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From Marine Protected Areas to MPA Networks

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The Ecology of Beauty

Just like terrestrial National Parks, Marine Protected Areas (MPAs) were first established at places where biodiversity had some prominent features. In the Mediterranean Sea, for instance, the first MPAs were established at places that were perceived as 'beautiful' by scuba divers who started to explore marine landscapes and singled out the most scenic ones (see Abdulla *et al.*, 2008 for a review on Mediterranean MPAs). The European Landscape Convention (ELC) (Council of Europe, 2000) is in line with this approach to site selection. The ELC, in fact, states that 'The sensory (visual, auditory, olfactory, tactile, taste) and emotional perception which a population has of its environment and recognition of the latter's diversity and special historical and cultural features are essential for the respect and safeguarding of the identity of the population itself and for individual enrichment and that of society as a whole'.

What is perceived as valuable in a given environment, then, is part of the heritage of the resident population and contributes to its culture. The positive impressions described in the ELC simply identify beauty,

defined as follows in a popular dictionary: 'a combination of qualities, such as shape, colour, or form, that pleases the aesthetic senses, especially the sight'.

The perception of beauty, however, is directly linked to cultural paradigms and can change with them. Cetaceans, for instance, were once perceived as evil 'monsters' that brave sailors had to exterminate, as Melville's story of *Moby Dick* tells us. Nowadays, they are worshipped as gods. Even white sharks (*Carcharodon carcharias*), again depicted as terrifying beasts in movies like Spielberg's *Jaws*, are now considered as highly valuable, deserving strict protection.

Following this aesthetic approach, large vertebrates or, in alternative, beautiful and scenic habitats (i.e. the charismatic expressions of nature) are usually identified as deserving protection, whereas important ecological actors are simply ignored. Everybody wants to save the whales, but nobody wants to save the bacteria, even if bacteria are indispensable for ecosystem functioning (and also for our own body functions), whereas whales are not. On the one hand, our impact on bacteria is not so huge: they become rapidly resistant to antibiotics and are not affected much by our

influence, being able to evolve rapidly so as to cope with environmental changes. On the other hand we could easily exterminate cetaceans, if only we intended to do it.

The preservation of beautiful portions of the environment, and of the fauna and flora inhabiting them, has been instrumental in the understanding of the value of nature. This approach to the defence of nature is shared by almost all environmentalist movements who evoke charismatic portions of nature in their logos, full of dolphins and panda bears. The growth of human population, with the adoption of economic paradigms aimed at the continuous growth of the economic capital, as if resources were infinite, has led to an alarming erosion of the planet's natural capital. Habitat destruction, both on land and in the seas, and climate change show that we need more than beauty to preserve nature. Protected areas, in this framework, have been some sort of surrogate that justified the destruction of nature where protection was not directly enforced. Focusing on the unique and beautiful facets of nature, often perceived as the sole expression of 'biodiversity', led to protection of natural structures, while disregarding natural functions that are not restricted to charismatic species and habitats.

Beauty is important, but the conservation of nature requires more than aesthetics.

From Landscapes to Habitats

The European Landscape Convention is centred on the way the culture of a population perceives and modifies nature, somehow 'improving' it with wise management. This is particularly evident in countries like Italy, where millennia of agriculture and architecture have led to unique landscapes that are considered of paramount importance in Article 9 of the Italian Constitution. In this sense, the landscape is the result of human interventions that led to changing a 'wild'

expression of nature into a 'gentler' one. Usually the products of these interventions are aesthetically valid, and the result is beauty. However, a beautiful landscape might be limited in the expression of biodiversity (especially if agriculture is involved), calling for the need of preserving nature *per se*, and not its modifications, whatever their aesthetic value. It can happen, furthermore, that a local 'culture' adopts some behaviours that are against the integrity of nature, as happened in Region Apulia with date mussel (*Lithophaga lithophaga*) consumption. The harvesting of date mussels from rocks caused extensive denudation of Apulian rocky bottoms (Fanelli *et al.*, 1994). The destruction of hard bottom habitats came to an end only after a long process of generating public awareness, together with the enforcement of new laws.

To cope with an overly anthropocentric approach to our interactions with the environment, the EU Habitats Directive (92/43/EEC) embraced a completely different perspective: habitats of community importance must be protected, even if this goes against the aspirations of the resident populations!

Sites protected under the Habitats Directive do not necessarily comprise beautiful landscapes, and the low level of ocean literacy in almost every country is often a source of conflict between the expectations of lay people and the preservation of natural capital. The resident communities are puzzled when they are prevented from building a new harbour just because there is a seagrass meadow on the bottom. Local populations often label as 'algae' the phanerogam *Posidonia oceanica*, whose presence can lead to the establishment of a protected site, and consider it as a nuisance. The decomposing leaves that accumulate on the beach repel tourists, who complain about their appearance and smell. The recognition of the ecosystem service of these accumulations of leaves is not part of local cultures, who do not realize that stranded leaves

protect the beach from erosion. The stranded leaves are removed, sometimes with bulldozers, and huge quantities of sand are removed with them. Lacking a buffer of amassed leaves, wave action starts to erode the beach. Beaches are a source of income, and the wider they are, the higher the income, since more tourists can be crammed onto them. Beach erosion reduces incomes, and this is redressed by beach replenishment. Without the protection of *Posidonia* leaves, however, the newly placed sand is also rapidly eroded and often accumulates on the seagrass meadow, smothering it. *Posidonia* meadows are bioconstructions, since the new rhizomes grow over the old ones, raising the bottom of the sea and making it more stable. The death of the meadow is a catastrophe for the coast, since its role of erosion buffer ceases to protect the shore. Once the protection from erosion is completely gone, due to unwise management of coastal systems, physical defences are built in order to protect the beach, with a radical change of the whole landscape.

It is undeniable that some 'cultures' have a vague understanding of the functioning of nature, and the Habitats Directive is an attempt to bring a more objective approach to our relationship with natural systems.

Our land-based culture, however, still biases the Habitats Directive because although it considers marine habitats that are not necessarily 'beautiful', they are invariably benthic. For the Habitats Directive, the marine space is bi-dimensional, just as the terrestrial one. The third dimension, on land, is occupied just by the size of bodies, and by the temporary presence of flying organisms in the air, so it is right to speak about 'areas'. In marine systems, however, the water column is a three-dimensional habitat for a host of organisms that have almost no interactions with the sea bottom. Since oceans cover over 70% of the Earth, the water column is the most widespread habitat of the planet, and it is a volume.

