

Opinion

Perception of Changes in Marine Benthic Habitats: The Relevance of Taxonomic and Ecological Memory

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Abstract: Having a reliable ecological reference baseline is pivotal to understanding the current status of benthic assemblages. Ecological awareness of our perception of environmental changes could be better described based on historical data. Otherwise, we meet with the shifting baseline syndrome (SBS). Facing SBS harmful consequences on environmental and cultural heritage, as well as on conservation strategies, requires combining historical data with contemporary biomonitoring. In the present “era of biodiversity”, we advocate for (1) the crucial role of taxonomy as a study of life diversity and (2) the robust, informative value of museum collections as memories of past ecosystem conditions. This scenario requires taxonomist skills to understand community composition and diversity, as well as to determine ecosystem change trends and rates. In this paper, we focus on six Mediterranean benthic habitats to track biological and structural changes that have occurred in the last few decades. We highlight the perception of biological changes when historical records make possible effective comparisons between past reference situations and current data. We conclude that the better we know the past, the more we understand present (and will understand future) ecosystem functioning. Achieving this goal is intrinsically linked to investing in training new taxonomists who are able to assure intergeneration connectivity to transmit cultural and environmental heritage, a key aspect to understanding and managing our changing ecosystems.

Keywords: environmental changes; biodiversity; historical data; benthic communities; biomonitoring; taxonomy; museum collections; environmental heritage

1. Changes in Marine Benthic Communities

Πάντα ῥεῖ, (panta rei), the well-known Heraclitus aphorism, admirably highlights change as the manifold aspect of Nature. Everything flows, as “one cannot descend twice into the same river and one cannot touch twice a substance in the same state”. Environmental space and time changes continuously occur, triggering variations in organism assemblages, whose description is the major goal of ecology. Both irreversible (evolutionary approach) and reversible (ecological approach) changes

characterize life history. Even in the ecological perspective, variations may be investigated at both synchronic (biological and physical–chemical differences in space) and diachronic (modifications in a temporal scale) levels.

Ecosystem dynamics have been the favorite topic among marine ecologists, including succession, persistence, and evolution, and the Mediterranean benthic communities have not been an exception (e.g., [1–3]). Such an interest is according to its relevance in resource partitioning processes. Indeed, successful strategies are linked to species alternation in biomass contribution through time in response to the adaptation to environmental changes and resource availability, as described by the “flush and crash” model [4]. Understanding changes also means distinguishing predictable and unpredictable modifications, as well as periodical/progressive fluctuations, from sudden/short-term variations. The manifold aspects of marine ecosystem modifications have been largely discussed, including the distinction between fluctuations and the role of episodic events in coastal community variations (see, e.g., [5,6]).

Along with ongoing environmental degradation from a local scale to the global scale, accepted thresholds for environmental conditions can be continually lowered, affecting the perception and awareness of community changes. Lacking past information or experience, each new generation of ecologists might accept their rising situation as the norm, a sociopsychological phenomenon known as the shifting baseline syndrome (SBS) [7].

Global changes of biota in marine environments are nowadays of emerging relevance because of the acceleration induced in recent decades by an increase in anthropogenic pressure (i.e., pollution, coastal constructions, overfishing), particularly in the Mediterranean Sea, whose enclosed basin magnifies global warming effects on water temperature [8–10].

Accordingly, instead of exhaustively reviewing changes in ecological studies, we focus here on long-term (i.e., from decades up to a century) relevant changes in marine biodiversity of Mediterranean benthic communities along the Italian coast.

We report six different cases of perception and detection of variations, which can be assessed due to the availability of historical records that provide clear baselines to understand the possible ecosystem change paths.

We speculate on the importance of these historical data as reservoirs of ecological memory, allowing the understanding of current and future changes. Moreover, we stress the pivotal role of taxonomists, who should be considered an essential link between old and new generations of ecologists. This, in turn, could be basal for preserving the knowledge required to understand changes in the benthic communities over time, as well as to allow the new generations of ecologists to avoid SBS.

