FINANCÉ PAR ANR

The ecosystem in practice: interest and problems of an old definition for constructing ecological models

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Ecology is an « integrative » or « synthetic » science

pedology

[bio]geography

systematics

geology

genetics

hydrology

demography

[bio][geo]chemistry

ecology

physiology

[micro]meteorology

cell biology

climatology

graph theory

thermodynamics

game theory

system dynamics

As a result of this « integration », ecological modelling is far from united
- PDE type models
- cellular automata
- individual-based models / multi-agent systems

Consequences:
- incompatible time and space representations
- problems with model comparisons
- and « the scaling problem » : changing from one type of model to another *for the same real-world system* is costly – when possible.

Can ecological concepts help us designing a broadly applicable framework for ecological modelling ?

Which concepts used in ecology are truely 'ecological', i.e. were not borrowed from another scientific field ?

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The ecosystem

...

What can we build upon the ecosystem definition ?

Problem: 'conceptual drift'

The ecosystem was defined in 1935 and has undergone many transformations since then.

Jax K., 2007. Can We Define Ecosystems? On the Confusion Between Definition and Description of Ecological Concepts. *Acta Biotheoretica*, 55:341-355.

« A major problem, which impedes the solution to these questions, is a common confusion between ***definitions*** *and* ***additional descriptions*** *of concepts »*

example:

O'Neill R.V., 2001. Is it time to bury the ecosystem concept? (with full military honors, of course). *Ecology*, 82:3275-3284.

“There is no proof of ecosystem showing stability, resilience, etc.”

These properties were never part of the initial definition.

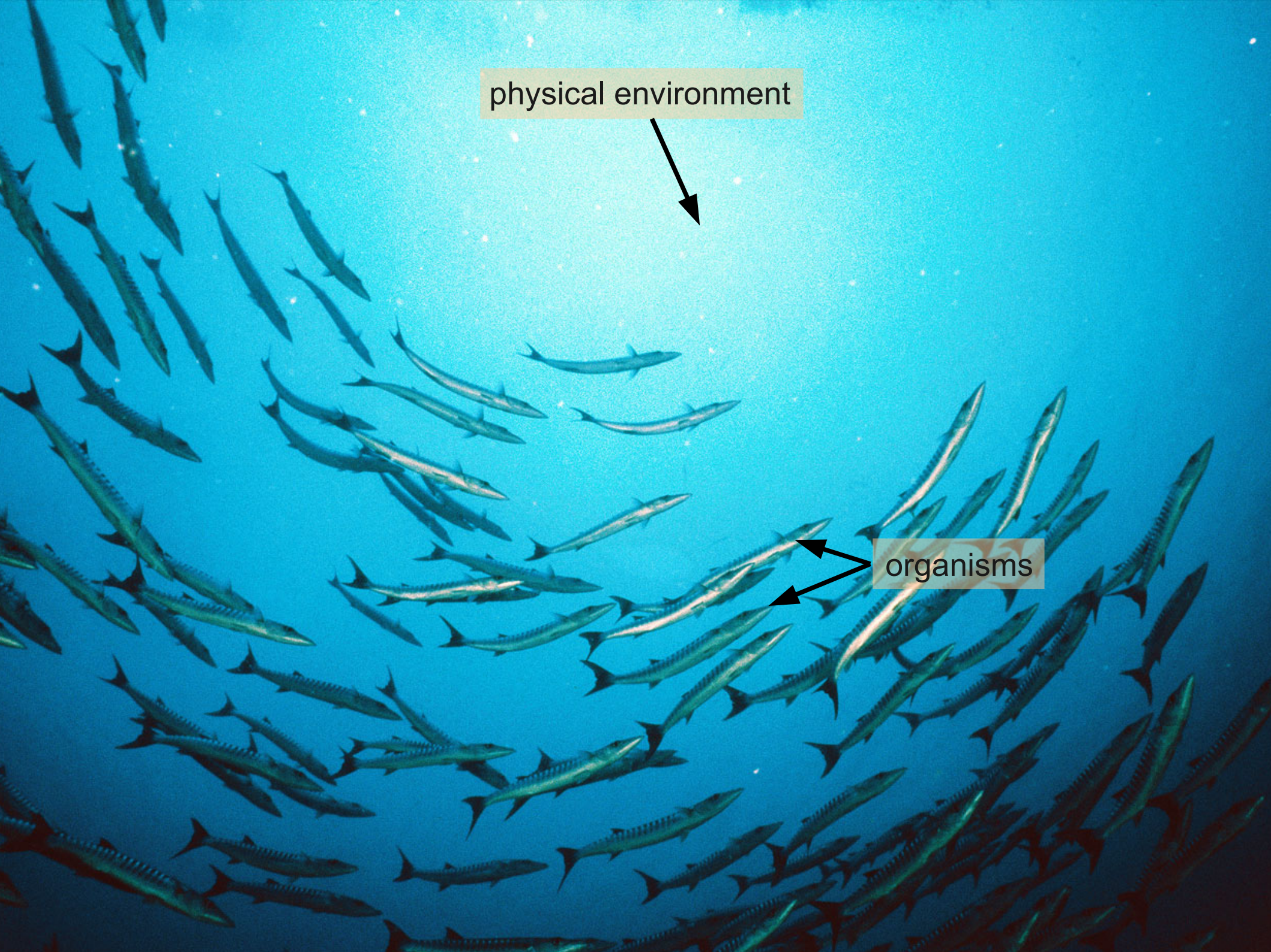
Back to the roots!