Many marine organisms live their whole life suspended in the water, and even benthic ones derive their food from currents, not to mention the spread of propagules. A Habitats Directive which includes the marine biome but does not consider the third dimension of the water column is fundamentally flawed.

Protecting beautiful places, and managing the habitats of European Community importance, is a first step towards recognizing the significance of the marine environment, inviting science to design an approach to its management and protection that goes beyond the biases of the current 'culture'. Indeed, it calls for actions aimed at developing the 'ocean literacy' to alter our scant perception of the values of the oceans that is linked to our terrestrial history.

From Hunting and Gathering to Farming

If we were just like all the other species on the planet, when our populations increase to above the carrying capacity (i.e. the maximum number of individuals of a species an ecosystem can bear), overly eroding the natural capital that sustains us, our numbers should decrease due to a shortage of resources. This would lead to the re-constitution of the natural capital, according to the popular prey-predator model developed by Lotka and Volterra (Gatto, 2009), in which we are the predators and the rest of nature is the prey. But we are not like the other species. When confronted with a shortage of natural resources, we abandoned hunting and gathering and invented agriculture (Diamond, 2002). We domesticated a restricted set of animal and plant species, and started to culture them so as to satisfy our needs. Agriculture leads to the eradication of all competing species from a piece of land so as to rear just the domesticated one. The terrestrial animals we

rear as food are almost invariably herbivores or, in some cases, omnivores, and we cultivate the plants we feed them with. This leads to habitat modification, and what the ELC considers as precious is often just the eradication of natural diversity and its substitution with agricultural systems.

In terrestrial systems there are no natural populations of both animals and plants that can provide massive amounts of resources. In the seas, by contrast, we can still extract resources from natural populations, and fishing is just a form of hunting. In recent decades, however, we have been rapidly passing from harvesting fish, crustaceans, molluscs and so on to aquaculture. What happened on land is now happening in the seas: wild populations cannot feed us all, and our pressure on them is leading several species towards commercial extinction, meaning the benefits from fishing are less than the costs incurred. Increasing the efficiency of fisheries, furthermore, is giving little hope of saving the remaining fish. The transition from fisheries to aquaculture is the final stage in the shift from hunting and gathering to farming. In the sea, contrary to what we do in terrestrial systems, we tend to rear carnivores rather than herbivores.

The Western world, in fact, is fed with farmed carnivorous species, such as sea bream (*Dicentrarchus labrax*) and salmon (*Salmo salar* and *Oncorhynchus* spp.), fed with smaller fish caught from surviving natural populations. This is clearly an unsustainable operation, since it exacerbates the overexploitation of natural populations: after having destroyed the populations of the larger fish, we culture them and we feed them with smaller fish caught from natural populations. Emerging countries cannot afford such costly forms of aquaculture and eat lower quality, but also less impacting, farmed herbivorous species such as tilapia (*Tilapia* spp.) and pangasius (*Pangasianodon hypophthalmus*).

The awareness of the impact of industrial fishing did induce some management of natural populations resulting in the protection of target species from overexploitation (Pikitch *et al.*, 2004). This has been done by restricting fishing activities at important places and during important periods. The relevance of these spaces and times depends on the biology of the species under management. Spawning grounds, nursery areas, and feeding grounds are identified species by species, and fisheries are restricted in order to allow for successful recruitment of the managed species. The ban of industrial fishing, *per se*, is a measure of protection and its positive impact, albeit temporal, is another form of marine conservation even though the aim is just to relieve fish from our excessive pressure, so as to continue to exploit their populations.

The reproductive rates of many fish species are so high that populations can be restored in reasonable time, as the abundance of fish in well-managed MPAs demonstrates (Guidetti *et al.*, 2008). Since the environmental impact of farming carnivorous species is higher than that of simply fishing, the survival of sustainable natural fisheries is a measure of the health of marine systems, and fisheries science must lead to better results, in conjunction with conservation science.

Landscapes, Habitats and Fish are Not Enough

The introduction of concepts such as 'ecosystem-based management', 'ecosystem approach' and 'integrated coastal zone management' is the clear expression of a broader view in the way we interact with the rest of nature (Pikitch *et al.*, 2004; Heip *et al.*, 2009). Ecosystems are not just structures, they also function through myriad processes, as their name implies. Knowledge of the connections

among the different structures is crucial for managing what we intend to exploit, and to conserve what we want to protect. The link between biodiversity (structure) and ecosystem functioning (function) is the conceptual tool that guides a proper understanding of how the natural world works (Heip *et al.*, 2009). In a strategic document, the European Marine Board identified the adoption of holistic understanding as the greatest challenge for marine scientists worldwide (Arnaud *et al.*, 2013). It is obvious, for instance, that fish do not proliferate as isolated entities from the rest of the environment: they need to be considered as part of ecosystems throughout their life cycle, from the fertilized egg to the adult. This, for instance, should oblige fisheries scientists to consider the impact of predators of fish eggs and larvae, such as gelatinous plankton, in their models of fish population dynamics (Boero, 2013). The match (or mismatch) of a bloom of the by-the-wind sailor (the hydrozoan *Velella velella*) with the spawning of fish species that deliver floating eggs, for instance, can have (or not have) devastating effects on the fisheries yields of the subsequent months (Purcell *et al.*, 2015). However, the cause-effect relationship is usually not perceived since the impact (fewer fish) becomes apparent only when the cause (increased *Velella* predation and/or competition) is over, the lapse of time depending on the growth rate of the fish species concerned. If larval mortality is treated as a constant in fisheries models, fisheries management cannot be effective. The causes of potential failures in fish recruitment (resulting from depressed larval development) must be ascertained and fisheries science must overcome the almost complete separation from gelatinous plankton science (Boero *et al.*, 2008).

Similarly, the quality of the various habitats that fish frequent during their whole lifespan can have a crucial impact on fisheries yields, determining more or less

successful recruitment. Yet, the scientists who study fish populations in MPAs are usually not directly involved in traditional fisheries science, even if their research tends to show that MPAs often improve fish yields due to spillover effects (Planes *et al.*, 2000). Fisheries scientists, though, usually disregard the role of MPAs and propose other management measures to promote sustainable exploitation of fish populations. Fisheries scientists are probably right, since the total surface of MPAs is scant, if compared with the vastness of the oceans, and the protected environments are almost invariably coastal and restricted to the sea bottom. While the current extent of protected marine space can improve local conditions, it is nowhere near sufficient to manage the entirety of fish populations. Furthermore, fisheries are just one of the manifold threats to the marine environment, and a more integrative approach to conservation is badly needed.

