The Cells of Ecosystem Functioning: towards a holistic vision of marine space

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The scientific community has produced lots of data, analyses and recommendations, the directives are there! We need science! but…

To truly progress this knowledge, European scientists across a broad range of disciplines and domains must make a quantum leap towards holistic approaches and integrated research on a scale which will help us to much better understand, protect, manage and sustainably exploit the seas and oceans which surround us. This is a Grand Challenge; not just Europe, but for human society as a whole.
NF IV paved the way to the approach of NF V: Marine Sciences must evolve into Marine Science.

However, to have a truly holistic approach that merges physics, chemistry, geology, biology, ecology and socio-economics, we should manage marine ecosystems in Cells of Ecosystem Functioning (CEFs). CEFs are the smallest fully connected portions (i.e. volumes) of the marine environment, where biodiversity patterns and ecosystem functions depend on each other (Boero et al., 2019).
“Man on the moon” is often taken as a paradigmatic “Mission” but the Earth is much more complex than the Moon and the mission is not just to get there and plant a flag!
The long and winding road of EU legislation towards sustainability. From Abiotic features, to Habitats and Species, to Biodiversity and Ecosystem Functioning, in a spatial framework.

**GES indicators**

- biodiversity
- hydrology
- contaminants
- litter
- energy
- aliens
- fish
- networks
- distrophy
- bottom

**Marine Biodiversity and Ecosystem Functioning: The Pillars of Good Environmental Status**


F. Boero
In the light of all this, to protect and manage the environment we need to know BEF. **Oh oh**: ocean observations mostly focus on biogeochemistry and physics!
observation systems must be upgraded so as to comprise also BEF
Descriptor 1 of GES prescribes that **Biodiversity is maintained**... but only charismatic expressions of biodiversity are covered

- **Iconic** habitats or species are not representative enough
- The protection of **patterns** of biodiversity distribution (hot spots) is not sufficient
- The **processes** that allow for the persistence of biodiversity hot spots must be considered
- We need to manage and protect both patterns and processes, i.e. BEF

**Protected Areas are not enough**

How to frame biodiversity and ecosystems into a spatial context and achieve GES in **ALL** waters?
Sustainability is a must
Many different measures in the same space

Maritime spatial planning
Marine spatial planning
MPA networks

The Maritime Spatial Planning directive

Integrated Coastal Zone Management (ICZM)

Integrated coastal zone management

Other Effective Conservation Measures

Sites of Community Importance

Maritime sustainability in an age of changing oceans and seas
Marine Science for a Sustainable Future
Navigating the Future V Position Paper 24
The ocean is ONE and it covers 71% of the Earth surface.

The ocean, however, is a volume and represents more than 90% of the life-inhabited space.
The formation of sea ice produces dense waters that sink and come back to surface in a grand circulation system where the bulk of ecosystem processes takes place.

The Great Ocean Conveyor connects all oceans.

A DYNAMIC AND CONNECTED SPACE
Most ecosystem processes take place in the **water column** where matter flows along different pathways.

**the microbial pathway**

for billions of years life functioned in this way
the microbes-
crustacea-fish path
way

our favorite
one
the herbivorous gelatinous plankton pathway

a rather neglected one
the carnivorous gelatinous plankton pathway

the most disliked one
ALL TOGETHER NOW!

with carbon sequestration
The four pathways that lead to ecosystems functioning occur through a series of fluxes: the processes that link biodiversity structures

- life cycles: intra specific fluxes from one generation to the next
- trophic networks: inter specific fluxes from one species to another one
- biogeochemical cycles: extra specific fluxes from living to non living matter and from non living to living matter
intra-inter-extra-specific fluxes

- ANIMALS
- PROTISTS
- FUNGI
- MONERA
- PLANTS
- PROTISTS
- MONERA

living matter

life cycles
intra-inter-extra-specific fluxes

living matter

ANIMALS

PROTISTS

Fungi

MONERA

life cycles

ZOO-

SYNTHESIS

ZOO-

DECOMPOSITION

trophic networks

PLANTS

PROTISTS

MONERA

living matter
intra-inter-extra-specific fluxes

- living matter
  - life cycles
  - ZOO-SYNTHESIS
  - BACTERIAL-DECOMPOSITION
  - trophic networks
  - PLANTS
  - PROTISTS
  - MONERA

- ANIMALS
  - PROTISTS

- FUNGI
  - MONERA
  - BACTERIAL-SYNTHESIS
intra-inter-extra-specific fluxes

ANIMALS
PROTISTS

BACTERIAL
DECOMPOSITION

BACTERIAL
SYNTHESIS

MINERALIZATION

ZOO-
SYNTHESIS

ZOO-
DECOMPOSITION

trophic
networks

PLANTS
PROTISTS
MONERA

AUTO-
SYNTHESIS

Fungi
MONERA

biogeo-
chemical
fluxes

life
cycles
Primary Producers
- Photo-chemio synthesis

PLANTA

Secondary Producers
- Zoo-synthesis

Tertiary Producers
- Zoo-synthesis

ANIMALIA
- Higher Trophic Levels

LC = Life cycles = Intra-specific Fluxes
ZD = ZooDecomposition
M = Mineralization
BFD = Bacterial-Fungal Decomposition
TN = Trophic Networks = Inter-specific Fluxes

BGC = Biogeochemical cycles = Extra-specific Fluxes
The continuity of living matter and the discontinuities of its constituents: do plankton and benthos really exist?

