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Changes in the benthic algae along the Adriatic Sea in the last three decades

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This article gives an up-to-date review of the status of and main changes in benthic algal flora that have occurred in recent decades along the Italian Adriatic coastline. Common traits among the main structural/functional changes observed and their causes are discussed. A synthesis of the challenges to and prospects of filling gaps in the data, ecological knowledge and protection measures are also given.

Keywords: biodiversity; flora; macrophytobenthos; Adriatic Sea; ecosystem functioning

1. Introduction

Over the past three decades, it has been recognised worldwide that spatial and temporal distribution patterns of organisms, species diversity and physical and biological habitat structure have changed as a result of anthropogenic disturbances, defined as any potential source of stress caused by human activities. However, change is a main feature of evolution [1], and the number of species in a region is set by a balance between speciation, extinction and the migration of species between regions, all of which can operate over long natural or short man-made time scales. Besides, on a small scale, species composition can be naturally highly variable and rare species may become abundant and vice versa. Consequently, it might be difficult to separate the effects of natural and anthropogenic processes [2,3]. The distinction between natural or unnatural changes may be more complex in ecosystems where disturbance is fundamental to the natural dynamics of communities (i.e. Fucales) [4].

Diversity within and among species and ecosystems drives the functioning of ecosystems (i.e. biogeochemical cycles, productivity, climate regulation) [5] through countless reciprocal interactions with the physical and chemical components of the environment, thus the conservation of biodiversity is essential to sustainability. All these processes may act and vary with scale. Even small changes in biodiversity may strongly affect ecosystem functioning and more important

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ecological processes, such as the incidence of herbivory, disease and the resistance of communities to invasion.

The distinction between the natural dynamics of a system and anthropogenic impacts, and the failure to account for large declines in ecosystems over long periods are biased by both redefinition of the ‘reference point’ (‘shifting baseline’) of each successive generation and the acceptance as ‘natural’ of progressively degraded states in the ecosystems [6].

Even if change is a natural trait of an ecosystem, the loss of biodiversity at an unprecedented rate, as a direct and indirect consequence of human population growth, unsustainable patterns of resource consumption and associated environmental changes, can be perceived as unnatural.

The benthic algal flora, widely used to monitor coastal ecosystems, is regarded as a good descriptor of environmental characteristics, and is able to highlight changes in the ecological parameters through its specific richness and community structure. This is also the basic approach of the European Water Framework Directive (EC, 2000). Moreover, a number of biological indices based on macroalgae have recently been proposed for use within the Mediterranean Sea [7,8].

In the last three decades, changes in the benthic algal flora have been reported for many Mediterranean regions and a decline in the most sensitive taxa has occurred as a result of anthropogenic disturbance (sewage, dredging, aquaculture, industrial and agricultural discharge) [9].

In this context, the reconstruction of historical data and the drawing up of a floristic database represent an essential first step in singling out appropriate strategies for management and conservation. In fact, they enable the identification of threatened species and provide a fundamental basis from which to understand the current status and changes in biodiversity over the medium- and long-term.

The aim of this article is to give an up-to-date review of the status of and main changes in the benthic algal flora that have occurred over past decades along the coastline of the Italian Adriatic Sea, together with a synthesis of the challenges to and prospects of filling gaps in the data, ecological knowledge and protection measures.

When possible, information was collected from the scientific literature but also from both the grey literature and unpublished data.

2. General Adriatic context

A number of catalogues of the benthic flora are available for the Italian coasts of the Adriatic Sea although, for some areas, owing to the rate of change, they are already out of date [10–13].

From a floristic point of view, the Adriatic Sea, compared with other Italian seas, is ‘structurally’ characterised by a lower number of species (577 taxa with only 39 exclusive species; Table 1). It also shows a different chorological spectrum (Table 2), characterised by dominance of the Atlantic element, followed by the Cosmopolitan, Mediterranean, Circumtropical, Indo-Pacific

Table 1. Italian macroalgal flora: composition of the whole flora, the flora of each Sea, species common to the three seas and sole species of the Adriatic Sea.