Good Environmental Status

Of course, a solution might be to increase the size and the density of MPAs, encompassing the SLOSS debate (Single Large Or Several Small) (Olsen *et al.*, 2013) with the Several Large approach. The increase in both the number and the size of MPAs, however, would cause conflicts between national and local authorities and the resident communities that, usually, are resistant to any limitation of their 'freedom' of (ab) using the environment.

Networks of MPAs seem the best solution for this conundrum (Olsen *et al.*, 2013). The Marine Strategy Framework Directive (MSFD, 2008/56/EC) sets the target of reaching Good Environmental Status (GES) in all EU waters by 2020. The situation of the European Seas will improve significantly if this strategic goal can be achieved, or at least

if the trend towards its achievement triggers effective conservation measures.

The MSFD includes 11 descriptors of GES, which in their synthetic formulation are:

- Descriptor 1: Biodiversity is maintained
- Descriptor 2: Non-indigenous species do not adversely alter the ecosystem
- Descriptor 3: The population of commercial fish species is healthy
- Descriptor 4: Elements of food webs ensure long-term abundance and reproduction
- Descriptor 5: Eutrophication is minimised
- Descriptor 6: The sea floor integrity ensures functioning of the ecosystem
- Descriptor 7: Permanent alteration of hydrographical conditions does not adversely affect the ecosystem
- Descriptor 8: Concentrations of contaminants give no effects
- Descriptor 9: Contaminants in seafood are below safe levels
- Descriptor 10: Marine litter does not cause harm
- Descriptor 11: Introduction of energy (including underwater noise) does not adversely affect the ecosystem.

As Boero *et al.* (2015) remarked, pursuing GES based on these measures represents a real revolution in the management of marine ecosystems. In the past, the precise measurement of key environmental variables (temperature, salinity, nutrients, pollutants of any kind) was considered to be sufficient to evaluate the state of the environment. This led to the establishment of sophisticated observation systems that check these variables through the use of satellites, buoys, gliders, and a vast array of sensors. The collected data are then stored in huge databases that contain the ‘history’ of environmental systems. The factors that should inform us about the quality of the environment, however, do not represent the real state of any habitat. From the perspective of GES, these variables acquire a meaning only when they affect the living

component: if some of these variables change but this does not lead to any change in the biological component of ecosystems, then the change is irrelevant. The individual stressors, furthermore, do not act in isolation from each other. Instead, they interact with each other, with cumulative effects that might lead to misinterpretations of the quality of the environment. If considered in isolation from each other, these variables can have values that are below the threshold that is known to affect the living component of the environment. These effects are often assessed by laboratory experiments, under controlled conditions, in which only one variable is altered, whereas the others remain constant. The ensuing tolerance curves assess the impact of each stressor on selected species. However, even if the values of each stressor are below the thresholds, it can happen that biodiversity loses vigour, and many key species show signs of distress due to cumulative impacts (Claudet and Fraschetti, 2010).

To cope with this shortcoming, the MSFD defines GES while considering the status of both biodiversity and ecosystem functioning. The first descriptor of GES is just the status of biodiversity, whereas all the other descriptors regard the impact of specific stressors on biodiversity, ecosystem functioning and, in the case of Descriptor 9, human health.

Once a stress is identified, in terms of biodiversity and/or ecosystem function perturbation, then it can be addressed so as to mitigate its impact.

The logic of this approach is impeccable, but its application is far from straightforward. It is very simple to produce sensors that measure physical and chemical variables; even biogeochemistry can be assessed with automated instruments. Moreover, the geological features of the sea bottom can be mapped and assessed with very powerful tools. The descriptors of GES, however, consider biodiversity and ecosystem

functioning, and the currently available instruments do not measure these features: they mostly consider abiotic features or measure some simple biotic variable, such as chlorophyll concentrations.

A new way of looking at the quality of the environment is then required, and the study of MPAs is somehow 'pre-adapted' to tackle this problem. Marine Protected Areas have been instituted to protect biodiversity and to enhance ecosystem functioning, and so adhere, at least in theory, to all the specifications of GES. The assessment of the efficacy of MPA management should consider the attainment of GES. If the requirements prescribed by some descriptors are not met, management should be changed in order to remove impediments to the attainment of GES.

Connectivity

The Marine Strategy Framework Directive of the European Union does not require the attainment of GES in MPAs only: GES is to be reached in all EU waters by 2020. This expectation is very ambitious, since GES is not reached even in the best-managed MPAs, but its logic is flawless. It is futile to hope for GES at any one place, if the surrounding environment is not in good condition as well. Marine Protected Areas are not like islands, separated from each other by the sea: the sea connects them.

Every individual living at a specific location produces propagules (the life cycle stages that propagate the species, whether as eggs, larvae, fragments, adults, etc.) that are taken away by the currents, to colonize other sites. Each site is a source of propagules for downstream sites that are reached by the current passing in its vicinity, and is a sink of propagules coming from the organisms living at upstream sites. Connectivity, then, is the degree of connection across sites within a given area. The very concept of connectivity teaches us that it is pointless to

manage specific sites (e.g. MPAs) without managing the systems in which they are nested in terms of connectivity. This insight is leading to a paradigm shift in conservation biology: from MPAs to networks of MPAs (Olsen *et al.*, 2013).

Connectivity is a very general concept: the connections among various parts of a given water body cannot be measured in a way that represents all living beings. Some species have a higher vagility (i.e. propensity to move from one place to another) than others and the differences greatly affect connectivity at a micro level. Grantham *et al.* (2003) tackled the problem of dispersal distances in a suite of habitats, considering just marine invertebrates, and reached the conclusion that the ensuing connections are very varied and that MPAs must therefore be designed based on the specific habitats that are going to be protected. Accordingly, networks of MPAs should encompass this problem, providing protection over large scales. However, it is also important to design MPA networks so as to respect complex connectivity patterns, in order to achieve a compromise that covers the different scales of vagility of the species assemblages that are going to be protected and/or managed. Knowing the basic biology of species, however, is not enough: ecological constraints and habitat availability can restrict the colonization of localities that can be reached by a given species but that are not suitable for its existence. For example, Johannesson (1988) considered two species of the mollusc genus *Littorina* with opposite dispersal strategies (planktonic versus brooding). The species with planktonic larvae should be a better colonizer than the brooding one. However, the brooder species had a higher propensity than the one with planktonic larvae to persist at a sink habitat widely separated from source areas. The 'paradox of Rockall' (Johannesson, 1988) shows that larval dispersal is not the sole factor responsible for connectivity. Sink areas that are

distant from propagule sources tend to be colonized by low dispersal species that can reach them by rafting and that re-colonize the area without dispersing their propagules. In this regard, Boero and Bouillon (1993), analysing the distribution of more than 300 hydrozoan species of the Mediterranean Sea, showed that species with a long-lived medusa stage do not have a wider distribution than that of brooding species, brooders often being more widespread than highly vagile species (Shanks *et al.*, 2003).