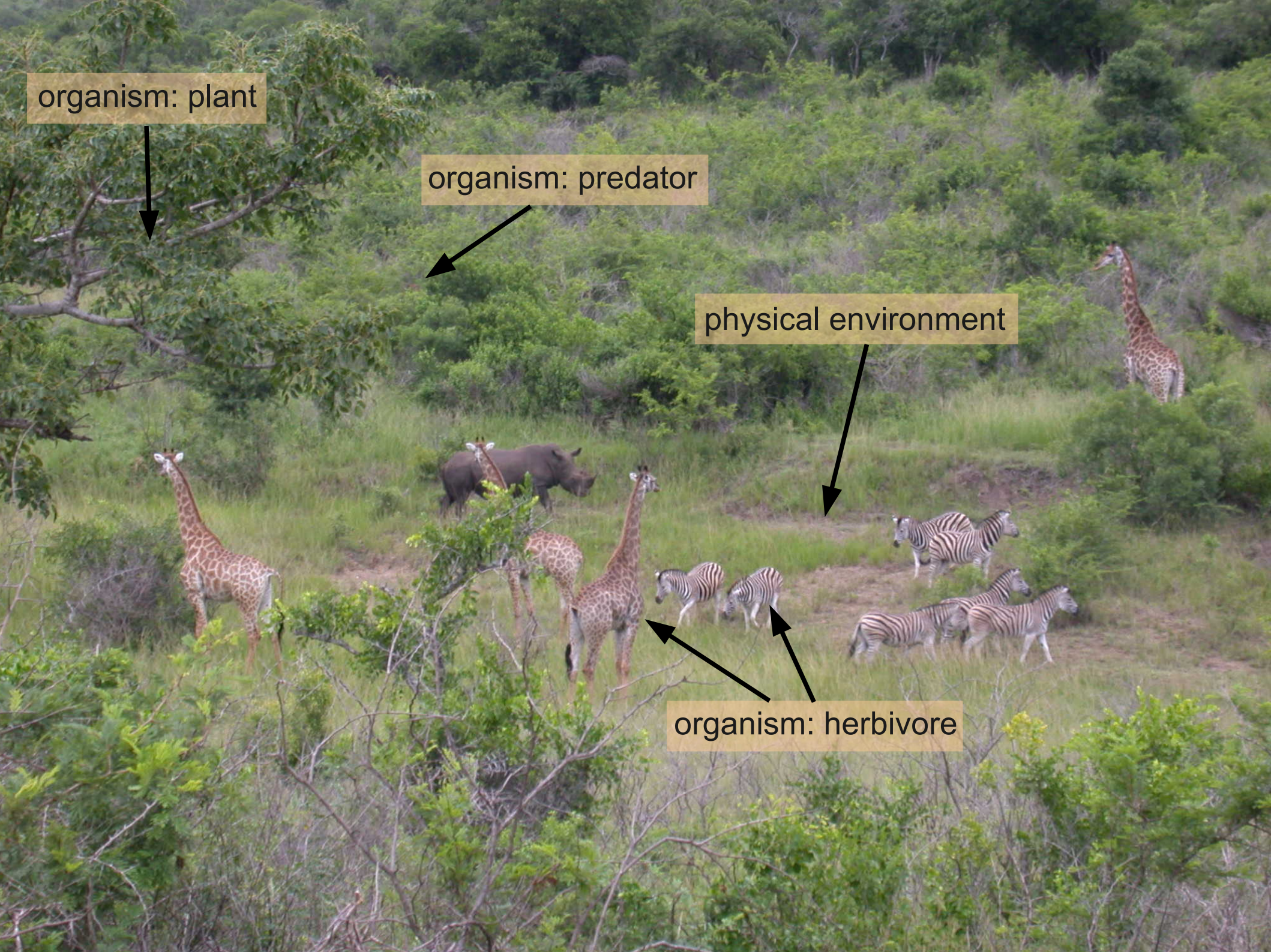
The ecosystem

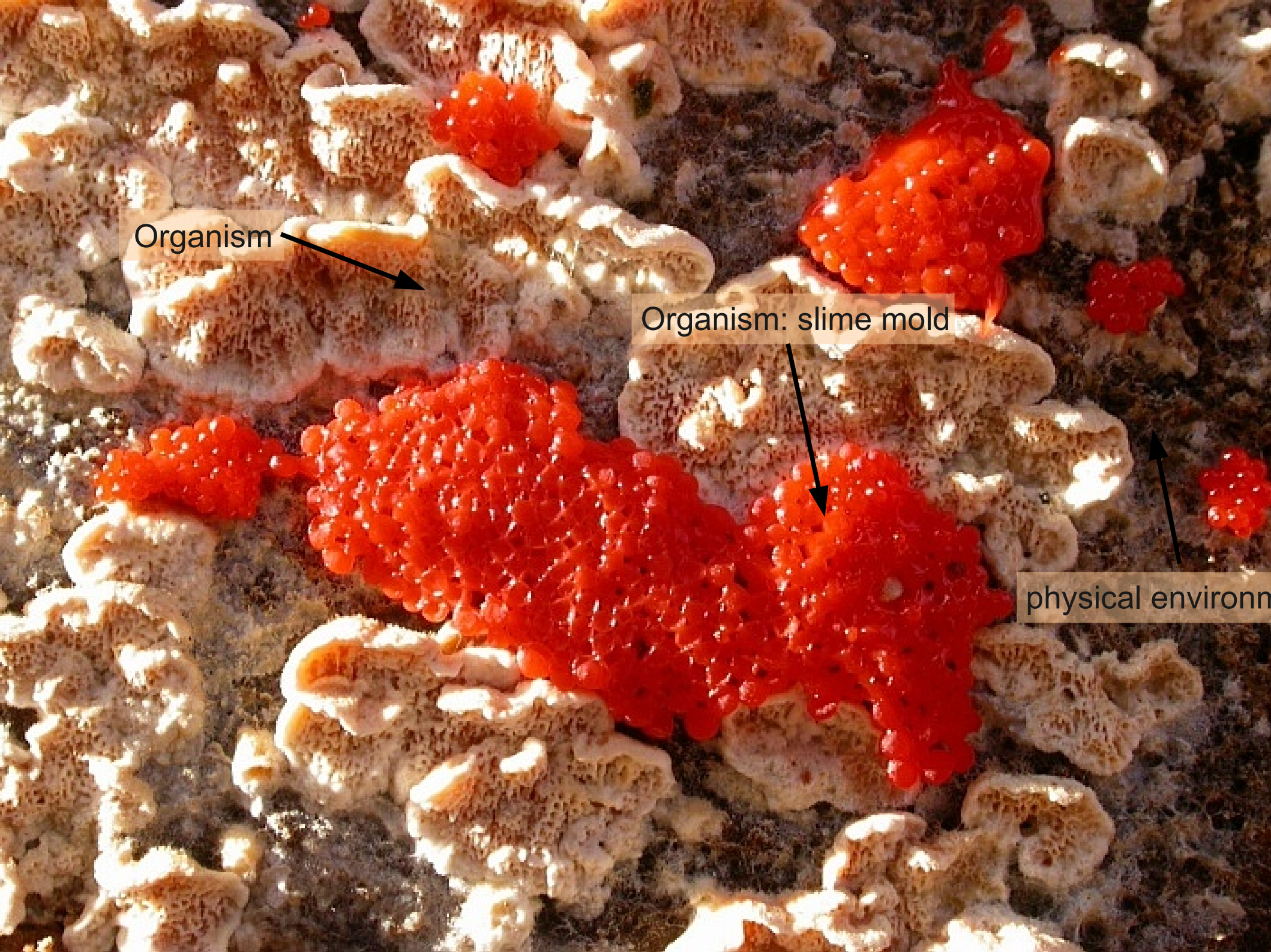
Tansley (1935) The use and abuse of vegetational concepts and terms. *Ecology* **16**:284-307:

> [...]
> But the more fundamental conception is, at is seems to me, the whole *system* (in the sense of physics), including not only the organism-complex, but also the whole complex of physical factors forming what we call the environment of the biome – the habitat factors in the widest sense. Though the organisms may claim our primary interest, when we are trying to think fundamentally we cannot separate them from their special environment, with which they form one physical system.

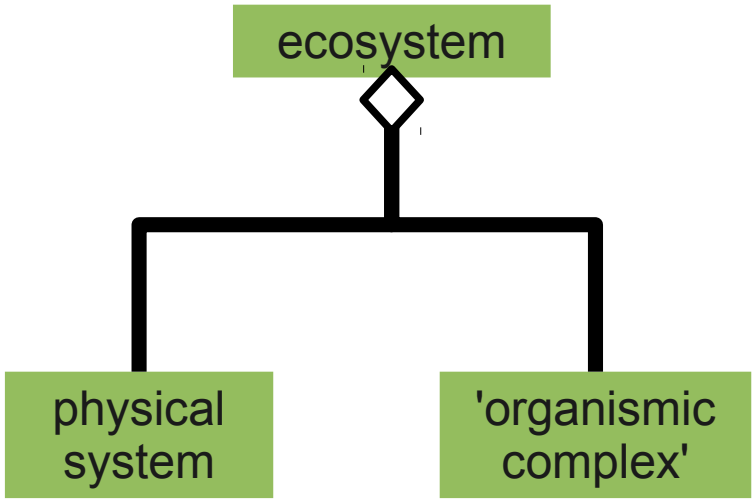
1. Ecosystem = biological system + physical system

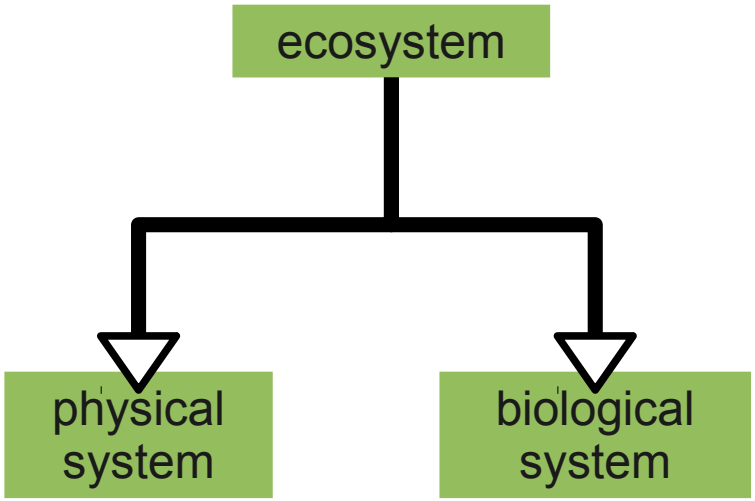

physical environment
organisms


organism: plant
organism: predator
physical environment
organism: herbivore


Organism
Organism: slime mold
physical environm

Biological or physical system: a creative ambiguity





the ecosystem *has* a physical and a biological part

*'the whole system (in the sense of physics), including not only the **organism-complex**, but also **the whole complex of physical factors**'*

