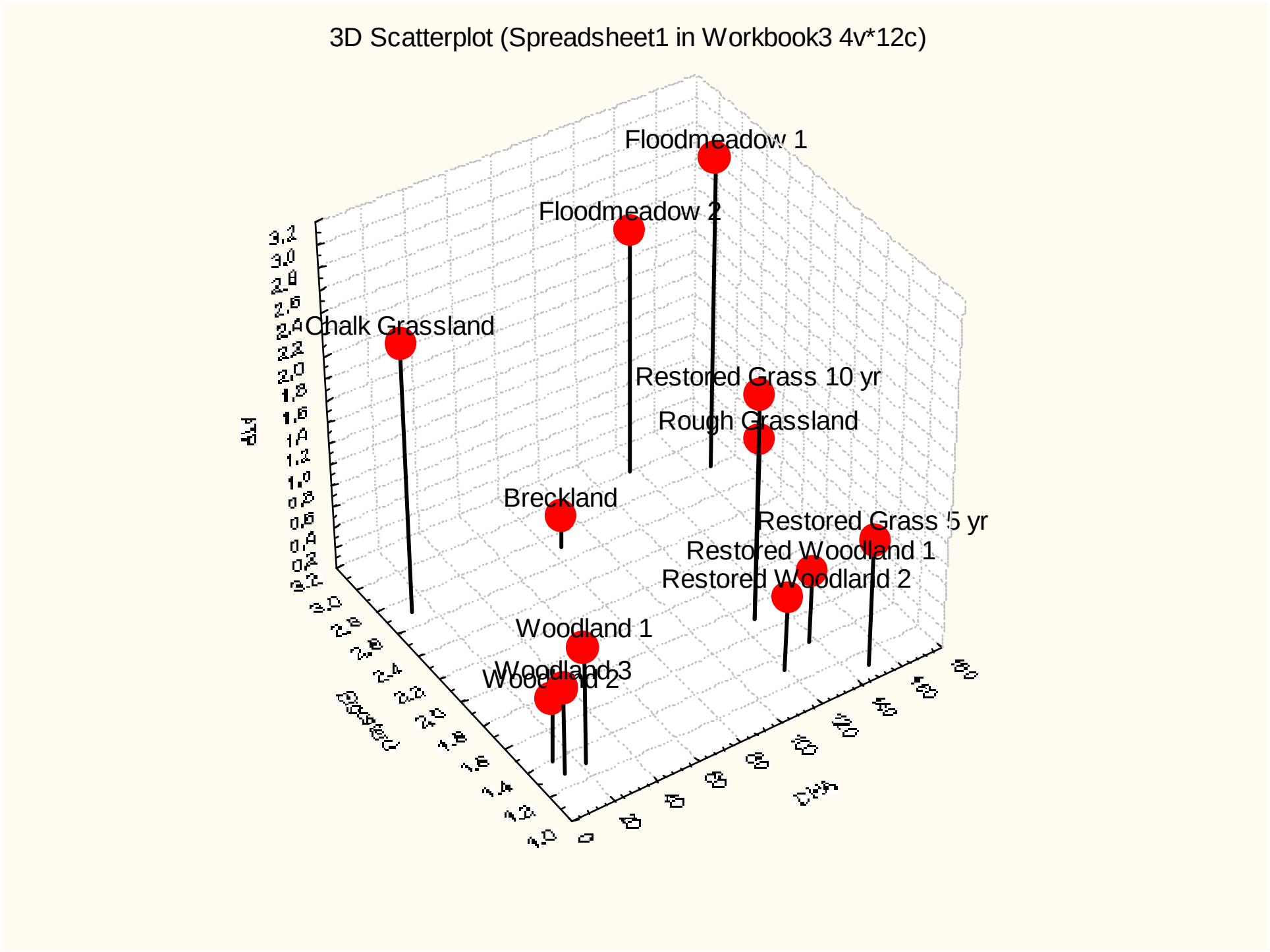
- Formulate model using decision tree
- Which are key drivers that discriminate between samples ?