2. Study Cases

2.1. *Ficopomatus* Reef

The serpulid polychaete *Ficopomatus enigmaticus* (Fauvel, 1923) had spread into the Mediterranean Sea since the beginning of the last century through unaided dispersal from native regional borders [11–13]. The first historical record of its massive tube agglomerations along the Italian coast dates back to 1919 [14]. This ecosystem engineer edifices conspicuous reefs in brackish water systems, consisting of complex clumps of cemented calcareous tubes (Figure 1a–d) that offer refuge, food, and habitat for reproduction to many other benthic organisms. Consequently, its presence strongly modifies the distribution and increases the abundance and diversity of brackish Mediterranean benthic fauna [15–22]. *Ficopomatus* reefs grow quickly and spectacularly in coastal lagoons, which are progressively filled up by reefs and skeletal debris of such serpulid and the associated benthic organisms that may change the ecosystem dynamics. For decades, the Italian *Ficopomatus* reefs have remained comparatively stable, and they are considered a characteristic habitat of the eurythermal and euryhaline lagoons [23].

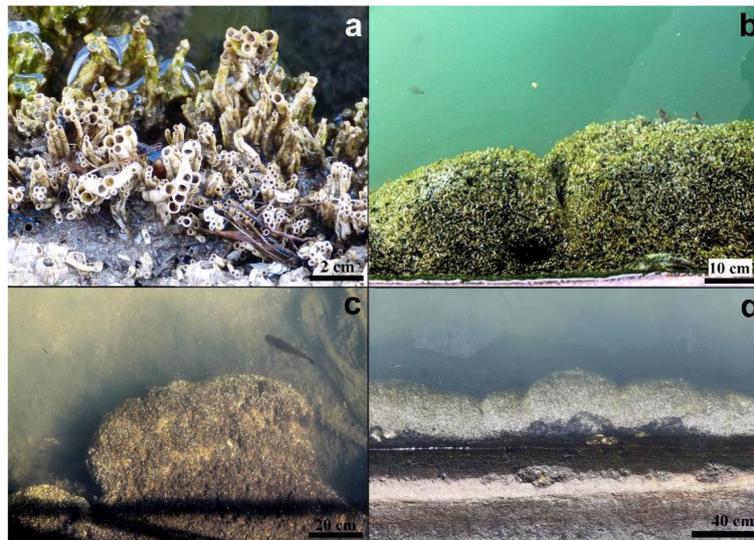


Figure 1. *Ficopomatus* reef at Fiumicino, Rome (Italy): calcareous tubes cemented one to another (a); details of the bioconstruction, forming belts that fringe the shoreline in a continuous layer up to 0.5 m thick, showed at progressively increased distances (b–d). Photo credit: A. Bonifazi.

2.2. *Sabellaria* Reef

Sabellaria alveolata (Linnaeus, 1767), a gregarious sabellariid polychaete, is able to build compact bioconstructions in the intertidal and shallow subtidal (Figure 2). They occur on sandy or hard bottoms in both the Northeastern Atlantic and the Mediterranean. Their massive bioconstructions (i.e., sheets, hummocks, banks) of cemented tube aggregates strongly modify coastal marine habitats as they support a high diversity and act as natural barriers against coastal erosion [24,25]. Along the Italian coasts, large *S. alveolata* reefs occur in Latium [24,26–28] and Sicily [29], while the first remarkable reef made by the cogeneric *Sabellaria spinulosa* (Leuckart, 1849) was recently reported along the Apulian coast [30,31]. The Latium and Sicily *S. alveolata* reefs have been well known since the 1950s [32–34] when its “pristine” condition represented a sound ecological baseline. Differences in reef structure and morphology mainly result from combining the current developmental phase with environmental conditions, balanced by the destruction/construction cycle [24,25]. Therefore, assessing long-term changes relies upon the comparison of present and past status; in the case of both Latium and Sicily reefs, there have been no noticeable changes [24,25,29,35], so this demonstrates that they have been thriving for over half a century.