As a result of such studies, it is clear that the levels of connectivity across an area are better studied by at least four methods:

- 1) The reconstruction of the oceanographic framework that potentially connects the various sites
- 2) The search for propagules (including asexual ones, and rafters) in the plankton collected in the connecting currents
- 3) The similarity of species assemblages across the considered area (so-called beta diversity)
- 4) The similarity in the genetic composition of a suite of species that represent a vast array of taxa.

The integration of the results of these different analyses leads to a more reliable representation of the degree of actual connectivity, helping to design more ecologically coherent networks of MPAs.

Networking According to Nature or to Bureaucracy?

The application of coherent policies of management and conservation of MPAs is particularly well developed in the Mediterranean area. The management entities of many Mediterranean MPAs are part of MedPAN (Webster, this volume) and, through it, the best practices evolved by the directors of each MPA are disseminated and improved, so as to find increasingly better

ways of protecting nature. It is undeniable that issues regarding nature conservation have to be addressed over vast scales, and that the comparison of the efficacy of measures at different places is conducive to increasingly better ways of protecting the environment. It is also true, however, that there is not a one-size-fits-all way of solving the problems stemming from our relationship with the rest of nature. Special measures are necessary to protect remarkable properties of the marine environment, such as the presence of unique expressions of biodiversity in terms of either species (e.g. monk seals *Monachus monachus*, or cetaceans) or habitats (e.g. bioconstructions of any kind). Defending unique structures, however, is not enough: connectivity calls for a more integrated approach than just a structural one. Structures must be coupled with the ecosystem functions that allow for, if not underpin, their existence, and this approach calls for the expansion of management far beyond the boundaries of MPAs.

It is crucial, in this framework, to identify the units of conservation, namely the portions of marine space that are highly connected with each other and whose features are more dependent on each other than on those of sites that belong to other units. The identification of these units leads to the construction of networks of MPAs that are based not only on the enforcement of protection measures through bureaucratic imperatives, but also on the recognition of ecological principles that rule the functioning of the managed environments, just as the definition of GES prescribes.

These units might be based on climatic and biogeographic features, comprising areas where species compositions are similar due to shared climatic conditions; or on oceanographic features, where current patterns determine propagule transport; or on geological features of the sea bottom; or, indeed, on geo-political features that might be conducive to common management by

various states. In such politically fragmented seas as the Mediterranean and the Black Seas, this approach requires development of and adherence to international agreements since it is highly unlikely that a single state will cover the whole extension of ecologically coherent conservation units.

It is evident, however, that the identification of these units of conservation must be holistic, covering most of the features that the single disciplines making up the complex of marine sciences now study in isolation. To satisfy this need, Boero (2015a) proposed to treat the marine environment as a living super-organism made of cells: the 'cells of ecosystem functioning' (CEFs). The exercise of dividing the marine space into larger conservation units than MPAs is not novel (see Olsen *et al.*, 2013 for a review), and its necessity is shared throughout the scientific community and among decision-makers.

Towards a Holistic View of Marine Systems

The previously mentioned quest for integrated, ecosystem-based, and holistic approaches to marine conservation requires a complex representation of marine spaces based on the assemblage of the available knowledge in an ecologically coherent fashion.

The physical background is the backbone of ecosystem description. The discovery of the oceanic conveyor belt (Broecker, 1991), with the recognition of the crucial role of polar regions as surface sites of deep water formation, marked a revolution in physical oceanography that parallels the discovery of continental drift to explain the current disposition of continental masses. The oceans are in fact one, the global ocean, and all are connected by horizontal and vertical currents. The cold and dense surface waters of the poles tend to sink and to become the deep waters of non-polar portions of the

ocean system, pushing up the spent waters of the deep. Everything is connected, in the oceans, and life is running on an apparently perpetual conveyor belt that distributes nutrients and propagules throughout the world. The single, interconnected oceanic system, however, can be divided into coherent portions, defined by the disposition of continental masses.

The Mediterranean Sea, in particular, due to its geological, oceanographic and bio-ecological features, is a miniaturized replica of the world ocean and, due to its smaller size, responds more quickly to the drivers of change that affect the whole planet (Lejeusne *et al.*, 2010). It is convenient, thus, as a first approach to the identification of coherent conservation units, to focus on the Mediterranean Sea so as to set up a feasible rationale that could possibly apply to whole oceanic systems.

From a physical oceanography point of view, the Mediterranean conveyor belts (Pinaridi *et al.*, 2004) can be considered as analogous to the large oceanic conveyor belt (see Figure 1.1).

The Mediterranean Sea has a higher salinity than the Atlantic Ocean since freshwater inputs are lower than evaporation rates. The superficial Gibraltar Current enters from the Gibraltar Strait and brings Atlantic waters into the Mediterranean Sea, compensating the water deficit due to excessive evaporation. The Gibraltar Current crosses the Sicily Channel and flows into the Eastern Mediterranean, to flow back at about 500 m depth as the Levantine Intermediate Current that returns to the Atlantic, through the deepest part of the Gibraltar Strait. Since the average depth of the Mediterranean Sea is 1500 m, and the deepest part of the basin, in the Ionian Sea, exceeds 5000 m, the water renewal of the upper 500 m is not enough to bring oxygen to the depths of the Mediterranean Sea, where plants and other primary producers do not have enough light to perform photosynthesis and produce