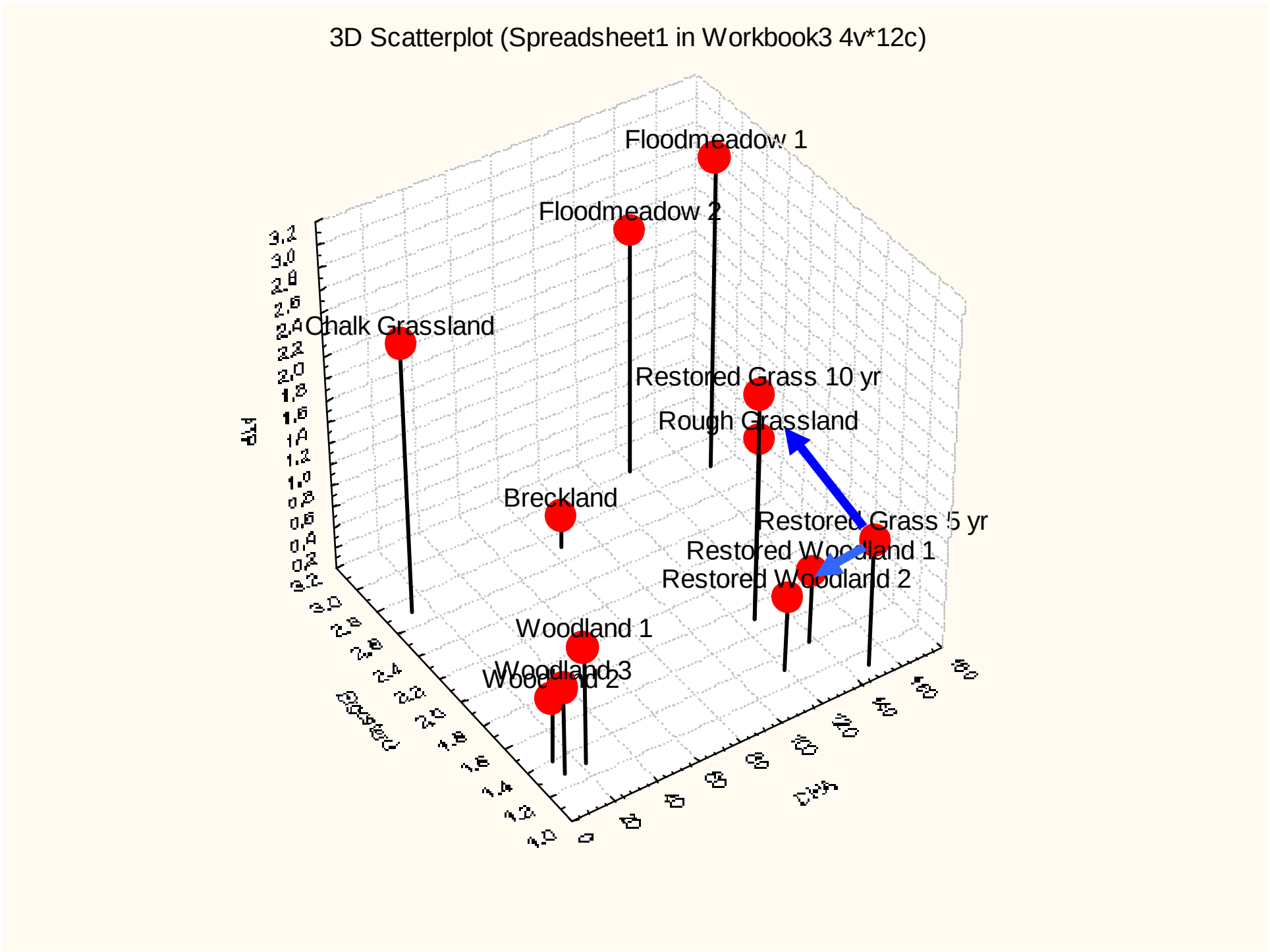
- Showed significance of
  - microbial biomass
  - certain key PLFA compounds