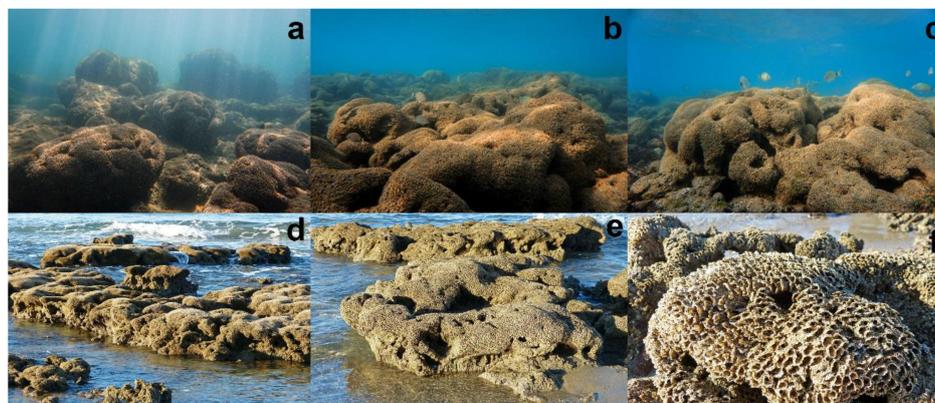


Figure 2. *Sabellaria alveolata* reef at Tor Caldara, Tyrrhenian Latium coast, Italy, in the upper infralittoral (a–c) and emerging during low tide (d,e); detail of the peculiar honeycomb-like bioconstruction, showing the tube openings with the “sand crown” as a diagnostic character (f). Photo credit: A. Bonifazi and D. Ventura.

2.3. *Posidonia oceanica* Meadow

The Mediterranean endemic seagrass *Posidonia oceanica* (Linnaeus) Delile, 1813 is characterized by its high leaf shoots thriving in the water column and its matte setting on the seabed. It is the main bioengineer species along Mediterranean coastal areas (Figure 3), where it creates an original and productive ecosystem that strongly promotes benthic and fish communities, supports marine biodiversity, and furnishes several ecosystem services [36–38]. Due to its ecological, heritage, and economic relevance, the meadows are identified as a priority habitat (1120 **Posidonia oceanica* bed) for conservation and are included in the Natura 2000 marine sites (Habitat Directive 92/43/CEE) and in the Barcelona Convention (16.02.1976) while being protected by different European directives (WFD, 2000/60/EC; MSFD, 2008/56/EC) and national laws. Nevertheless, many meadows have suffered a decline caused by anthropogenic disturbances altering their spatial extent and density [39–44]. Consequently, there has been strong concern and warnings about their conservation status, leading to extensive investigations and monitoring that have revealed their main change trajectories during the last decades [45,46]. The large size of the plant and the complex structure of the meadows facilitate the understanding of the time and causes of damage; virtually all of them are attributable to anthropogenic activities in the coastal areas. In the Middle Tyrrhenian Sea, along the Latium coasts, the large body of historical data available has allowed an effective comparison with the present meadow conditions, including the magnitudes of impact and the main causes of its decline [27,39,41,42,46–51], information of crucial interest for conservation and management strategies in the region.



Figure 3. *Posidonia oceanica* meadow at Isola del Giglio (Tuscan Archipelago, Tyrrhenian Sea, Italy) in good ecological status (a,b); *P. oceanica* flowering (c); example of an impacted meadow, showing the lower regression limit with dead matte and dead shells of *Pinna nobilis* Linnaeus, 1758 (d). Photo credit: D. Ventura.

2.4. “Sponge Garden” of La Strea Bay

The “sponge garden” of La Strea Bay, along the Ionian coast of Apulia (Italy), was a unique ecosystem dominated by an extraordinarily diverse number of sponge species of different sizes. Particularly, *Geodia cydonium* (Linnaeus, 1767; Figure 4), an Atlantic–Mediterranean sponge commonly living in sheltered coastal waters, thrived as a dense population in the bay, composed of specimens that were variable in dimensions, reaching up to 40–100 cm in diameter [52–54]. Both sessile and nonsessile specimens coexisted, the latter being able to roll on a soft bottom, dragged by slow circular currents [52,53]. Since 1976, *G. cydonium* has been considered an “umbrella species” for the entire

sponge garden, where it has played a crucial role in harboring invertebrates and algae, offering sites for fish spawning and nurseries and strongly contributing to increased biodiversity in La Strea Bay [54–56]. La Strea Bay was not included in the Marine Protected Area of Porto Cesareo, established in 1997 [57]. As a consequence, a dock for mooring recreational boats was built, leading to an abrupt change in the benthic communities, including the loss of the “sponge garden” (G. Corriero personal communication). The comparison between present and past pristine conditions has provided pivotal information on the last change of the sponge assemblage.