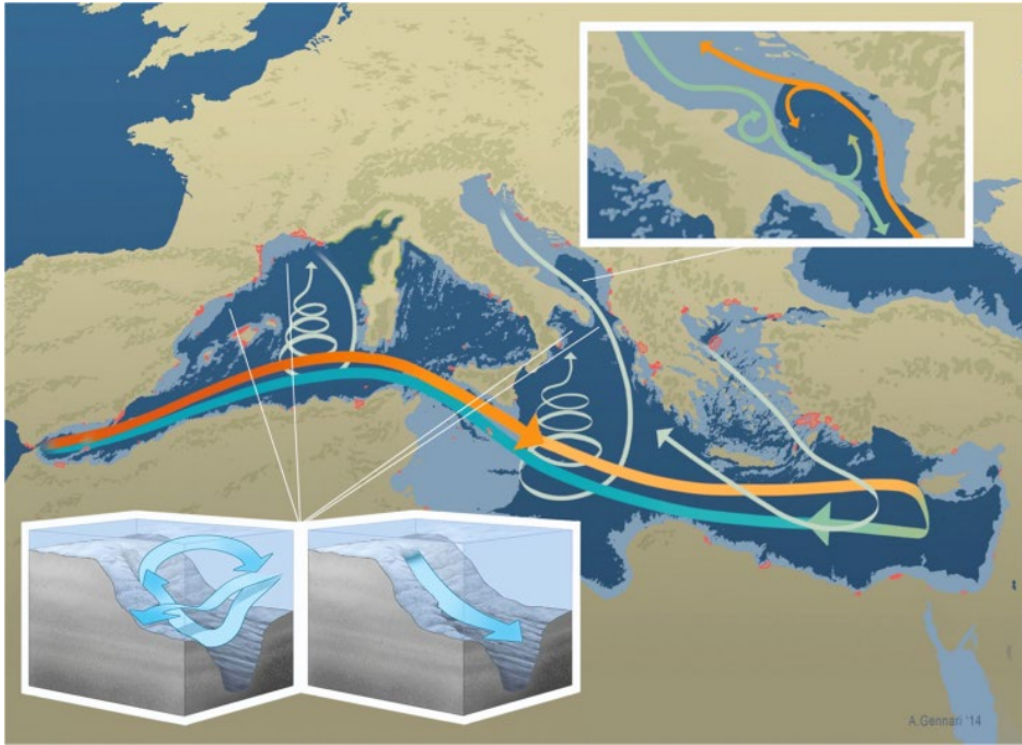


Figure 1.1 Circulation patterns in the Mediterranean Sea. A surface current enters the basin from the Gibraltar Strait, flows through the Sicily Channel and reaches the Levant Basin. The Gibraltar Current flows back at about 500 m depth as the Levantine Intermediate Current. Water renewal below 500 m occurs through the ‘cold’ engines in the Gulf of Lions for the Western Basin and in the Northern Adriatic and Northern Aegean Seas for the Eastern Mediterranean. In the cold engines, cold, oxygen-rich water flows through canyons (bottom left inset) with a ‘cascading’ process. The canyons outside cold engine areas can trigger upwelling events (bottom right inset). Other patterns of circulation regard the formation of gyres (top inset). Artwork: Alberto Gennari.

oxygen. Without photosynthesis, deep-sea animals would rapidly consume the oxygen dissolved in the water, leading to anoxic conditions that are not favourable to meta-zoan life. Without an oxygen supply from the surface, the Mediterranean deep-sea biodiversity would be much reduced and just a few simple life forms would survive, as happens in the Black Sea below 300 m depth.

The ‘cold engines’ of the Gulf of Lions, the Northern Adriatic and, from time to time, the North Aegean are crucial to the existence of deep-sea life in the Mediterranean Sea. At these sites, northern winds enhance

evaporation and lower the temperature, causing a marked density increase in the well-oxygenated surface waters. The thermo-haline differences of the water masses of the cold engines in respect to the surrounding waters result in the so-called cascading of dense oxygenated waters that cross the continental shelf and, then, reach the deep sea through marine canyons. The cold engine of the Gulf of Lions renews the deep waters of the Western Mediterranean Basin, whereas the Northern Adriatic engine, sometimes replaced by the North Aegean one, refreshes the depths of the Eastern Mediterranean Basin.

The Gibraltar and the Levantine Intermediate currents join the various parts of the basin, defining the Mediterranean Sea as a single and very large unit. The cold engines produce vertical thermo-haline exchanges that define the Western and the Eastern Mediterranean as two large sub-units that, based on coastal morphology, are in their turn divided into the well-known 'seas' that make up the Mediterranean system.

Oceanographic conditions determine further sub-divisions of the seas that make up the Mediterranean. In the Adriatic Sea, for instance, the cold engine causes a thermo-haline current that flows southwards across the continental shelf and along the Italian coast to the Ionian Sea through the Bari Canyon. To balance this outflow, an incoming current enters the Adriatic Sea from the eastern coast of the basin, and reaches the Gulf of Trieste, where the circle is closed. The presence of headlands such as those at Istria, Conero and Gargano leads to the formation of a northern, a central and a southern gyre, with horizontal currents that connect the western and the eastern coasts of the basin, along which the currents flow in opposite directions. In this way, the Adriatic Sea could be divided into three coherent oceanographic cells, where ecosystems might function in distinct fashions, while being anyway connected by the northward current along the eastern Adriatic coast and the southward current along the western coast.

The Adriatic Sea is shallow and does not have canyons in its central and northern part, but canyons leading to the deep sea from the coast are a common feature of the rest of the Mediterranean shelf. Some are involved in the cascading phenomena generated by the cold engines but, in the majority of the canyons, the currents that flow parallel to the coast tend to sink offshore, bringing oxygen to the deep sea. These offshore downwellings push deep

waters through the canyon, resulting in upwelling currents that connect the deep sea with the coastal areas (Hickey, 1995). There are about 500 Mediterranean canyons that, presumably, play the role of auxiliary engines to the three main cold engines, and underpin the survival of life in the deepest part of the Mediterranean Sea through vertical water exchanges. The upwellings, furthermore, bring nutrients towards the shore, enhancing primary production such as the spring phytoplankton bloom. Based on these oceanographic patterns and on the presence of a higher concentration of resting stages of both phyto- and zooplankton than outside the canyons, Della Tommasa *et al.* (2000) proposed that marine canyons are reservoirs of propagules (in this case resting stages of planktonic organisms) that are injected towards the coast together with the nutrients, so triggering the phytoplankton and zooplankton blooms that are at the base of the functioning of all oceanic systems.

The hydrodynamic patterns, generated by a combination of wind energy, changes in salinity and temperature, and interactions of currents with bottom and coastal morphology, define the physical framework that leads to the formation of masses of water that are more connected within their boundaries than they are with neighbouring masses, while remaining part of a coherent water body. The main sub-units can be further divided into smaller units according to the presence of fronts, gyres, eddies, upwellings and downwellings, defining what Boero (2015a) called the cells of ecosystem functioning, CEFs, mentioned earlier. With this metaphor, the Mediterranean Sea is a body (which is anyway dependent on other bodies, in this case the Atlantic Ocean) that can be divided into increasingly smaller functional parts, from wide ecological regions *sensu* Longhurst (2010) to CEFs as the smallest functional units.