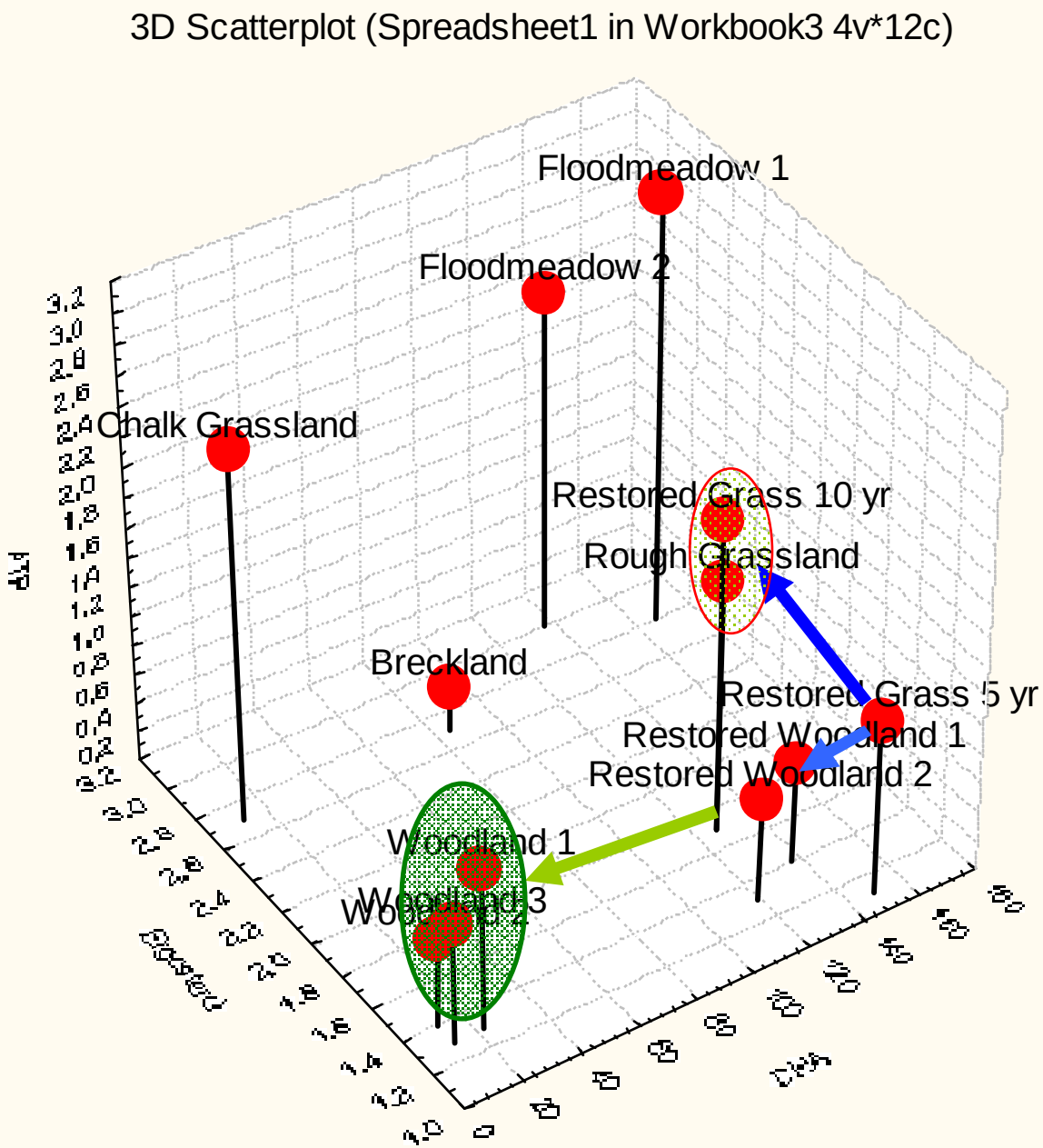
- Predict to 93% accuracy to which disturbance level a soil sample corresponds