	Italy	Tyrrhenian Sea	Adriatic Sea	Ionian Sea (including the Straits of Sicily)	Common species	Sole species of the Adriatic Sea
Rhodophyta	509 (58.4%)	470 (61.1%)	340 (58.9%)	444 (63.2%)	314	4
Phaeophyta	208 (23.9%)	169 (22.0%)	124 (21.5%)	148 (21.1%)	93	21
Chlorophyta	154 (17.7%)	130 (16.9%)	113 (19.6%)	110 (15.7%)	84	14
TOTAL	871	769 (88.3%)	577 (66.2%)	702 (80.6%)	491 (56.4%)	39 (4.5%)

Note: Modified from Furnari et al. [10].

Table 2. Chorological spectra of the floras from each sea around the Italian coast.

Phytogeographic elements	Tyrrhenian Sea	Adriatic Sea	Ionian Sea (including the Straits of Sicily)
Atlantic	342 (44.5%)	253 (43.8%)	302 (43.0%)
Mediterranean	204 (26.5%)	132 (22.9%)	180 (25.6%)
Cosmopolitan	147 (19.1%)	137 (23.7%)	145 (20.7%)
Indo-Pacific	33 (4.3%)	20 (3.5%)	32 (4.6%)
Circumtropical	31 (4.0%)	24 (4.2%)	29 (4.1%)
Circumboreal	12 (1.6%)	11 (1.9%)	14 (2.9%)
TOTAL	769	577	702

Note: Modified from Furnari et al. [10].

and Circumboreal elements [12]. Moreover, in having a minor incidence of the Mediterranean element, the Adriatic Sea seems to be a discontinuity, probably because of the reduced extension of the rocky circalittoral zone where the Mediterranean element is dominant [14].

3. North Adriatic Sea

The most inclusive study of the algal flora of the Gulf of Trieste was made by Pignatti and Giaccone [15]. Subsequent studies were carried out on narrower seasonal periods or areas [16–22].

With the aim of evaluating long-term floristic changes during previous decades, extensive studies along the artificial and natural rocky shores of the Gulf of Trieste were conducted in 1999–2000 [23–25]. Comparisons with 1967 data highlighted environmental stresses (overgrazing, aquaculture and loss of habitats) which had led to large changes in benthic algal vegetation in terms of floristic diversity and dominant algal associations. The current algal assemblages are characterised by the absence of well-structured communities. Floristic comparisons showed a 20% decrease in the number of species and a reduction in Fucales stands, which made the vegetation uniform and dominated by perennial turf-like mats of *Gelidium*, *Gelidiella* and *Pterosiphonia* species. In particular, a 28% reduction in species among the Phaeophyceae (*Ectocarpales* and *Fucales*) and a 27% reduction among the Ulvophyceae (*Cladophorales*) were recorded. The disappearance of a large number of epiphytic species is attributable to the decline in the larger Phaeophyceae. *Cystoseira barbata* (Stackhouse) C. Agardh and *Cystoseira compressa* (Esper) Gerloff & Nizamuddin are still present, though with reduced stands, probably because of their wider tolerance [23]. Moreover, other species became rare and were found only in some sites [23,25]. Comparison of chorological spectra for both floras shows the prevalence of the Cosmopolitan, Atlantic and Indo-Pacific elements, with percentages very close to one another. It is, however, possible to find a further reduction in the Mediterranean element, represented mainly by Fucales in the 1967 flora. Another phenomenon, which has been related to increased turbidity, is the upward migration of several species from the lower sublittoral zone to the eulittoral zone [e.g. *Halimeda tuna* (J. Ellis & Solander) J.V. Lamouroux and *Flabellia petiolata* (Turra) Nizamuddin] [23]. These results are consistent with observations by Munda [9] and Sfriso [26] for the Istrian coasts and Venice littoral, respectively.