The Cells of Ecosystem Functioning

Oceanographic conditions shape the associated ecological processes. The ensemble of areas where physical processes connect different portions of the environment might be considered a CEF. However, the long-term observation of oceanographic features shows high variability, including sudden and radical changes, as happened with the Eastern Mediterranean Transient (Pinaridi *et al.*, 2004). Phenomena such as El Niño, the North Atlantic Oscillation, and, in recent decades, global warming, lead to a suite of multiple states that might not overlap in space. Eddies and gyres, furthermore, can have variable strengths, and even invert their rotation. Upwellings are stronger in some seasons and weaker in others. Extreme events such as the occurrence of very hot or very cold periods can have huge impacts on biological features, with effects that persist for a long time after the occurrence of the episodes. Rivetti *et al.* (2014), for instance, showed that the deepening of the summer thermal stratification caused large-scale mass mortalities of resident species of cold-water affinity. Temperature increases, furthermore, have favoured the massive expansion of non-indigenous species that continue to enter through the Suez Canal, establishing viable populations in the Mediterranean Sea.

The strong annual (seasonal) and inter-annual fluctuations and variations of the physical drivers determine the biological features that represent an integration of these fluctuations over the long term (Boero, 1994), with episodic events adding variability to this complex situation (Boero, 1996).

The interactions among species assemblages (the expression of biodiversity) and the physical variables lead to the formation of ecosystems and determine their functioning (Boero and Bonsdorff, 2007).

The inter-annual variability of planktonic communities is well known from long-term series (Boero *et al.*, 2014), whereas only recently has the long-term response of benthic communities to important physical changes, mainly due to global climate change, started to be quantified (Puce *et al.*, 2009). It is important, then, to establish not only the potential CEFs, in terms of physical features, but also the tangible CEFs in terms of biodiversity and ecosystem functioning: a CEF is defined by a higher level of internal connectivity compared with connections to nearby CEFs. It can happen, however, that cells that appear physically separated, at least temporarily, such as the central and southern Adriatic cells, defined by two adjacent gyres, might have such connected biological populations that a single, larger cell and, hence, a single large conservation unit, should be defined.

Obviously, these multiple physical states, leading to multiple ecosystem states, can be revealed only through continuous observation and cannot be predicted by current modelling techniques. No model, for instance, predicted the occurrence of the Eastern Mediterranean Transient.

Moreover, the approaches followed so far to assess the quality of the environment are more focused on structure than on function. The evaluation of ecosystem functioning in large marine ecosystems has been assessed only rarely (e.g. Godø *et al.*, 2012).

Mapping the Seas

Mapping benthic communities is relatively easy and, with state-of-the-art technologies, can be accomplished in reasonable time frames. Benthic communities can be subject to strong seasonal variation, especially in coastal areas, but their areas of occurrence are generally rather stable in space. Maps can be made from time to time and compared so as to ascertain changes in habitat distribution.

The Habitats Directive, with the associated Natura 2000 network, applies a terrestrial approach to the marine realm. The description of habitats, furthermore, is based on the features of vegetation and on the concept that the dynamics of communities leads to climax conditions after a series of deterministic seres. These concepts apply only partially to the marine domain. In marine systems the water column is the most crucial component, being the habitat of both plankton and nekton, whose temporal variability is very high if compared with that of the benthos. The connections between the sea bottom and the water column are so intimate that the functioning of their communities cannot be understood if they are considered as separate entities (Boero *et al.*, 1996).

Terrestrial habitat maps are bi-dimensional and consider the vegetation as a descriptor of diversity. Maps of marine habitats resulting from the application of the Habitats Directive are similar to terrestrial ones, since they consider just the benthic realm. However, marine habitat maps would be far more complex if the water column was taken into account. What is happening at the surface does not necessarily reflect the rest of the water column, and temporal patterns are very distinct, so the same physical space has different ecological features in different periods of the year, usually changing from year to year. The dimensions are four: the two of the surface area of the sea bottom, the third one of the volume of the water column (and its diversity through its entire depth), and finally the time dimension.

As a result, CEFs are fuzzy units that cannot always be sharply defined (due to their temporal instability) but nevertheless are more internally coherent than they are with neighbouring cells. Some cells may be relatively distinct, such as the northernmost part of the Adriatic Sea, whereas others can be alternately separated or joined, as occurs in the two gyres that characterize the central

and the southern Adriatic Sea. According to the source and sink approach (Pulliam, 1988), some cells are a source for other cells that receive their products as sinks and, in their turn, can be sources or sinks for other cells, but the roles can be inverted according to different situations. The cold current generated in the Northern Adriatic, flowing southwards along the Italian coast, brings nutrients that support the white coral formations that thrive in the depths of the Southern Adriatic and Ionian Seas. The Northern Adriatic, in its turn, receives propagules from the current that enters the Adriatic from the Ionian Sea and that flows northwards along the coasts of Greece, Albania, Croatia and Montenegro, reaching Slovenia and then Italy.

It is clear, in this framework, that connectivity is not only a matter of propagules (of any kind) but also of food and nutrients, becoming almost a representation of ecosystem functioning, from the base of trophic networks (in terms of nutrients for phytoplankton, due to terrestrial runoffs and bacterial and fungal decomposition) to their very apex, namely the nekton.

The features of CEFs must be georeferenced, but the maps do not need to be overly accurate. These features of the environment, being very variable in time, cannot be found again with absolute precision, based on their representation on a map. An area where a gyre is enhancing primary production cannot be mapped with the same precision as an area covered by a seagrass *Posidonia oceanica* meadow. For sea grasses, the accuracy of the map can be tested by repeating the observation, and checking if the mapped feature is exactly in the place reported by the map. But this is not feasible for an area where fish forage, reproduce or spawn, or where phytoplankton and zooplankton bloom. It is however possible to identify some stable features that can be mapped with high accuracy. Canyons, as mentioned, can generate upwelling currents that bring

nutrients from the deep sea to the coast. These upwellings provide a nutrient supply that favours primary production, and this ecosystem feature can be mapped. The 500 canyons that indent the continental shelf of the Mediterranean Sea (with the exclusion of those that are influenced by cascading phenomena generated by the cold engines) should be considered putative CEFs due to vertical currents. Their presence could lead to the testable hypothesis that the upwellings they generate foster ecosystem functioning in terms of phytoplankton production. Merging the representation of these vertical currents with the horizontal currents generated by both the winds and the configuration of the coast (i.e. gyres, eddies, fronts, etc.) should lead to maps that reflect the functioning of ecosystems in space. The multiple states of ecosystem features should be referred to these spaces, with maps that allow for temporal variability, supplemented with the distribution of habitats on the bottom, and of the behavioural patterns of important fish species (in terms of nursery, foraging and spawning areas).