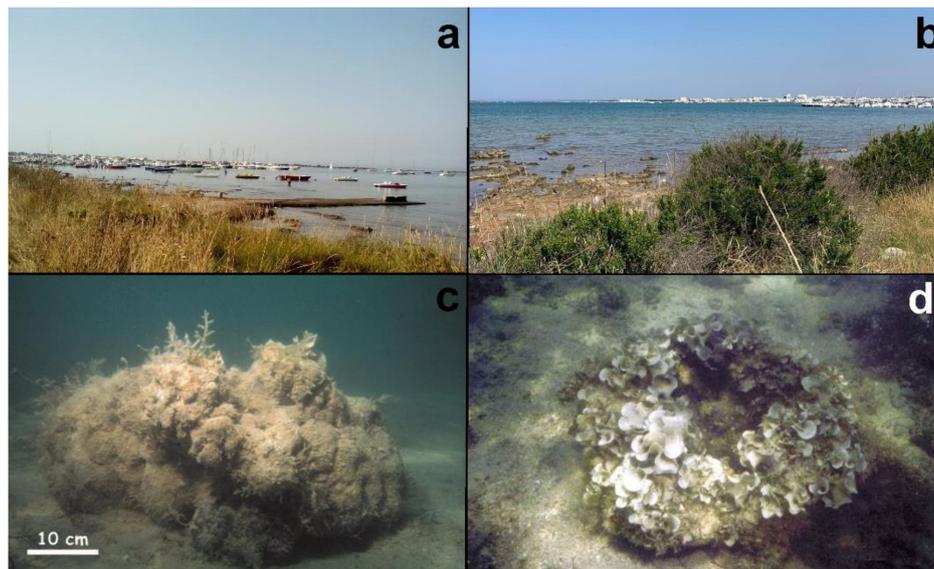


Figure 4. La Strea Bay at the Ionian Apulian coast, Lecce (Italy) showing the dock for the recreational boat mooring (a,b), photo credit: M.F. Gravina; massive *Geodia cydonium* subspherical specimen (c); *Geodia cydonium* specimen covered by epibionts, which protect this sciaphilous sponge from high solar radiation (d). Photo by courtesy of G. Corriero, University of Bari, Italy.

2.5. Introduction of *Ruditapes philippinarum*

The human-mediated changes caused by the Manila clam *Ruditapes philippinarum* (A. Adams and Reeve, 1850) (Figure 5) in sandy seabeds are well known and clearly documented. The species was introduced in Italian North Adriatic brackish waters through an aquaculture program in 1983 [58,59], resulting in a quick adaptation due to its great resistance and fast growth. Three years later, it was breeding freely and had colonized all suitable areas, where it completely replaced the carpet-shell clam native *Ruditapes decussatus* (Linnaeus, 1758). The rapid growth and high densities of the exotic bivalve caused abrupt changes in harvesting technology and the fishery market. However, the local soft-bottom assemblages did not show remarkable changes in biodiversity [58]. The only remaining populations of *R. decussatus* occur in some brackish lagoons and ponds along the Sardinian coast of the Tyrrhenian Sea (e.g., Tortoli, San Giovanni, Merceddi–Corru s’ittiri, Santa Gilla, Calich) and Latium (Lago di Paola) [60–62], where they are extensively cultured and collected for human consumption. The definite date and site of the introduction constitute a clear before-and-after impact example, allowing us to suggest specific timing and methods for conservation plans of the still-surviving populations of the autochthonous *R. decussatus*.