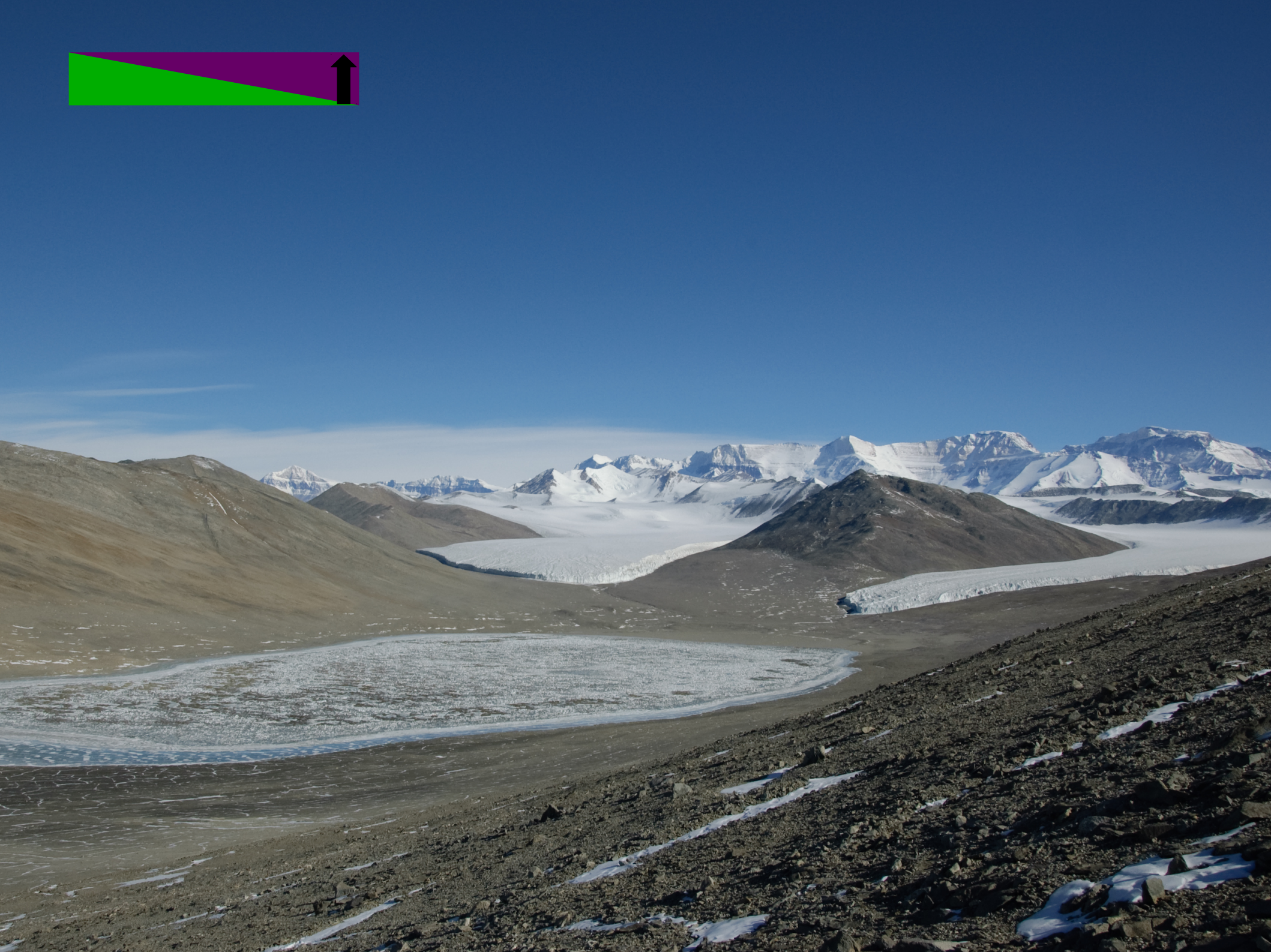
ecosystem = a mixture of organisms and 'physical factors'

the ecosystem *is* a physical and a biological system

*'when we are trying to think fundamentally we cannot separate them from their special environment, with which they form **one physical system**.'*

ecosystem = a system studied with the methods of physics and biology

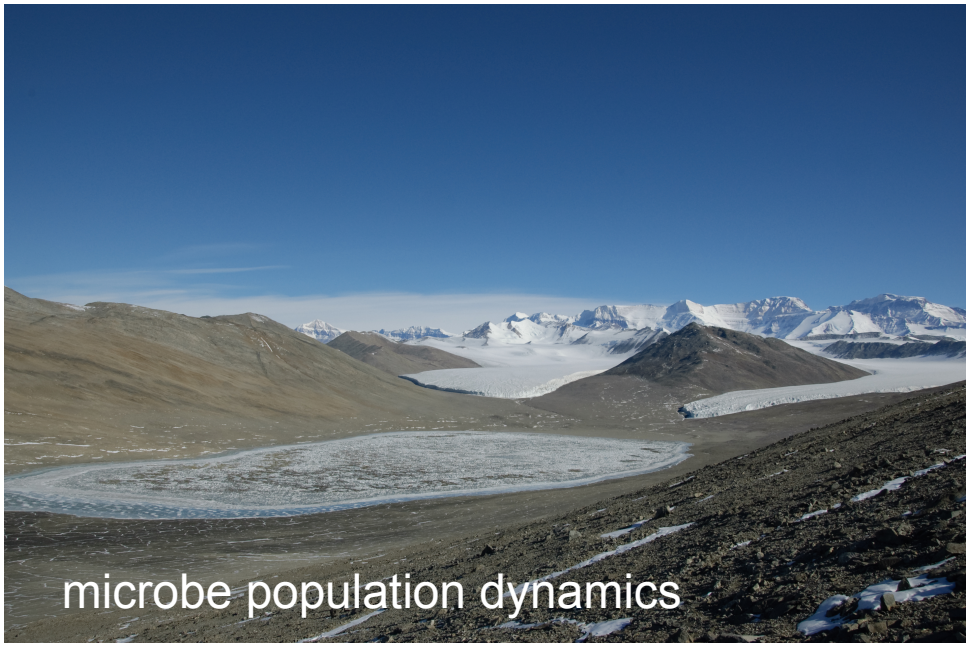

physics-dominated
ecosystem
organism-dominated
ecosystem



The dual nature of ecosystems

Ecosystems as biological systems :
birth, death, reproduction, demography, discrete states, decision, stochasticity

Ecosystems as physical systems :
matter and energy fluxes, thermodynamics, continuous states, determinism, conservation laws