Such maps are not available yet, and their realization is a compelling challenge, leading to the integrated, holistic and ecosystem-based approach that, in spite of being continuously invoked, has been rarely accomplished, so far.

Upgrading the Observation Systems and Managing the Networks

As mentioned earlier, the enforcement of the MSFD, so as to reach and maintain GES, calls for observation systems that assess the quality of the environment according to 11 descriptors of GES, which in turn are based on two main pillars: biodiversity and ecosystem functioning in all its facets. Current

observation systems must be upgraded, so as to cover all the relevant variables. Marine Protected Areas are the perfect places to perform continuous observation of the descriptors of GES, in terms of biodiversity (structure) and ecosystem functioning (function). The personnel of MPAs must be instructed on how to make these measurements, building on the experience of several marine stations that have been constantly monitoring the features of the water column for decades (Boero *et al.*, 2014).

Marine Protected Areas, however, are not enough and it is important to observe also control sites that are not under special protection regimes so as to be sure that GES is reached not only at already protected sites but throughout the sea. This calls for continuous evaluation of the features of biodiversity inhabiting both the sea bottom and the water column, with the establishment of long-term series of observations; this approach has tended to be unwisely dismissed due to the illusion of measuring the quality of the environment through the use of automatic devices. While current sensors can provide physical, chemical and biogeochemical information, they cannot measure either biodiversity or ecosystem functioning, and are therefore inadequate for the purposes of the MSFD (Boero *et al.*, 2015).

The continuous observation of ecosystem features should have two goals:

- 1) Assess the attainment of GES
- 2) Measure the efficiency of management.

Based on the definition of CEFs, and on the continuous check of their features through upgraded observation systems, the managers of MPAs must collaborate across networks of MPAs, leading to the definition of common policies within each network, based on the integrated study of the marine environment so as to perform efficient management and protection: the MedPAN structure, in the Mediterranean Sea, already represents a partnership of MPA managers.

Marine stations and other research institutions, furthermore, must be involved in a science-based management of the networks, leading to collaboration among states, in order to design regulations that will be tailored on the ecological conditions of the managed area, and not on the contingencies of political or bureaucratic situations.

Some goals of the MSFD might be difficult to reach through local management. Descriptor 2 of GES, for instance, requires that non-indigenous species do not affect the ecosystems in a negative way. It is undeniable that some aliens are real pests that impair the functioning of ecosystems. The case of the alien ctenophore *Mnemiopsis leidyi*, for instance, led to a disaster in Black Sea fisheries (Boero, 2013), although, in this case, the management of a hypothetical network of MPAs might have had little responsibility for an event that was mediated by species transport in ballast waters.

The early detection and risk assessment of non-indigenous species (NIS) is essential to determine appropriate action to prevent their spread, or to identify routes of arrival and to control them, whenever possible. Ship-driven introduction of alien species is particularly important (Boero, 2002) and is amenable to control measures. The recent doubling of the size of the Suez Canal, however, is likely to ease the arrival of more species of Lessepsian immigrants (Galil *et al.*, 2015; Galil, Chapter 10, this volume), and is much more difficult to control. This will probably aggravate the impact of non-indigenous species on the functioning of Mediterranean ecosystems, so worsening the situation required by Descriptor 2 of GES.

The observation systems, thus, will have to be set up also at the gateways to the Mediterranean Sea, with a particular focus on the Suez Canal, both in the Mediterranean and in the Red Sea.

Marine Protected Areas, *per se*, do not offer protection from NIS invasion, even though healthy ecosystems such as those

ensuing from effective protection might be more resistant to invasions. In some cases the prohibition of human activities might enhance the chances of success for an invasive NIS. In such cases protection can be suspended and eradication measures might be taken, resulting from careful scientific assessments.

Human Capacity Building

The reliance on automated and physically oriented measurement of environmental quality has led to the perception that ‘simple observation’ as performed by the old naturalists is obsolete. In particular, the importance of describing species and understanding their roles, having taxonomic expertise at its base, has been disregarded and taxonomic expertise is vanishing across Europe and the Western world in general. In the era of biodiversity, the science of naming species (taxonomy) is in distress (Boero, 2010a), a rather paradoxical situation.

The definition of biodiversity (the first descriptor of GES) without taxonomy is simply flawed. The second descriptor, furthermore, covers the impact of alien species on ecosystem functioning. This requires knowing not only the resident species but also the species that might reach places where they have never been found. This means knowing all species, at a planetary level, since the introduction by shipping can bring species from any part of the world.

Furthermore, species identification is not enough. We must also assess the impact of alien species on the functioning of the ecosystems, and this means understanding their roles and their relationships with other species (Piraino *et al.*, 2002).

This level of knowledge requires a revival of traditional natural history (Boero, 2010b), while exploiting the most advanced techniques to tackle these very difficult problems. We need to create new expertise that is able

to integrate the expert observation of nature with the so-called ‘next generation’ instruments (Boero and Bernardi, 2014; Boero *et al.*, 2015).

Marine Protected Areas, together with marine research stations, are the best places to build the new expertise required to manage the environment in a holistic way, as required by the MSFD. This will have to be accomplished by the collaborative effort of consortia of European universities and natural history museums.

Taxonomy, for instance, cannot just concern naming specimens by reference to already known species, or the description of new species based on some preserved specimens or on some genetic sequence. The knowledge of both phenotypes and genotypes is necessary but not sufficient. It is also necessary to elucidate the life cycles and life histories of species, and to define their ecological niche at least in terms of ‘who eats whom’, so as to ascertain the roles of species. Trait analysis, for instance, is often performed, ascribing the same traits to species that resemble each other, extending the knowledge acquired for one species to a whole group of species.