The taxonomic distinctness and diversity indices applied highlighted a spatial variability in the flora caused by environmental disturbance. This is particularly evident in the northern area of the Gulf of Trieste where reduced algal cover, mainly represented by turf species, discontinuous vegetal colonisation with a significantly higher number of Rhodophyceae and a concomitant lower number of Phaeophyceae were observed [25]. The abundance of *Paracentrotus lividus* (Lamarck) (Echinodermata, Echinidae) and its selective feeding behaviour [27] have been recognised as the most probable cause of the reduction in Phaeophyceae. At that site, bare slopes with some remnants of crustose coralline algae were observed. Similar patterns were reported from the Slovenian coast during 1972–1974, where overgrazing caused the disappearance of the *Cystoseira* stands. These areas were recovered in 1992 [28].

Despite the observed current reduction in floristic richness compared with 1967, the total number of species is fairly high compared with other areas of the north Adriatic Sea [9]. The specific richness found may indicate the presence of a genetic reservoir and the potential capability for restoration of the environment following conservation planning and habitat protection [23,25].

Because the northern Adriatic is the coldest part of the Mediterranean Sea, it hosts a number of species of boreal affinity, for example, the endemic *Fucus virsoides* J. Agardh. It has been assumed that this area and its endemic cold water affinity species, may be most concerned by meridionalisation and tropicalisation caused by global climate change [3].

In past decades, the regression/disappearance of *F. virsoides* has been signalled from different areas of the north Adriatic Sea [23,24,29,30]. This species presents an optimum at moderately exposed rocky shores with a gentle slope and low salinity [29,31], while on exposed shores, it usually occurs at lower density and smaller size [32]. It has been shown that temperatures $\geq 20\,^{\circ}\mathrm{C}$ reduce productivity, whereas periodic emersion favours photosynthesis [33]. If exposed to eutrophic waters or heavy metal contamination (Zn, Co, Mn) growth is reduced [33]. Comparison between cartographic monitoring of *F. virsoides* (using GIS technology) carried out in May 2009 along the Italian and Slovenian coasts of the Gulf of Trieste, combined with density measures and historical data (*Herbarium* TSB and literature data) has allowed analysis of the change in the distribution of this species over the last 100 years (Falace, Orlando-Bonaca, unpubl. data). Actually, *F. virsoides*, like others Fucales, undergoes large spatial and quantitative variability over a long period [34]. It is currently spread along the Slovenian and Italian coasts and in the Venice and Grado-Marano lagoons also showing, in some areas, high density.

The rocky outcrops of biogenic concretions, called 'trezze' or 'tegnúe', scattered at different distances from the coast (3–13 nautical miles) and at depths between 9 and 40 m, on the sandy–muddy bottom of the north Adriatic Sea, are considered an infralittoral coralligenous habitat, according to the definition of the RAC/SPA [35] and Ballesteros [36]. Their number is still unknown (1000 or up to 3000 including the smallest ones) and they range in size from a single small block of one square metre to a few thousand square metres [37]. Also, the morphology is highly variable, depending on both the host rock and organic growth. Even if they represent a 'hotspot' of biodiversity in the rather monotonous landscape of the Adriatic Sea, these reef communities (particularly macroalgae, poriferans, anthozoans, bryozoans and ascidians) differ from the deeper Mediterranean coralligenous assemblages, because they present less important concretions of builder algae and a reduced number of species ([37] and references therein). Research on the builder organisms has recently been published and only few studies deal with macroalgal assemblages [38]. The macroalgae consist of >150 species but with a low total coverage value. The dominant elements are sciaphilous Corallinaceae and Peyssonneliaceae, together with some *Rhodymenia*, *Halymenia* and *Cryptonemia* species [38]. At the Veneto 'tegnúe', deeply affected by suspended particles and a high sedimentation rate, the main factors that differentiate the algal cover seem to be the distance from the coast, the depth and the dimension of outcrops [39]. Conversely, research on some outcrops off the Friuli Venezia Giulia show a higher coverage of encrusting macroalgae [40,41].