1 system, 2 ***representations***

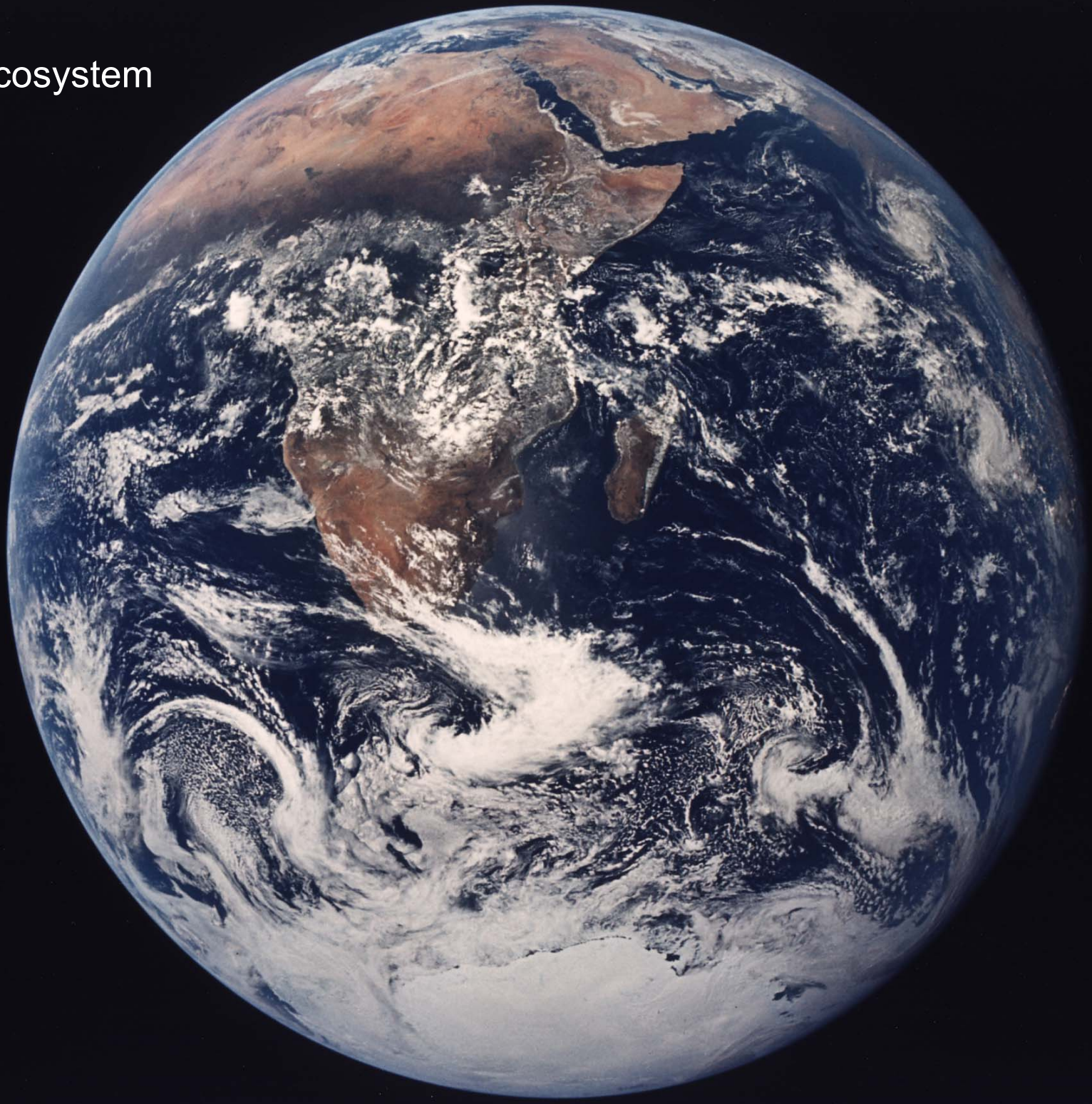
representation = description of a system using a particular method

[...]
But the more fundamental conception is, at is seems to me, the whole *system* (in the sense of physics), including not only the organism-complex, but also the whole complex of physical factors forming what we call the environment of the biome – the habitat factors in the widest sense. Though the organisms may claim our primary interest, when we are trying to think fundamentally we cannot separate them from their special environment, with which they form one physical system.

There is no idea of space, time, or scale in Tansley's definition

2. The ecosystem is a scale-independent concept

a large ecosystem



a small ecosystem

Further down in Tansley's paper:

'... a system we isolate for the purpose of the study'.
'The isolation is partly artificial, but is the only possible way in which we can proceed'
'The mental isolates we make are by no means all coincident with physical systems, though many of them are, and the ecosystem among them.'

3. The ecosystem is a *subjective construct*, a *representation* of the real world

The *holocoen* [(Friederichs 1927) = 'a naturally delimited part of the biosphere'] never achieved the success of the ecosystem concept.

Jax 2006: criteria for a good definition: clarity, consistency, *applicability*

there is a problem with ecosystem boundaries when dealing with the real world. As a physical system, the ecosystem needs to be delineated – we need *space* to locate and isolate the system we want to study when working in the real world

Everything is an ecosystem !

1. ecosystem = physical + biological system
2. scale independent
3. subjective construct

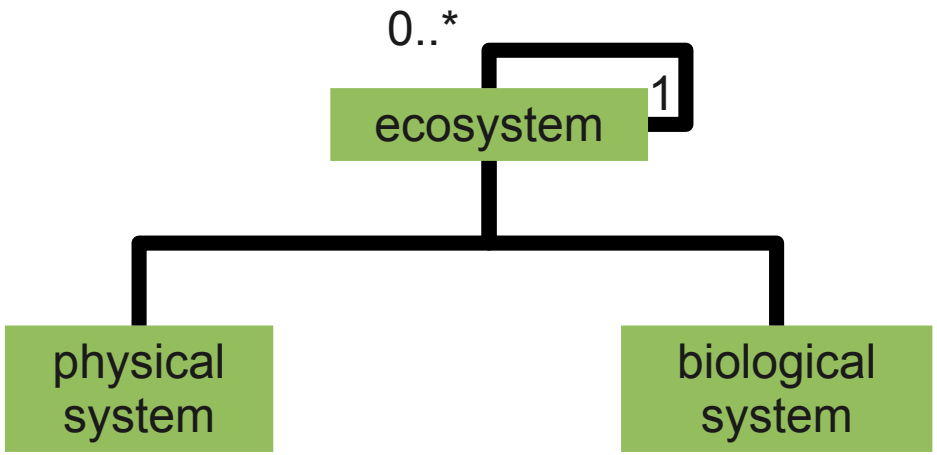
→ **(almost) anything can be studied as an ecosystem**

The ecosystem is the basic building block of ecology. **Ecology consists in viewing everything as ecosystems.**

The ecosystem as a self-similar object

If anything can be treated as an ecosystem, any part of an ecosystem is still an ecosystem:

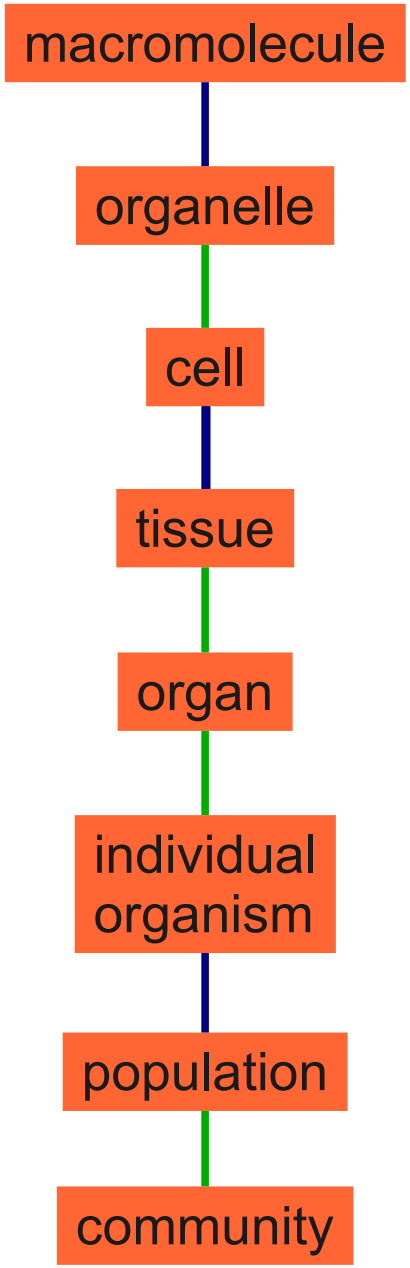
Ecosystems can be nested



how ?

How can we nest ecosystems ?

1. the biological organization hierarchy



An 'objective' hierarchy ?