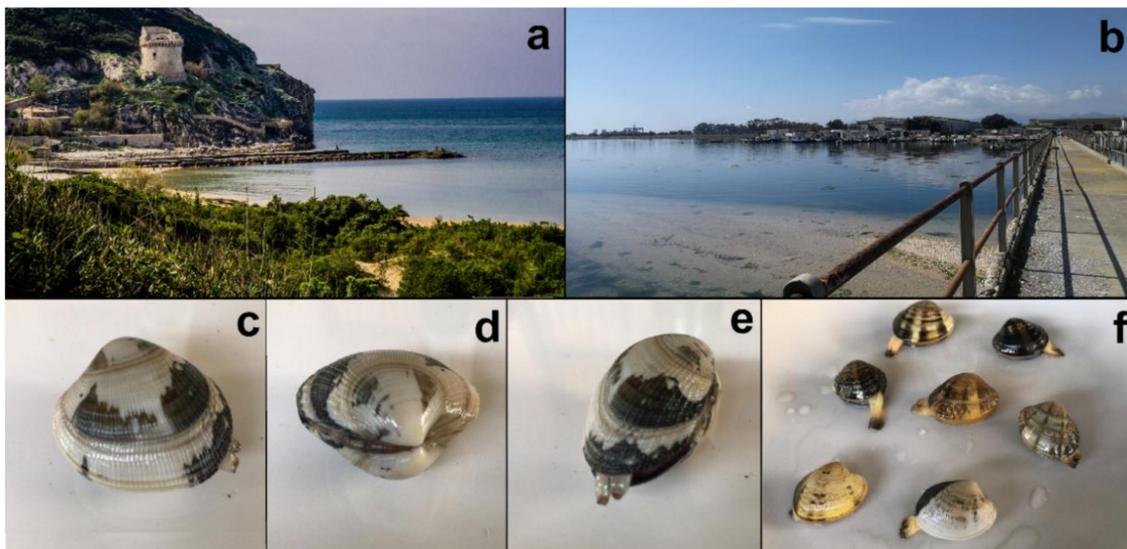


Figure 5. Lago di Paola, Latium, Italy: detail of the mouth channel, photo credit: D. Ventura (a) and Santa Gilla lagoon, Sardinia, Italy, photo by courtesy of Serenella Cabiddu, University of Cagliari, Italy (b) as examples of sites where populations of the autochthonous *Ruditapes decussatus* occur; specimens of the allochthonous *Ruditapes philippinarum*, showing shells and the almost-fused siphons as diagnostic characters (c–f). Photo credit: A. Bonifazi.

2.6. Fouling Community of the Mar Grande of Taranto

The fouling community of the Mar Grande of Taranto has been investigated, and its distinctive nature was exhibited from 1969 up to the next thirty-five years [63–66]. The arrival of nonindigenous species during the last fifteen years significantly changed the structure and function of the entire community [67–74]. Particularly, two allochthonous sabellid polychaetes, *Branchiommma luctuosum* (Grube, 1870) and *Branchiommma boholense* (Grube, 1878), appeared. At first, *B. luctuosum* was highly invasive and outcompeted the dominant native fan worm *Sabella spallanzanii* (Gmelin, 1791; Figure 6a,b) [75]. Then, *B. boholense* spread and became dominant, together with *B. luctuosum* (Figure 6c) [76]. Nowadays, the fouling assemblage is highly diverse and includes all three sabellids, although *S. spallanzanii* is still the most abundant (Figure 6d) [77]. The present vs. past community comparison highlights changes that are still ongoing.



Figure 6. Fouling at the Mar Grande of Taranto, Ionian Sea, Italy: the autochthonous fan worm *Sabella spallanzanii*, the only dominant species thirty years ago (a); the allochthonous *Branchiomma luctuosum* (b); the allochthonous *B. luctuosum* with *B. bohollense*, invasive for fifteen years (c); *Sabella spallanzanii*, the most abundant species nowadays (d). Photo credit: M. Del Pasqua, A. Giangrande and F. Mastrototaro.

3. Perception of Changes

Perception means to become aware of reality, consequently implementing a cognitive process. In a biodiversity context, change perception is a basic condition to assess variations, detect reliable causes, and foresee possible consequences, depending on the type of environmental impact and anthropic alteration. In our study cases, the evaluation of change perception in established benthic communities depended on different criteria (Table 1). It also required a comparison of different spatial and temporal status and the identification of the main causal processes and factors. A temporal baseline, representing the boundary between pristine and impacted conditions, is the primary step to check changes in a diachronic sequence (Table 1: Temporal baseline reference). “Pristine status” is generally considered the natural, original ecosystem condition, i.e., the “good status” to be expected, while an “impacted status” has suffered human pressures and is, thus, deteriorated and “poor”. Communities generally show high diversity in the former and low diversity in the latter. Assessing community status is particularly relevant in conservation science to both protect species, habitats, and ecosystems and to ward biodiversity from being excessively eroded. Moreover, the analysis of time changes allows us to infer possible consequences on ecosystem functioning and biodiversity, raising its interest beyond the scope of ecologists.