Because of their importance as a biodiversity hotspot, unique geological features and their weakness to anthropogenic impact (mostly trawling and other destructive forms of fishing), some outcrops of the north Adriatic Sea have recently been proposed as Sites of Community Importance (SICs) [40,41].

A study conducted in 1994 on the breakwaters of the Venice inlets, during years of eutrophication and extensive proliferation of macroalgae in the Venice lagoon, reported an increase in the number of species (133 taxa) [42], compared with the 1980s (106 taxa) [26] and 1960s (108 taxa) [31]. This may be mainly due to the use of scuba diving and new sampling procedures (monthly or seasonal sampling instead of 1–2 samplings per year) and not to an environmental improvement. In fact, such an increment was coupled with a decrease in high-quality environmental species [i.e. *C. barbata*, *C. compressa*, *Sargassum hornschuchii* C. Agardh, *Taonia atomaria* (Woodward) J. Agardh, *Bonnemaisonia asparagoides* (Woodward) C. Agardh, *Dohrniella neapolitana* Funk, *Grateloupia cosentinii* Kützing and *Phyllophora sicula* (Kützing) Guiry & L.M. Irvine] and an increase in eutrophic species (seven species of the genus *Cladophora* and two of the genus *Blidingia*). A number of nonindigenous species were recorded among those new to the area, i.e. *Antithamnion pectinatum* (Montagne) Brauner *ex* Athanasiadis *et* Tittley, *Heterosiphonia japonica* Yendo, *Polysiphonia morrowii* Harvey, *Bonnemaisonia hamifera* Hariot, *Grateloupia turuturu* Yamada, *Neosiphonia harveyi* (J. Bailey) M.S. Kim, H.G. Choi, Guiry & G.W. Saunders, *Sargassum muticum* (Yendo) Fensholt and *Codium fragile* (Suringar) Hariot subsp. *tomentosoides* (Goor) P.C. Silva. More recent data from both artificial and natural hard substrata of the Veneto marine areas report a further increase in species, with a total of 215 (130 Rhodophyta, 42 Ochrophyta and 43 Chlorophyta) and a significant presence of *C. barbata* and *C. compressa*, although restricted to a depth of 2–3 m. *F. virsoides* presents a scattered distribution with lower density compared with the Venice lagoon (Curiel, pers. obs.).

Starting from Venice, the low-crested coastal defence structures (i.e. breakwaters, sea walls, dykes) for protection against erosion that develop for up to 100 km (∼60% of the coastline), have become the main structural feature of the north Adriatic coastline. Over the last 20 years, along the coast of the Veneto, different submerged structures have been placed for up to 10 km to protect and integrate the beach nourishment interventions and the hydraulic defence of the Venice lagoon littorals (Mose, Pellestrina, Malamocco). These substrata have been rapidly colonised by rich benthic communities [43,44]. The community of the Pellestrina artificial substrata, after ∼6–7 years, presented a total of 140 taxa, 61 of which were macroalgae. Also the composition and structure of the benthic community of the Malamocco reefs, after 2 years, appeared diversified, with a total of 130 taxa, 62 of which were macroalgae [43]. In particular, on shallower reefs, extensive stands of *C. compressa* and *C. barbata* rapidly developed, acting as habitat-forming species and improving the fish community. Moreover, on the landward side of the Pellestrina reef, the dominance of *Corallina elongata* J. Ellis *et* Solander, *Ulva rigida* C. Agardh, *Dictyota dichotoma* (Hudson) J.V. Lamouroux v. *intricata* (C. Agardh) Greville and *Dictyopteris polypodioides* (A.P. De Candolle) J.V. Lamouroux was noticed, whereas on the most deep reef of Malamocco Ochrophyta dominate, and in particular *D. polypodioides*. Like the rocky outcrops, the artificial structures along the Veneto littoral may play an important role as a ‘biological zip’ connecting the marine areas and the biggest lagoon of the Mediterranean Sea showing a richness of ∼300 species [13].