'part of' relation in the biophysical system hierarchy (Aleschenko & Bukvareva 1991)

— **'statistical system':**
subsystems redundant, can be lost without destroying the whole system

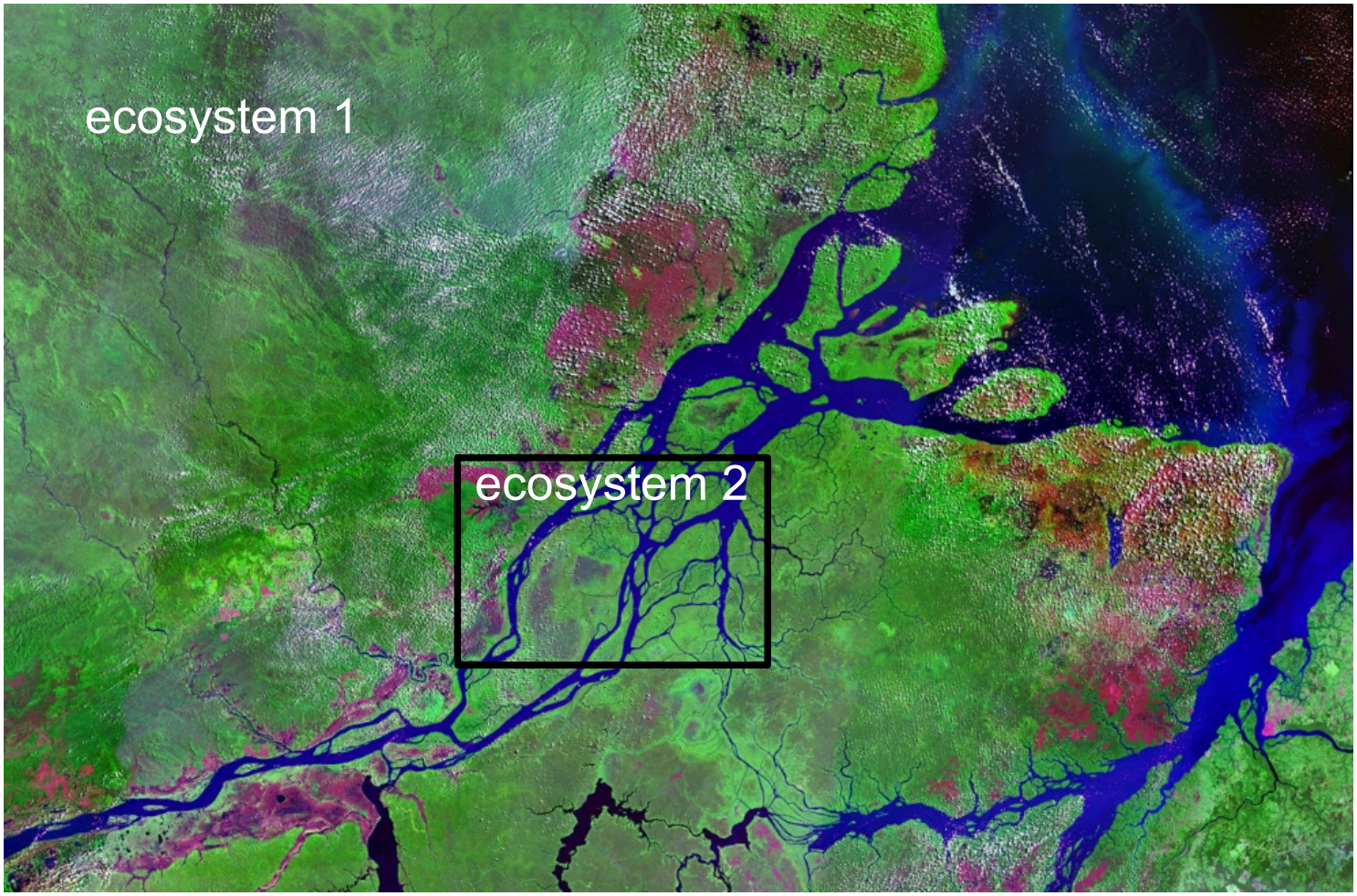
— **'structured system':**
subsystems play different but vital roles, if lost the whole system is destroyed

Problems: colonial animals ? clonal plants ? trees ? subpopulation ? metapopulation ? metacommunity ? beyond the community ?

This is *not* an universal, objective, hierarchy

How can we nest ecosystems ?

2. the spatial zooming operator



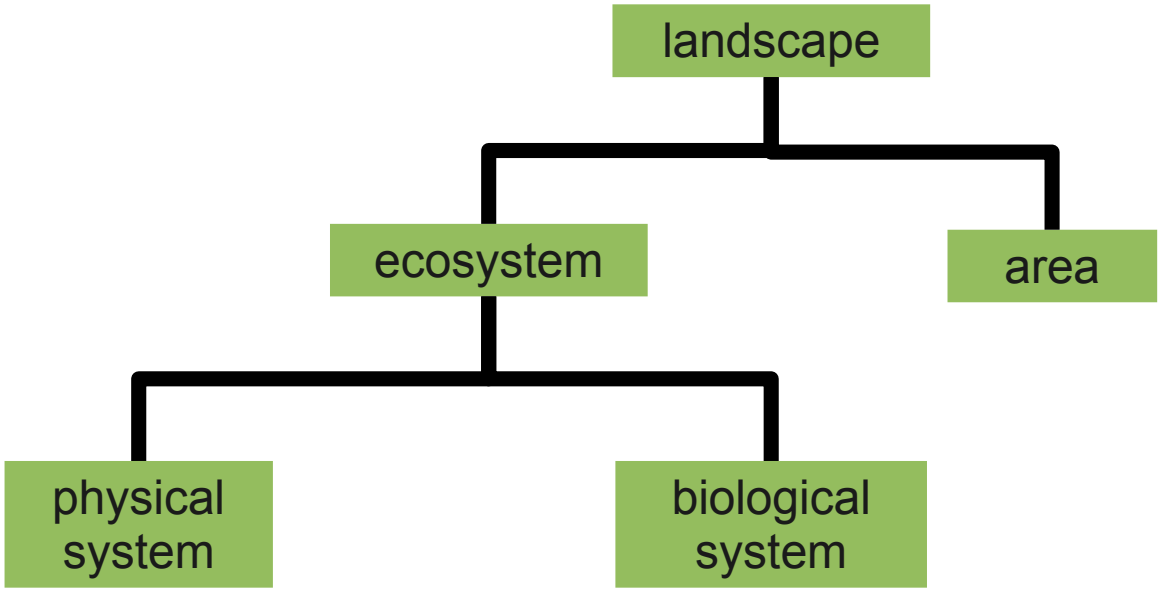
very natural,
intuitive,
operation,

but...

Space comes into play!

this applies to ***landscapes***, i.e. the spatialized counterpart of ecosystems

A landscape is an ecosystem within an area (Lepczyk et al. 2008)



The landscape is needed to delineate ecosystems in the field or to nest ecosystems using the spatial zooming operator

Lepczyk C.A., C.J. Lortie & L.J. Anderson, 2008. An ontology for landscapes. *Ecological Complexity*, 5:272-279

How can we nest ecosystems ?

3. topological nesting

Forest = soil + vegetation

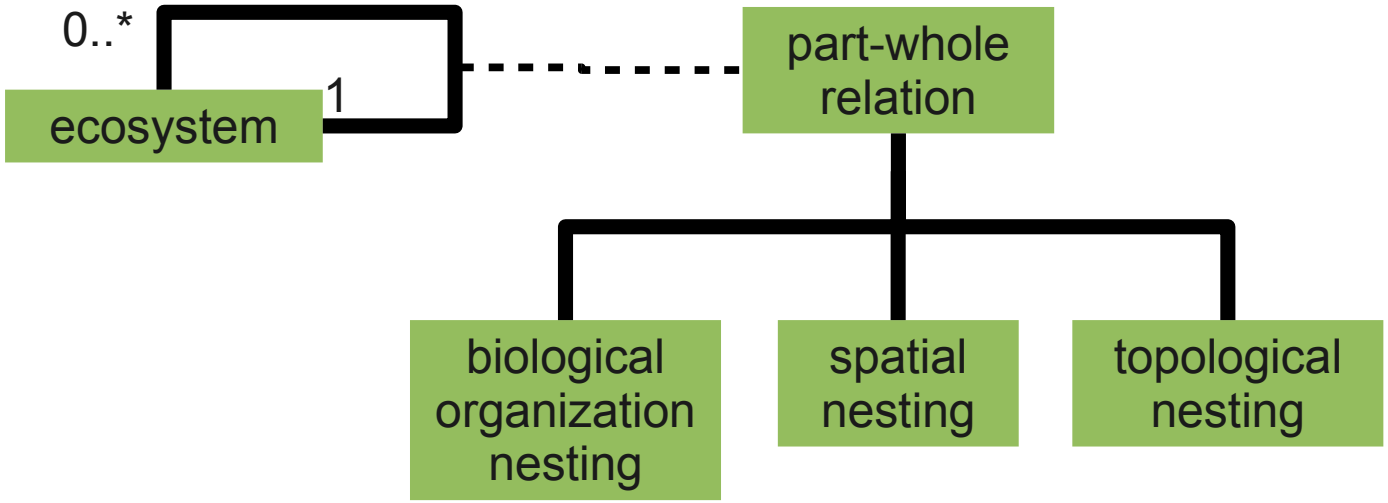
2 different media

1 interface

organisms are adapted to specific media or interfaces

At least 3 (and maybe more) relationships can be used to construct hierarchies of nested ecosystems