Putting it all together

Cranfield UNIVERSITY

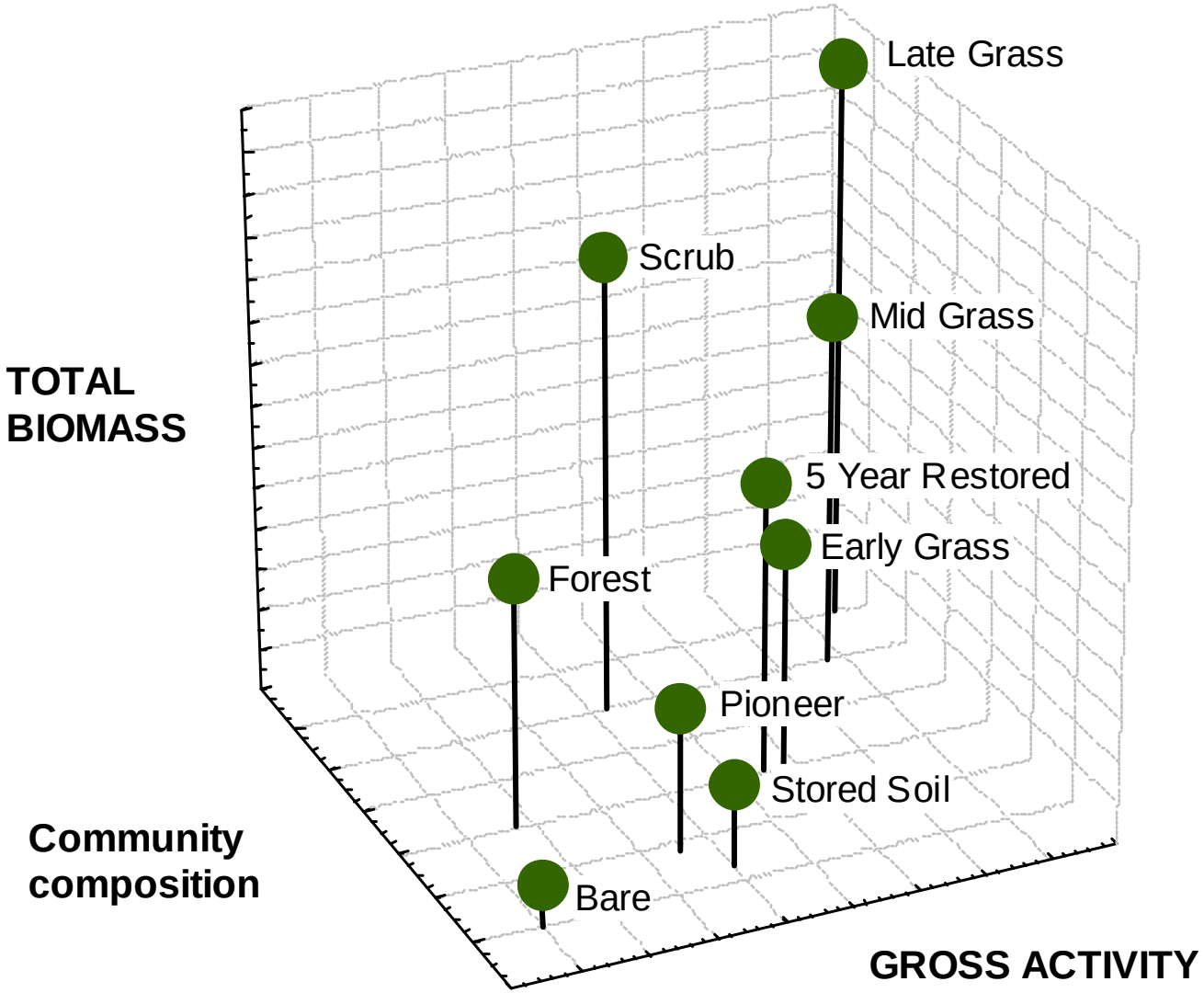

3D Scatterplot (Spreadsheet1 in Workbook3 4v*12c)
Floodmeadow 1
Floodmeadow 2
Chalk Grassland
Restored Grass 10 yr
Rough Grassland
Breckland
Restored Grass 5 yr
Restored Woodland 1
Restored Woodland 2
Woodland 1
Woodland 3
Woodland 2


3D Scatterplot (Spreadsheet1 in Workbook3 4v*12c)
Floodmeadow 1
Floodmeadow 2
Chalk Grassland
Restored Grass 10 yr
Rough Grassland
Breckland
Restored Grass 5 yr
Restored Woodland 1
Restored Woodland 2
Woodland 1
Woodland 3
Woodland 2