Table 1. Criteria of understanding changes of the study cases. In brackets the references of the temporal baseline.

Study Cases	Historical Memory		Conservation of Taxonomic and Ecological Data			Popularity of Dominant Species	Change Perception	
	Temporal Baseline Reference	Available Literature	Years of Investigation	Museum Collections	Scientific Collections			Available Images (Maps, Charts)
<i>Ficopomatus</i> reefs	1919 [14]	Lindegg, 1934; Fauvel, 1938; Rullier, 1955; Peres & Picard, 1964; Gravina et al., 1989; Bianchi & Morri, 1996; Bianchi e Morri, 2001; Nonnis Marzano et al., 2003; Cardone et al., 2013; Giangrande & Gravina, 2015	60	no	yes	yes	yes	no change
Tor Caldara <i>Sabellaria</i> reef	1956 [32]	Taramelli Rivosecchi, 1961; La Porta & Nicoletti, 2009; Ventura et al., 2018; 2020; Bonifazi et al., 2019; Lisco et al., 2020	60	no	yes	yes	yes	no change
<i>Posidonia</i> meadow, Middle Tyrrhenian Sea-Latium coast	1959–1961 [47,48]	Ardizzone & Migliuolo, 1982; Ardizzone & Pelusi, 1984; Ardizzone & Belluscio, 1996; Diviacco et al., 2001; Ardizzone et al., 2006; Telesca et al., 2015; Ventura et al., 2017; 2018; 2020	40	no	no	yes	yes	in progress
La Strea Sponge garden	1976 [53]	Corriero et al., 1984; Gherardi et al., 2001; Corriero et al., 2004; Mercurio et al., 2006; 2007	40	yes	yes	yes	yes	completed
<i>Ruditapes philippinarum</i> , North Adriatic Sea	1983 [58]	Breber, 1985; 2002	40	no	no	no	yes	completed
Fouling of Mar Grande of Taranto	1969 [63]	Gherardi & Lepore, 1974; Tursi et al., 1976; 1982; Giangrande et al., 2000; Brunetti & Mastrototaro, 2004; Mastrototaro & Brunetti, 2006; Longo et al., 2007; Pierri et al., 2010; Petrocelli et al., 2013; Giangrande et al., 2014, Del Pasqua et al., 2018; Lezzi et al., 2018a; 2018b	50	yes	yes	yes	no	in progress

Assessing variations during several decades to a century requires repeated monitoring to understand change trends and rates [78–80]. This has led us to search for the main available studies and their extent in our study cases (Table 1: Available literature; Years of investigation) as the core of “ecological memory”, allowing the past sequences of community events to be encoded and stored. This way, the variations in assemblage structure, dynamics, and biodiversity remain as ecological memories, allowing us to understand their current and future structures and functioning [78,81]. Ecological memories concerning benthic communities are also stored in specimen collections and distribution maps/charts in both museums and academic offices (Table 1: Museum and scientific collections; Available images). Taxonomic and ecological references are not simply inventories but reservoirs of historical community components, allowing present vs. past pattern comparisons. Museum and scientific collections provide key relevant cues to studying ongoing and predicting future community changes. In turn, the large gaps typically suffered by most historical quantitative datasets can be bridged by descriptive observations and qualitative datasets that specifically regard the emblematic and common species (Table 1: Popularity of species).

In our study cases, the available literature and images were the main source of historical memory of the *Ficopomatus* reefs, as well as the popularity of the species, which is widespread among the lagoon fishermen. The existence of images constitutes the cartographic baseline support, allowing us to perceive the changes in the *Posidonia* meadows. Taxonomic skills were most relevant in the fouling of the Mar Grande of Taranto and the *Ficopomatus* reefs, as distinguishing between different species is required to assess whether defining their biological traits allows the perception of changes in community structure and interspecific interactions between species. Beyond the other memory reservoirs, museum collections are particularly relevant in the case of the La Strea sponge garden. Indeed, the specimens preserved in the Museum of Porto Cesareo were key in evaluating size variations of *G. cydonium* in the La Strea sponge garden, as well as assessing its population dynamics. The popularity in the case of the *Sabellaria* reefs of Tor Caldara also played a key role, as the status of the local reefs was well known by several human generations because they occur in recreational bath areas. Similarly, the popularity and commercial interest of *R. philippinarum* have been very useful to perceive changes.