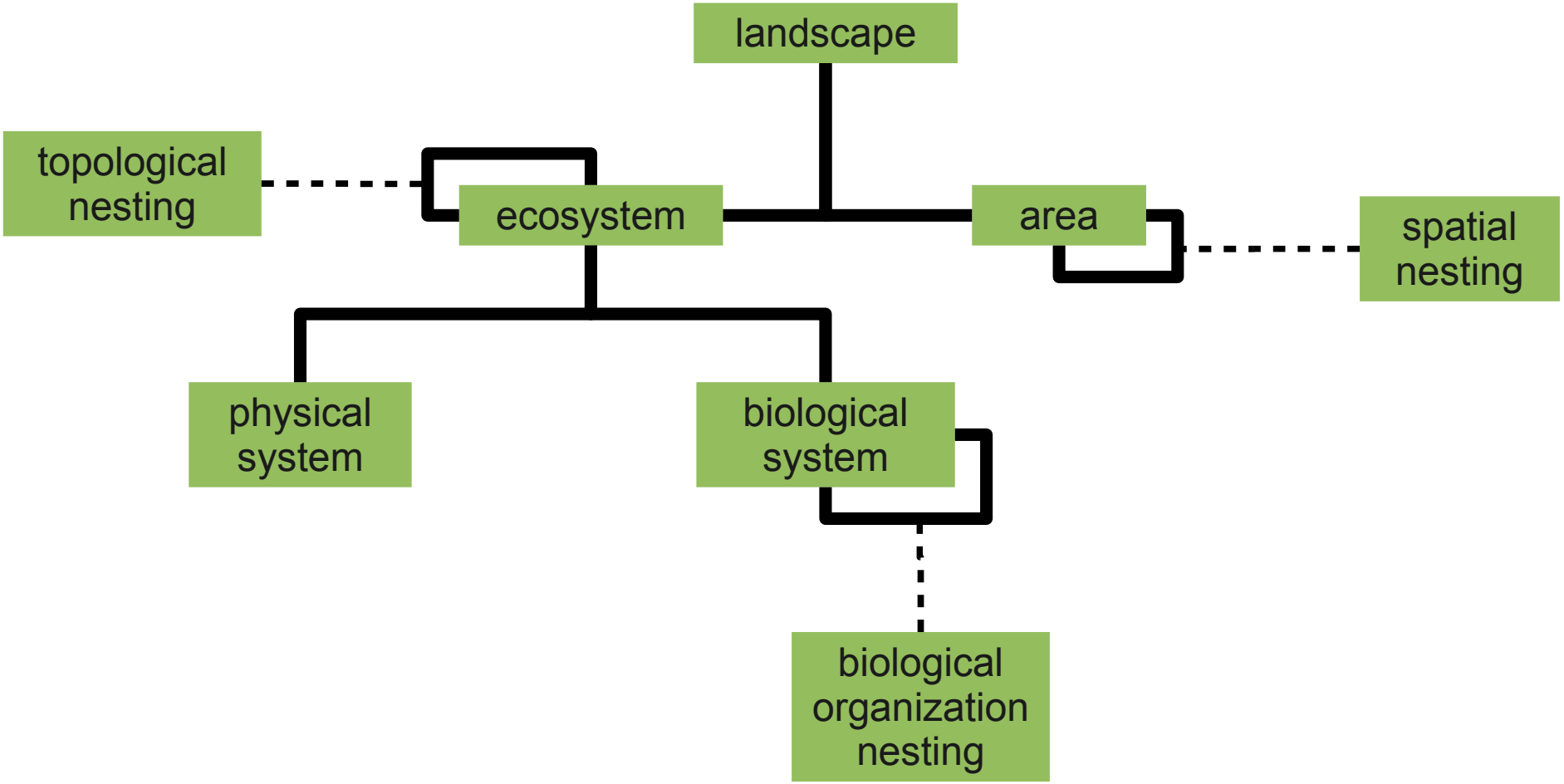
➡ The ecosystem is a ***complex system***



'A ***complex system*** is a system composed of interconnected parts that as a whole exhibit properties not obvious from the properties of the interconnected parts (***emergence***).' [wikipedia]

1) in an ecosystem parts are of the same type as the whole
2) 'not obvious' introduces subjectivity in the definition

A modern view of the ecosystem: a self-similar complex system



2 problems

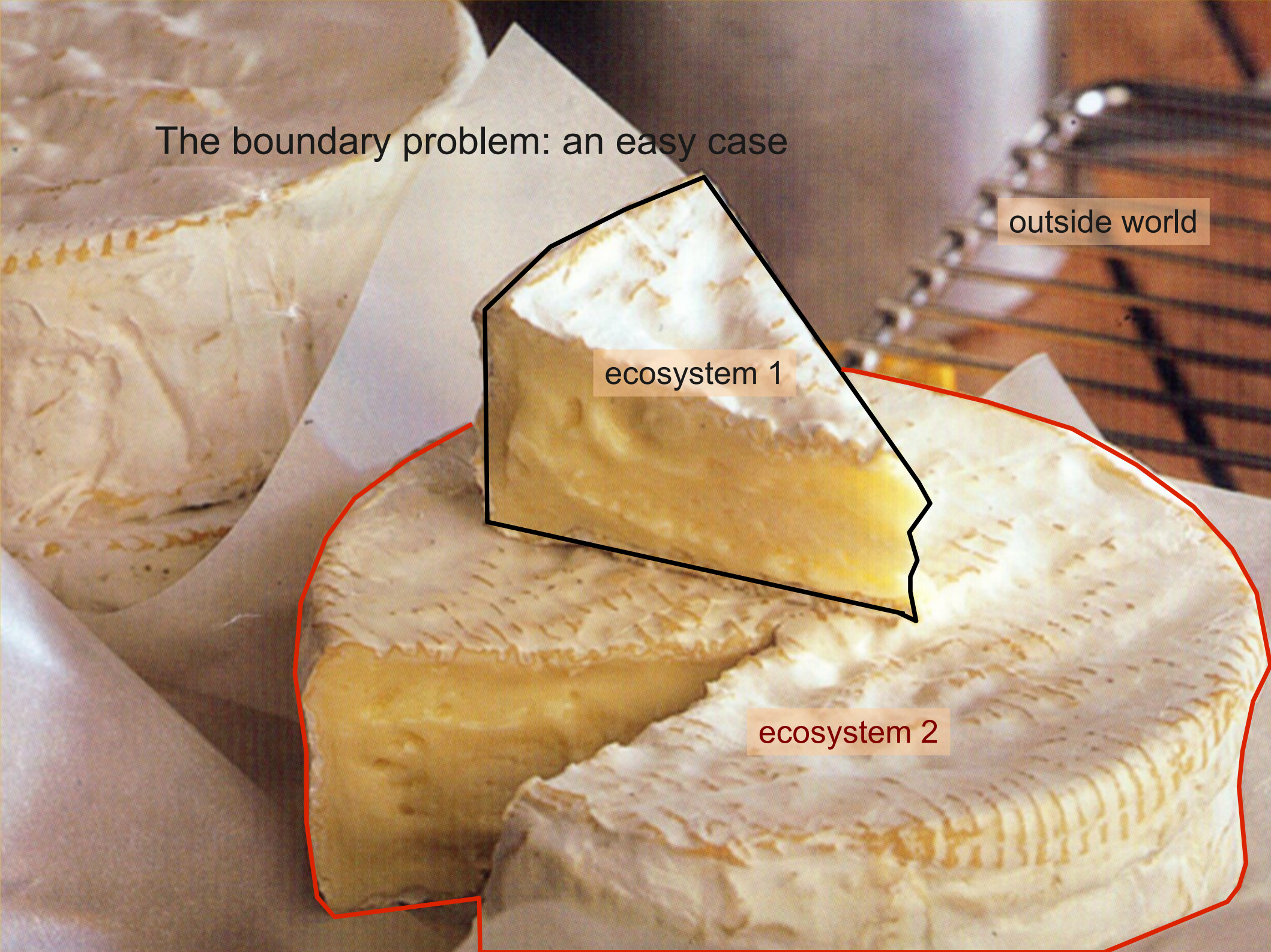
The boundary problem:

In practice, how do we delineate ecosystems in the field?