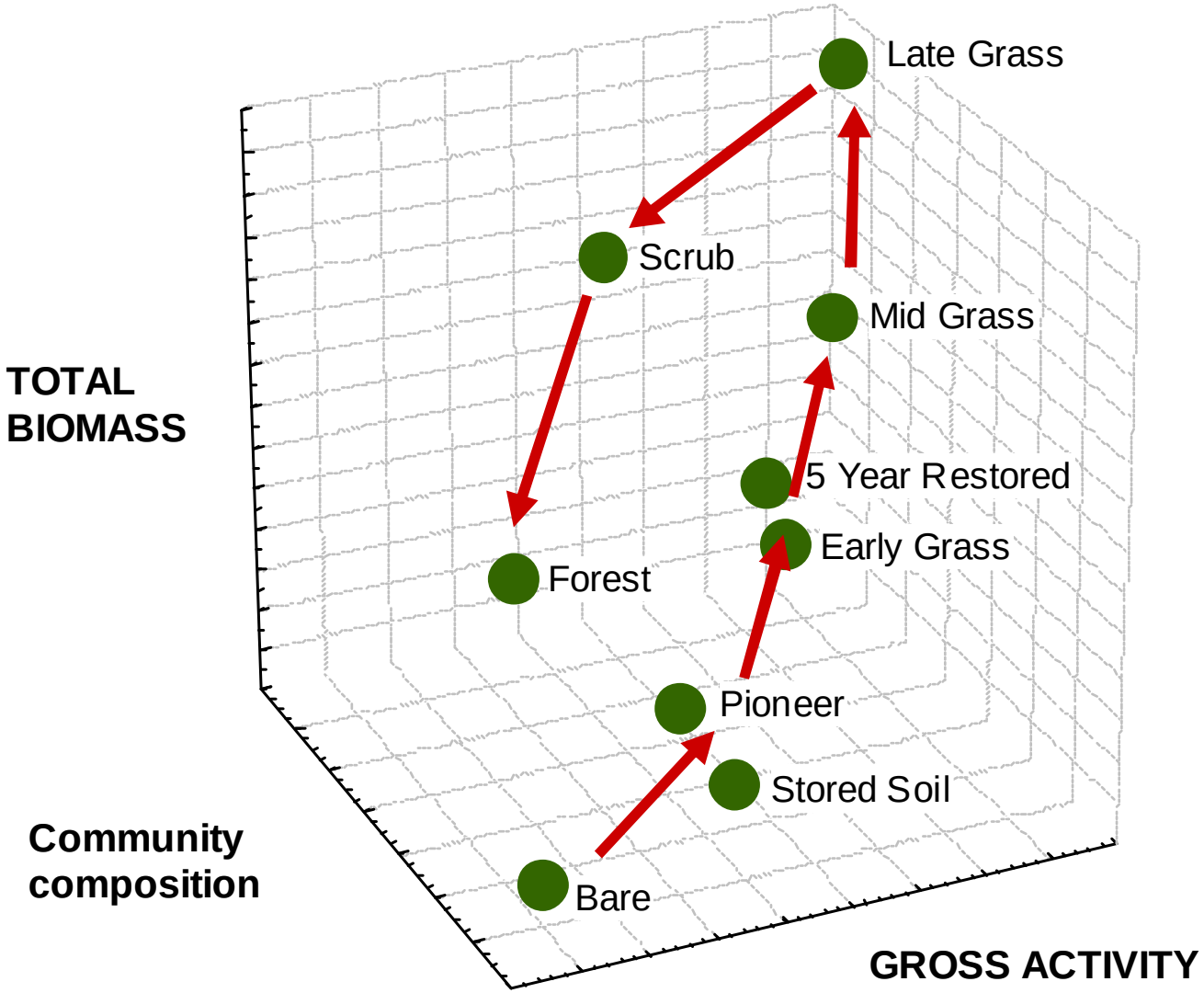

3D Scatterplot (Spreadsheet1 in Workbook3 4v*12c)
Floodmeadow 1
Floodmeadow 2
Chalk Grassland
Restored Grass 10 yr
Rough Grassland
Breckland
Restored Grass 5 yr
Restored Woodland 1
Restored Woodland 2
Woodland 1
Woodland 3
Woodland 2

Cranfield UNIVERSITY Silsoe

SOIL MICROBIAL PROPERTIES AS ECOLOGICAL INDICATORS



COMMUNITY TRAJECTORIES…



CONCLUSIONS:
BIOLOGICAL STATUS OF SOILS

- Microbes provide sensitive indicator of ecological status / ecosystem health
  - assessment of degree of disturbance
  - assessment of current status in relation to management of degraded and restored ecosystems
  - quantify where the system ‘is’ and where it is ‘going’
- Restoration context
  - assess potential for restoration and status of such management (target setting)

Facilitators or Followers?

- Facilitation by modifying soil conditions
- Facilitation by symbionts
- Inhibition by symbionts
- Facilitation by pathogens and herbivores
- Inhibition by pathogens and herbivores
- Maintenance of stability in late-successional assemblages

Principal research gaps

- How much genotypic and functional diversity is required to facilitate plant community function?
- What community players, other than symbionts, are essential for facilitation or inhibition?
- Do shifts from bacterial to fungal dominated communities result in ecosystem stability?
- A large scale survey of restoration and reference sites
- What are the feedbacks between the soil biological community and soil structural formation and stability?

Nine attributes of a restored ecosystem

Cranfield UNIVERSITY

1. Reference ecosystem, characteristic assemblages
2. Indigenous species, some exceptions
3. Functional groups present or available
4. Physical environment appropriate
5. Ecosystem functions normally for successional stage
6. Landscape integration, biotic and abiotic interactions
7. Potential threats eliminated
8. Resilience and integrity
9. Self-sustaining

Nine attributes of a restored ecosystem

Cranfield UNIVERSITY

1. Reference ecosystem, characteristic assemblages
2. Indigenous species, some exceptions
3. Functional groups present or available
4. Physical environment appropriate
5. Ecosystem functions normally for successional stage
6. Landscape integration, biotic and abiotic interactions
7. Potential threats eliminated
8. Resilience and integrity
9. Self-sustaining

Conclusions

- The soil biological community is a a key component of the soil ecosystem, crucial in supplying ecosystem goods and services
- Understanding it is critical to provide successful outcomes in restoration programmes
- It may be use to indicate objectively the progress, or lack of it, in such programmes