Conversely, the groynes and breakwaters placed south of the Po River along the Emilia Romagna coasts seemed to cause severe alterations in shallow sedimentary habitats and have negative effects on native habitats and assemblages [45,46]. These breakwaters, in particular the wave-sheltered sides, seemed to favour the expansion of nonindigenous, invasive *C. fragile* subsp. *tomentosoides* [46] as well as a change in competitive relationships in the recipient habitat. *C. fragile* subsp. *tomentosoides*, a native taxon of Japan, has become an important component of the intertidal and shallow subtidal rocky assemblages of many temperate seashores in the northern and southern hemispheres [47]. Its worldwide spread has been related to its wide physiological tolerance and high reproductive capability [48]. Considering several establishment categories (pollutant tolerance, reproductive mode, growth strategies and grazing defence mechanism) together with dispersal categories and ecological impact, Nyberg and Wallentinus [49] ranked *C. fragile* subsp., *tomentosoides* among the five marine algal species with the highest risk of becoming invasive. However, it is worth mentioning that even if this taxon is present in the Venice Lagoon, on artificial structures of the Veneto coast and in the Gulf of Trieste, it has not shown invasive traits, being present with single and sporadic thalli, like its congeneric native *Codium vermilara* (Olivi) Chiaje.

Compared with the artificial structures of Veneto coast, those of Emilia Romagna are characterised by lower species richness and the dominance of mussels [45]. No canopy algae were found and the other dominant macroalgae, besides *C. fragile* subsp., *tomentosoides*, are *Ulva intestinalis* Linnaeus, *Cladophora* spp., *Polysiphonia* spp. and *Ceramium* spp. [45]. The observed differences are probably related to: (1) the influence of rivers outflows (salinity variations, the presence of herbicides and other pollutants); (2) the different architecture of the artificial substrata; and (3) the absence, along the Emilia Romagna coastline, of nearby natural rocky substrata that act as 'biotic source'. The species that colonise the Veneto breakwaters are in fact also very common on hard substrata (natural or artificial) inside the Venice lagoon. Studies conducted on the Catalan coasts have shown that the presence of natural rocks nearby the artificial sea defences minimises the differences between the communities growing on natural and artificial substrates, even if they never reach the same 'climax' community [50].

4. Middle Adriatic Sea

The first research on the phytobenthos of the middle Adriatic Sea is represented by the floristic studies carried out along the Marches coast, in particular near Ancona, by Irma Pierpaoli; the results of which are reported in only one article [51]. With specimens collected, Pierpaoli prepared a rich herbarium now kept in the Marine Biological Station of Porto Cesareo (Lecce, Apulia) [52]. The floristic list obtained by Cecere et al. [53] from both her scientific paper and the revision of her herbarium consists of 76 Rhodophyta, 25 Ochrophyta and 22 Chlorophyta, giving a total of 123 taxa (four *taxa inquirenda* included). Because in the catalogue of the Adriatic flora [10], 202 species (127 Rhodophyta including five *taxa inquirenda* and two *taxa excludenda*, 41 Ochrophyta including one *taxon excludendum* and 34 Chlorophyta including one *taxon inquirendum*) were reported from the middle Adriatic Sea, we can conclude that Pierpaoli's studies are exhaustive. Moreover, it should be pointed out that comparison between the two floristic lists resulted in 31 Rhodophyta, 6 Ochrophyta and 11 Chlorophyta which were collected by Pierpaoli only.