A new kind of biodiversity expertise is badly needed, if the requirements of GES are to be achieved. Moreover, it is also urgent to train ‘integrative scientists’ who are able to bridge the various disciplines, in order to reach the holistic approach so often invoked and yet so rarely achieved. Mathematical modelling leading to predictions of the kind ‘if the situation is A at time 0, it will be B at time 1’ is of course to be encouraged but the complexity of the highest levels of organization of nature does not produce the same results as those that have been reached at the lowest ones. The intertwining between biodiversity and ecosystem functioning cannot be treated as interactions of subatomic particles or black holes. When life enters the game, the number of variables becomes too high to handle with the tools of simpler

disciplines. It is not by chance that the insights provided by the work of Charles Darwin cannot be translated into algorithms (Boero, 2015b) and the ‘natural history’ approach (upgraded with all the next generation technologies) is conducive to better insights about the functioning of complex natural systems (Ricklefs, 2012; Tewksbury *et al.*, 2014).

Extinction in the Mediterranean Sea

The re-building of taxonomic expertise, in the light of current concepts of ecology, biogeography and conservation, will probably show that current data on the distribution of species and habitats, as well as the models ensuing from them, should be treated with great caution. It is often the case that the distribution of biota is reconstructed by assembling data derived from different sampling methods and periods, lumping together very old records with recent ones. This leads to mistakes in evaluating the current state of biodiversity, since a species recorded from some place several decades ago might not still be present at the same place. Hence, a distribution map constructed by assembling new and old records does not account for the actual distribution of a given species (or habitat), and any conservation measure based on such data will prove ineffective.

This matter has become particularly salient in recent decades, since global change is rapidly modifying the physical features of the seas, especially as far as temperature is concerned. This is leading to radical modifications of biota, with increasingly widespread signs of stress for species that are adapted to temperate conditions and cannot withstand temperatures that reach values above their limits of tolerance (Rivetti *et al.*, 2014). It would be not surprising if

some species have become extinct due to such changes in physical conditions, as well as to the arrival of more competitive aliens, pre-adapted to the new, warmer conditions.

The analysis of the distribution in time and space of a well-known group of Mediterranean invertebrates demonstrates the shortcomings of taking simplistic approaches to represent the distribution of biodiversity. Stemming from recent monographic work (Bouillon *et al.*, 2004), Gravili *et al.* (2015) divided the records of Mediterranean species of non-siphonophoran Hydrozoa into time intervals. Out of the 398 known species, only 162 (41%) have been reported in the last decade, while 53 (13%) were not recorded in the literature for at least 41 years. According to the Confidence of Extinction Index (Boero *et al.*, 2013), 60% of the 53 missing species are extinct, and 11% are probably extinct from the basin. From a biogeographical point of view, the missing species are 34% endemic, 19% boreal, 15% Mediterranean-Atlantic, 11% Indo-Pacific, 11% circumtropical, 4% cosmopolitan, 2% tropical-Atlantic, and 4% non-classifiable. Fluctuations in species composition in a certain area cause high variability in the expression of both structural and functional biodiversity. As a consequence, regional biodiversity should be analysed through its temporal evolution, to detect changes and their possible causes. This approach has profound implications for biodiversity assessments and also for the compilation of red lists of species that are in danger of extinction. Such analyses require a detailed knowledge of the literature covering a given taxon, so as to ascribe records to different periods. In spite of continuous claims of biodiversity crises, extinction has rarely been proven in the Mediterranean Sea, or indeed in any other oceanic system (Boero *et al.*, 2013). Nevertheless, the example of the Mediterranean non-siphonophoran Hydrozoa suggests that biodiversity is changing at a fast pace, and that current

species lists are the result of adding new records (usually made up of non-indigenous species) to the old ones, leading to an apparent steady increase of the species pool of a basin. This artefact, furthermore, is biased by the distribution of sampling effort, the distribution of species often directly corresponding to the distribution of specialists and of their sampling effort, which is often concentrated around their institutional location.

All this calls for regular monitoring of species diversity at key locations, with all-species inventories, in order to produce solid estimates of the extant species pools and to observe their evolution in time. Puce *et al.* (2009), for instance, comparing recent and 25-year-old assessments of the phenology and the species pool of hydrozoans at a specific location, found substantial changes that suggest a great influence of global change on biodiversity expression. It is rather unfortunate, in this respect, that long-term series are not being maintained in most countries and that they run the risk of being dismissed even where they have been carried out over a long period (Boero *et al.*, 2014).

Conclusion and Recommendations

Marine systems are still generally in such conditions that, with fisheries, we can extract resources from natural populations, but this will not last for long if we do not enforce appropriate measures of both management and conservation of the natural capital. All governments and nations concur in recognizing the value of biodiversity, and the integrity of nature has been the object of a recent Encyclical by Pope Francis (Bergoglio, 2015), with full recognition of the central role of science in the preservation of nature, since it is impossible to protect something that is ignored. Increasing our understanding of complex natural

objects such as the oceans, and the life therein, is still a 'great challenge' (Arnaud *et al.*, 2013) and there are no shortcuts that will improve our knowledge with little effort. Naming all species is probably a feasible accomplishment, with adequate investment (Costello *et al.*, 2013) and this should be the first step towards the inventory of biodiversity (the bulk of the natural capital). A second step is the understanding of the roles of species (Piraino *et al.*, 2012), and then the link between the diversity of species and the functioning of ecosystems (Boero and Bonsdorff, 2007). This will require an understanding of the geographic distribution of ecosystems in the marine space, and the concept of CEFs probably deserves further consideration; at present it represents only a scientific hypothesis and it needs to be tested at multiple places. The identification of management and protection units, however, is crucial to enforce efficient policies and this has not been accomplished yet.

The 11 descriptors of GES of the MSFD cover the most important features of the environment, but their principles need to be translated into action through the enforcement of policies, and these, to be effective, must be science-based.

The need for new observational approaches developed by new types of expertise is the logical outcome of a century of extreme reductionism and specialization. We have built a series of very solid bricks of knowledge. Now they have to be assembled so as to acquire a conceptual continuity. This challenge cannot be avoided.

Acknowledgements

This chapter stems from the author's recent work as coordinator of the European Community's 7th Framework Programme (FP7/2007–2013) project CoCoNet (Grant Agreement No. 287844, <http://www.coconet-fp7.eu/>) and thorough discussions throughout the project consortium. Financial

support was also provided by the project PERSEUS (Grant Agreement No. 287600, <http://www.perseus-net.eu/site/content.php>) also of the 7th Framework Programme, and by the flagship Italian project RITMARE (<http://www.ritmare.it/>). Support by the European Union for VECTORS (<http://www.marine-vectors.eu/>) and from the Italian Ministry of Research (PRIN) is also acknowledged.

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