4. Taxonomy and Comprehension of Change

Morphological and functional knowledge of species is key to understanding variations and interpreting changes; this is the main purpose of taxonomy. Thus, this science branch is certainly crucial to understanding causes and detecting trends and rates of change in ecosystems over time. Long-term studies require periods often exceeding individual professional lifetimes. Taxonomic works are long-lasting and require specific skills that must be handed over from one generation to the next to preserve historical knowledge and allow new generations to have a more comprehensive awareness of biological changes, as well as to prevent them from suffering SBS [82,83]. The gradual change in human perception of environmental conditions often results in increasing tolerance to environmental degradation in parallel with increasing ignorance of past conditions, leading to harmful consequences on environmental and cultural heritage and conservation (see, e.g., [7,81,84,85]). Taxonomy is, thus, a basic science to deal with changes in biodiversity and ecosystems. Taxonomists also record the background on species in museum collections, which are rich in informative contents and baselines [86–91]. Museum collections have also been used in research on marine biodiversity changes, with particular regard to depauperation/loss of species (see, e.g., [92–94] for tropical and [95] for Italian species, together with examples of personal observations (M.F. Gravina) in the Civic Museum of Rome regarding the popular Mediterranean monk seal *Monachus monachus* (Hermann, 1779) and the sea lamprey *Petromyzon marinus* Linnaeus, 1758, from the Sardinian and Latium coasts, respectively. Unfortunately, collections are too often overlooked because the taxonomic expertise that allows the interpretation of the information associated with the specimens deposited is disappearing together with the specialists.

The identification of organisms to the species level is pivotal in the study of biodiversity. It appears to be a conflicting and obvious paradox that in the present era of biodiversity, as endorsed since the Rio Convention on Biological Diversity, taxonomy based on phenotypes still remains a marginal science [96–98], notwithstanding its crucial role in understanding causes and processes of changing ecosystems over time (see, e.g., [99]). It is really nonsense to prioritize molecular approaches rather than phenotypical studies on species because they both encompass key aspects of the same organism! Moreover, changes in diversity and community structure are particularly studied in monitoring and environmental quality assessment programs, which addressed possible disturbance causes and anthropic impacts according to the requirements of National and European current legislation (WFD, 2000/60/EC; MSFD, 2008/56/EC). In such studies, the identification of organisms at the species level is a key requisite. In other words, the survey of biodiversity changes requires good taxonomic work!

With this in mind, we hope for an increase in the taxonomic workforce through retraining of taxonomic schools to preserve the knowledge of older generations while attracting new generations to taxonomy, allowing them to have a more comprehensive awareness of biological changes in our changing Mediterranean biota.

5. Conclusive Remarks

The large number of studies on synchronic and diachronic ecosystem dynamics conducted in the Mediterranean has stressed different types of changes in community structures and diversity patterns as unquestionable evidence derived from variation, one of the most characteristic traits of the history of life.

Our study cases have highlighted the importance of having taxonomic and ecological knowledge of benthic communities, coupled with the correct interpretation of the available species lists, as a reference baseline to evaluate the variations occurring in the present and assess long-term changes in the benthic communities. Knowing the species has, thus, a pivotal role in understanding variations and interpreting changes. Taxonomists know the morphological, molecular, and ecological traits of the species and are essential to understanding changes in biodiversity. This certainly includes the extensive but often overlooked knowledge on the species that is presented by museum collections, which need to be revalued as reference baselines, reliably supporting observational and literature data. In addition, new collections need to be set up to be compared, a particularly useful tool during identification procedures. In this way, taxonomists could provide robust identifications.

We conclude that the better we know the past ecosystem composition, the more we will understand the present ecosystem functioning and the better we will be able to foresee its future. In the era of biodiversity, we support reevaluating the study of species as main ecosystem actors. Therefore, we strongly recommend new investments in taxonomic schools to assure intergenerational connectivity, together with the transmission of cultural and environmental heritage, a key aspect to understanding and managing our changing ecosystems.

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