Unfortunately, there are no recent exhaustive floristic studies and the only available data, mostly fragmented or focused on a few transects, come from unpublished research, so it is not possible to accurately appraise the temporal changes. Nevertheless, over the last 4–5 years at the Conero promontory, a regression in communities with *Cystoseira* spp., currently reduced to small patches of small individuals, has been observed (Romagnoli and Totti, pers. obs.). In particular, a number of studies carried out in 1997–2007 (Romagnoli and Totti, unpubl. data) have highlighted an increase in eutrophication and turbidity and the occurrence of algal communities chiefly characterised by the qualitative/quantitative dominance of Rhodophyta. Moreover, the abundance of ephemeral species forming extensive turfs, like *Polysiphonia* spp. and C*eramium* spp., was observed from spring to autumn. *Corallina officinalis* Linnaeus, *D. dichotoma* and *U. rigida*, occurring in shallow water, were abundant all year round, whereas *Ulva compressa* Linnaeus and *U. intestinalis* were abundant only in spring.

5. South Adriatic Sea

Knowledge of the Apulia coast flora is also scarce and fragmented. The most studied areas are the Tremiti Islands [54–56], Brindisi [57], the Gargano coast [58,59], some deeply anthropised areas of the Taranto Gulf (Ionian Sea) [60–63] and some areas of the Ionian Neretina coast [64–66].

The total flora of the Apulia coast (both Adriatic and Ionic versants) consists of 616 taxa [57], of which 569 occur in the Adriatic versant and 450 in the Ionian versant. A total of 164 taxa were present only in the Adriatic versant compared with 45 only in the Ionian versant. The differences between the two versants may be related to both different coastline extents (∼600 vs. 230 km of the Adriatic and the Ionic versant, respectively) and the higher number of floristic–vegetational studies carried out along the Adriatic shores.

Moreover, it should be noted that the R/P ratio of the flora of the Adriatic versant (3.3) is rather similar to that of the Mediterranean Sea (3.0), whereas that of the flora of the Ionic versant (4.1) indicates tropical rather than Mediterranean phytogeographic features. This is probably because of the lower number of floristic studies carried out along the Ionian coast, in particular, in areas less anthropised and with a higher ecological value [56].

From the Gargano Promontory, Cecere et al. [59] reported 234 taxa (169 Rhodophyta, 33 Ochrophyta and 32 Chlorophyta), of which 152 were first reported from that area. By contrast, only 82 of the previously recorded 162 taxa were found. On the whole, both a decrease in ‘canopy-forming’ species and an increase in ‘turf-forming’ ones, mainly represented by Ceramiaceae, Ectocarpaceae, Cladophoraceae and Gelidiaceae, were observed. In particular, the disappearance of *Cystoseira corniculata* (Turner) Zanardini, *Cystoseira foeniculacea* (Linnaeus) Greville f. *tenuiramosa* (Ercegovic) Gómez Garreta et al. [as *Cystoseira schiffneri* Hamel f. *tenuiramosa* (Ercegovic) Giaccone], *Cystoseira spinosa* Sauvageau, *Sargassum acinarium* (Linnaeus) Setchell and *Sargassum hornschuchii* C. Agardh was pointed out. The decrease in Ulvaceae and the occurrence of sciaphilous taxa on shallow waters were also recorded. The current species composition might be related to both a reduction in light penetration and an increase in the sedimentation rate [59]. A strong decrease in *Cystoseira amentacea* (C. Agardh) Bory was also reported during 2001–2004 from Torre Guaceto coast where, to date, it is present only in small patches (10 × 10 cm) (Fraschetti, pers. obs.). The distribution of *Cystoseira* spp. along all the Apulian coast was studied by snorkeling in May 1996 at 28 sites [67]. Three species characterised the mid-littoral fringe (0–2 m depth): *C. barbata*, *C. compressa* and *C. amentacea*. The last was the most widespread, being present at all sites, forming a continuous belt (Fraschetti pers. obs.) [67].