The abstraction problem:

Can the sub-systems of an ecosystem be represented at the same abstraction level ? Is the ecosystem a consistent representation of the real world ?

The boundary problem: an easy case




A not so easy case
Should the lake be isolated from its water catchment ?

The decision to consider the lake or the lake within its catchment is a **choice**.

It is usually motivated by 'the purpose of the study', although scientific tradition also interfers.

What is the link with 'the purpose of the study' ?

Examples:

- considering the water catchment around the lake means we are dealing with water runoff (a particular **ecological process**).

- if we were interested by the full trophic network of the lake, we might consider migratory birds as top predators. We would then extend the spatial domain differently (eg where is the lake on a migration route). That's another **ecological process.**

➡ The spatial domain we consider depends on the **ecological processes** we want to consider in the study (which depend on the purpose of the study).

In our lake, if we want to study **both** water runoff and trophic network, then logic suggests to use **two** spatial domains :

The spatial domain of an ecosystem might not be unique

We can infer the spatial domains associated to an ecosystem from the processes **we decide** to consider:

There are no *objective* spatial boundaries for an ecosystem.

1) This is different from the landscape
2) Delineating a landscape is easy, delineating the spatial domains of an ecosystem is not
3) which may explain why we need the landscape concept to work on ecosystems

Jax K., 2006. Ecological units: Definitions and application. *Quarterly Review of Biology*, 81:237-258:

'In everyday practice of ecology, this mingling of *definition criteria* and *factual information* manifests itself, *when spatial boundaries are regarded as identical to functional ones*'

Ecosystem boundaries are *functional* by construct; 1 or more spatial scales

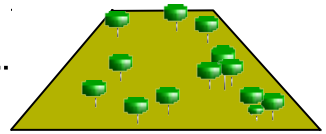
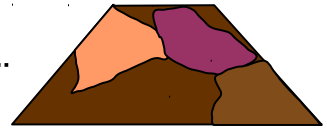
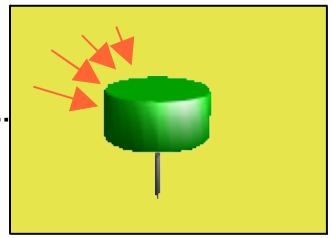
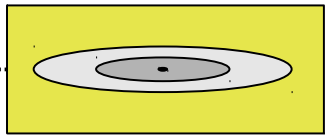
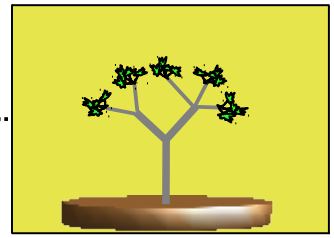
Landscape boundaries are *spatial* by construct; 1 spatial scale

Application for modelling

1 associate processes to spatial representations of an ecological object (based on computation optimisation)

2 manage interaction between processes through spatial overlaying of spatial representation of an ecological object

ANR Project : the 3Worlds modelling platform for ecosystem simulation

ecological processes	**spatial representation**
local competition, population dynamics	
variability of the physical environment	
radiation absorption, photosynthesis	
seed dispersal, competition for nutrients	
carbon allocation, morphologic plasticity	

The abstraction problem

'*Abstraction is used to reduce and factor out details so that one can focus on a few concepts at a time*' [wikipedia]

Do we need to know every organism in an ecosystem?
What is the correct level of detail for an ecosystem ?
- parsimony principle.

Can we describe an ecosystem to the same level of, e.g., biological organization (e.g. population or individual)?

What is the consequence of inconsistency in the level of abstraction of ecosystem components?

At first sight, it makes sense to decribe an ecosystem at the same level of abstraction for all its components (as a complex system)

But this seems **impossible**: whatever ecosystem is studied, some of its parts will *always* be more detailed than others.

Examples:

- population level: too many & unknown species !

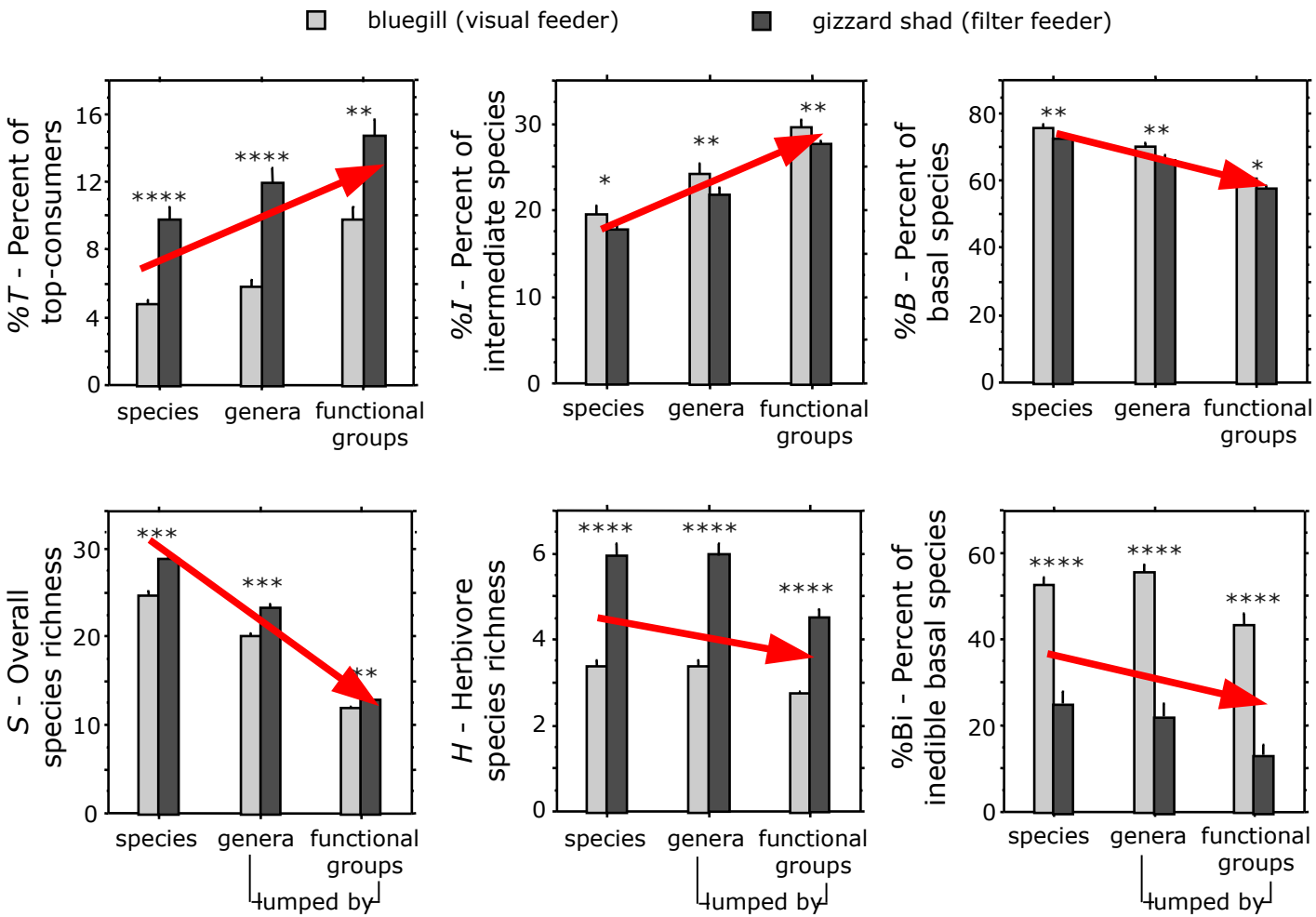
- individual level: sizes of individual organisms span 7-8 orders of magnitude.