F. Boero, G. Belmonte, G. Faccini, S. Ferri, F. Ruino

represented by high numbers of individuals for short times and less diverse from the water column as in the case of nekton. Sticklebacks, in the tropics at the mouth of coastal estuaries, filamentous algae and macrovegetation have discontinuities in the pressure of species that might be explained if we are to consider the nature of their species...

AS WE SEE IT

Gelatinous plankton: irregularities rule the world (sometimes)

F. Boero, G. Belmonte, G. Faccini, S. Ferri, F. Ruino

PLANKTON BENTHOS AND NEKTON?

A WORLD OF CARNIVORES?

Bacteria do the job

All die and are decomposed

Nutrients

All fish start their life as larvae that eat herbivores...

This is the grass (phytoplankton)

These are the herbivores (zooplankton: copepods)

We do not see them

...then they grow and eat each other

We see them

A. Geiger 2019
SEASONS SHUFFLE THE CARDS

FALL

WINTER

SUMMER

SPRING
The ocean is not a surface: it is a volume! and it keeps changing.

A 4th dimension (time) must be added to the 3 spatial dimensions.

Predictive science eh?
defining the **spatial units** of management and conservation

- They must be based on **sound ecological grounds**
- We cannot base the units based on **our activities**
- We must **tailor** our activities on the features of the environment
- **Connectivity** is crucial to define the spatial units of management and conservation
The world Ocean is highly connected, but it can be divided into volumes that are more connected within their boundaries than they are with neighboring ones.

From physics to ecology: the Cells of Ecosystem Functioning
Connectivity can be assessed in many ways

- **Currents** determine a dynamic medium that “flows” but not all species respond in the same way to current regimes

- **Beta diversity**

- **Genetic fluxes**

- **Propagule fluxes**

- **Trophic fluxes**
Currents disperse **propagules**, connecting similar habitat types where **beta-diversity** and **gene flows** are a measure of connectivity.

**Biodiversity patterns** are generated by **ecosystem processes** that are spatially defined.
Connectivity occurs not only through propagule exchange but also through food webs and artificial transport.

The cold water corals in the Ionian Sea depend on the nutrients conveyed by the cold engine of the Northern Adriatic.
Ecosystem processes are carried out by millions of species.

It is estimated that 8 million species inhabit the planet.

We named just 2 millions.

The knowledge of biodiversity is incomplete.
The decade of biodiversity is ending but biodiversity expertise is vanishing…

Sustainability is based on BEF!!!
CONSISTENCY

• We cannot adopt several ways of protecting, managing and exploiting the same marine volumes (ICZM, MSP, MPAs, MPA networks, SCI Networks, Other Effective Conservation Measures)

• The MSFD is adopted in different fashions by different EU states

• Nature does not care about artificial boundaries

• CEFs are natural spatial units of management and conservation

• We must adapt our activities to nature, and not vice-versa!
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Contents

1. Summary 130
2. Introduction: Plankton, nekton and benthos 131
3. The four dimensions of marine systems 131
4. A very dynamic system 135
5. Habitats and ecosystems 136
6. Assembling the components into ecosystems 137
7. Life cycles: Intra-specific fluxes 139
8. Food webs: Inter-specific fluxes 141
9. Biogeochemical cycles: Extraspsecific fluxes 142
10. Putting ecosystems into a spatial framework: The cells of ecosystem functioning 142
11. Identifying the Cells of Ecosystem Functioning 148
12. Challenges 150
Acknowledgements 151
References 152

Abstract

Marine space is three dimensional; the turnover of life forms is rapid, defining a fourth dimension: time. The definition of ecologically significant spatial units calls for the spatio-temporal framing of significant ecological connections in terms of extra-specific (biogeochemical cycles), intra-specific (life cycles), and inter-specific (food webs) fluxes. The oceanic volume can be split in sub-systems that can be further divided into smaller sub-units where ecosystem processes are highly integrated. The volumes where
The next grand challenge

Map the structure and the functions of the ocean
In 4 dimensions!!!
(as suggested in NFV) and...
explore biodiversity