At the Tremiti Islands, Cormaci et al. [55] found changes in the benthic macroalgal flora with respect to that reported in studies carried out ∼30 years before. Although the total number of species had increased slightly (321 species compared with 275 from the literature), the floristic composition was quite different, with 108 previously recorded species not found and 147 species new to the area. In particular, the increased R/P value (from 2.63 to 3.83) was pointed out. According to Cormaci et al. [55], this does not constitute evidence for the tropicalisation of the flora, because it is mainly due to an increase in the number of Rhodophyta, and not a significant decrease in the number of Ochrophyta. Such an increase was instead related to a localised environmental instability like the reduced transparency of water because of the presence of suspended inert material.

The flora of S. Cesarea Terme (Lecce) is characterised by an elevated richness if compared with other areas of the Apulia [68]. Of the 154 species collected, 127 are common to both the Adriatic and the Ionian Seas, 19 are exclusive to the Adriatic Sea and 3 are exclusive to the Ionian Sea; 5 species are new to Apulia. The flora is mainly characterised by coralligenous community species occurring even in shallow waters. That is probably due to the presence of crevices, holes and caves that support the development of sciaphilous species. The R/P value of 4.32 for Santa Cesarea Terme flora indicates an in-progress tropicalisation process. That is also confirmed by the affinity of its chorological spectrum with those of southern areas like Linosa and Lampedusa islands [69] especially as concerns Indo-Pacific and Pantropical elements.

Finally, the occurrence along all the Apulian coast (both Ionic and Adriatic versants) of the nonindigenous taxon *Caulerpa racemosa* (Forsskål) J. Agardh var. *cylindracea* (Sonder) Verlaque, Huisman *et* Boudouresque should be pointed out [70].

6. Discussion

6.1. *Biodiversity changes*

On the basis of the above, the most evident conclusion that can be drawn is that in recent years in the Adriatic Sea, macroalgal assemblages have undergone a general trend towards change. In some localities of both the north and middle Adriatic Sea, changes are often coupled with a decrease in species richness. In other areas, like the Venice Gulf, along the Apulia coast and at the Tremiti Islands, differences in species composition are also connected with an increase in the total number of species.

Changes in sets of floristic data collected over time and their comparison are not always easily understandable and often show a number of restrictions. Variations in richness and species composition may not, in fact, be indicative of real change and may not be monotonic responses to anthropogenic disturbances. Conversely, they may be affected, for example, by different sample sizes, sampling effort (in time and space) or taxonomic expertise and resolution [25]. Assessments based on nondestructive methodologies (visual and/or photographic), functional groups, higher taxonomic levels or focusing on the survey of key species, misplace the importance of rare, cryptic or not *in situ* easily identifiable algal species and greatly affect the analyses of the assemblages [25].

Recent years have seen advances in our knowledge of biodiversity, the identification of factors that drive its evolution and distribution, and our understanding of its importance. Actually, little is known about the marine environment, in particular, the effects of changes in biodiversity on ecosystem functioning and properties (i.e. nutrient use and cycling, productivity, invasion resistance, stability and trophic transfers). However, dramatic changes at a global scale in genetic, specific and functional group diversity have given us an awareness of its influence [71–74]. Habitats loss and fragmentation, overexploitation and other causes have reduced species richness on large spatial scales [75]. But the increase in other regions of biodiversity through intentional and accidental introductions [76] means that the net change in species richness is not always clear. These two processes combined may alter the trophic structure of food webs and a better understanding of how such simultaneous changes in diversity can impact ecosystem function is crucial for the prediction of future changes [74,77].

The influence of diversity on community dynamics is very complex and relies on the type of stress, as well as the relative importance of both species richness and composition [73]. Natural systems are even more complex because of combined abiotic and biotic effects (i.e. grazing, chemical defences, etc.) which may alter ecosystem biomass and/or identity. Finally, the interpretation of ecological models and cause–effect relationships may be more controversial because of ‘hidden treatments’ and mechanisms that operate in combination, like selection and complementarity effects (i.e. resource partitioning or facilitation, nonrandom selection of key species, etc.) [74,78,79].