The common practice is to focus on dominant species, features, traits. Which may affect resilience and other traits, eg response to climate change

This is a BIG issue !

Importance of the level of abstraction: an example from trophic networks

Hulot et al. 2000; Lazzaro et al. 2009



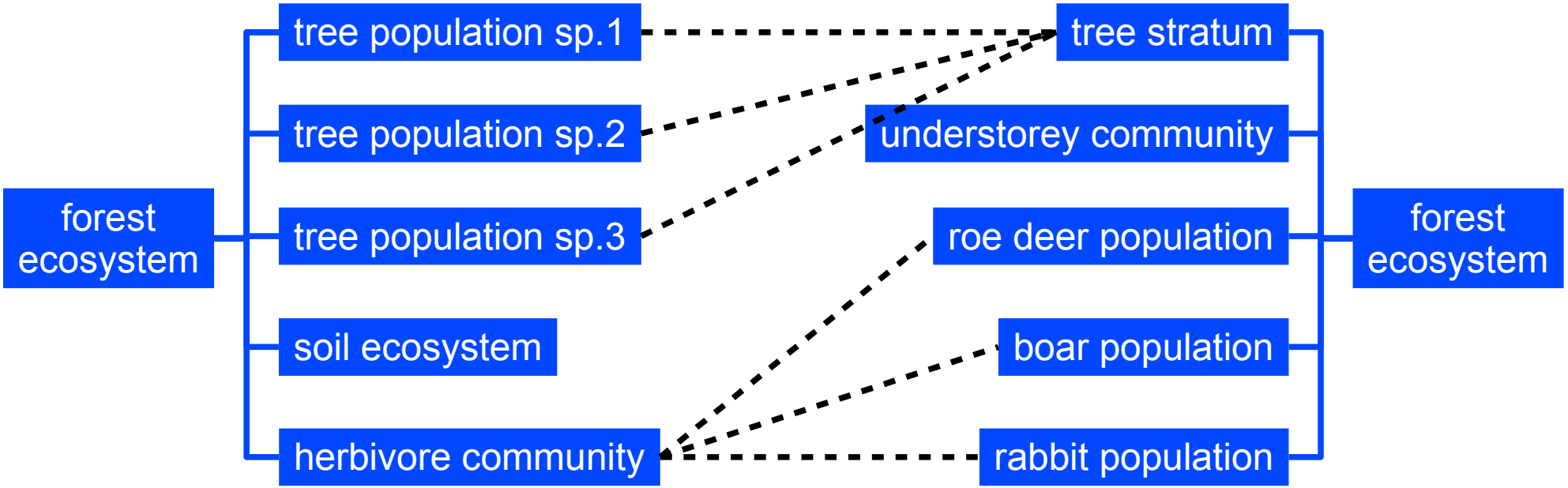
Properties of trophic network as a function of the lumping of trophic species (=abstraction level of the network)

System-level (emergent) properties depend on the level of abstraction

This is bad news.

We cannot describe a trophic network at a consistent level of abstraction.

It is certainly even worse for an ecosystem:



Would these two representations of the same system display the same emergent properties ?

The abstraction problem: solutions ?

1 There is no fully consistent representation of an ecosystem

2 The level of abstraction impacts the system-level properties

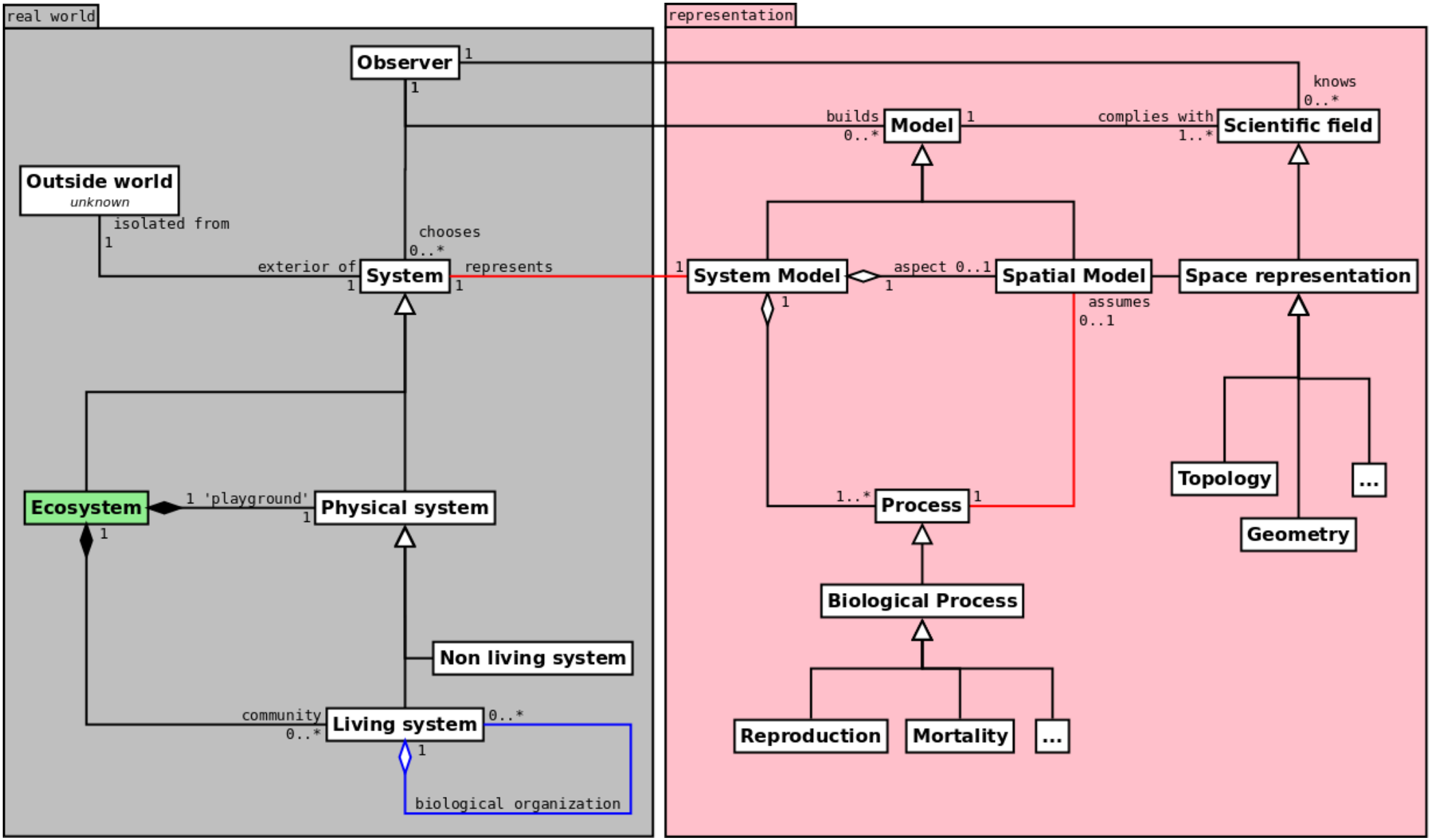
Possible fixes:

- simulation platforms that allow to play with the level of abstraction (using eg the self-similarity of ecosystems)

- base the high-level representation of emergent properties on simulated emergence at lower levels

e.g. Boulain N, Simioni G, and Gignoux J. (2007). Changing scale in ecological modelling: a bottom up approach with an individual based vegetation model. Ecological Modelling, 203:257-269.

Conclusion : an ontology for ecosystems



Conclusion

Broad applicability only comes from general concepts – but we need *good* concepts to do so

The ecosystem definition is rich enough to constrain a simulation platform

The ecosystem boundary problem can be solved by multiscale modelling

The abstraction problem can be contained by allowing to play with abstraction levels