It is noteworthy that many experiments probably underestimate the strength of diversity on ecosystem processes because they are conducted over the short-term and/or in the absence of data on recruitment and the expression of niche differences [74], which means data on environmental heterogeneity are insufficient to capture population-level responses.

6.2. *Structural changes*

Important changes in the Adriatic marine vegetation involve the structure of the algal communities, e.g. migration of sciaphilous macroalgae in shallower waters, a reduction in habitat-forming species (mainly *Cystoseira* spp., and *Sargassum* spp.), together with an increase in Rhodophyta and opportunistic species. These shifts have generally been considered to be one of the main effects of environmental variations on macroalgal communities [80–84]. They have been ascribed to an overall worsening of water quality (due, for example, to eutrophication, turbidity and sedimentation rates), which, in turn, is related to aquaculture, beach nourishment, drainage, rivers discharge, etc. However, even if the structural changes of assembleges are widespread, the cause–effect of these switches and their consequences on a larger scale are less understood [4,85].

Undoubtedly, positive interactions between species play a significant role in reducing physical or biotic stresses in existing habitats and creating new habitats on which many species depend. A number of habitat-modifying species (foundation species *sensu* Dayton) [86] form the basis on which the entire community is built, enhancing the diversity and abundance in many ecosystems [87]. Marine benthic communities such as coral reefs, kelp forests and rocky shores rely on the occurrence of these foundation species [88]. In turn, these habitat-forming species often benefit, directly or indirectly, from species they host or shelter (i.e. being kept free of their own predators/competitors, decreasing their reliance on external nitrogen sources, etc.), thus improving host performance and the overall stability of the system [87,89].

In some traits of the Adriatic coast for which time series of macroalgal data are available, theoretical evidence for the occurrence of regime shifts and the detection of alternative stable states can be acknowledged. In the literature, there are a number of available definitions and models of shifts regime, varying in the extent to which they apply [90,91]. Predictions from these models have been demonstrated in a variety of ecosystems [91,92].

The switch between ecosystem states can be caused by gradual, cumulative changes in the forcing variable(s) or it can be activated by acute disturbances, either anthropogenic or natural [93,94]. The matter is to separate the driven forces of regime shifts and, in particular, to discern human incidence, given that natural ecosystems are neither stable nor in equilibrium and that spatial/temporal cyclic or chaotic changes in the relative species abundance and community structures are natural features of ecosystems, particularly those dominated by Fucales. Moreover, the combination of human impacts with fluctuations in abiotic parameters and general climatic changes, together with biotic cyclical perturbations (e.g. grazing of sea urchins) can amplify their effects to a great extent. In fact, changes observed along the Adriatic shoreline consist of: (1) substitution with congeneric more tolerant species; (2) simplification of the community structure; and (3) the complete disappearance of foundation species like some species of *Cystoseira* replaced by either fast-growing or turfs species.

Ecological theory predicts that human-dominated environments promote opportunistic species, so that longer lived and larger species are replaced by small, fast-growing, ‘weedy’ species [95]. Changes from the dominance of late-successional species to that of opportunistic macroalgae are also the basis of some functional parameters recently proposed for the water quality status assessment (*sensu* European Water Framework Directive; EC, 2000) [96]. The index EEI [7,97], for example, classifies benthic macrophytes into two groups that respond differently to environmental disturbance and combines ecophysiological traits such as nutrient uptake, photosynthesis, growth rates and grazing resistance with life-cycle strategy (r, k selection) [97]. In coastal and transitional ecosystems, shifts seem to both control and be controlled by key biogeochemical processes in a sequence of reactions, switches and feedbacks [96,97]. In the context of the assessment of ecological status, changes in macroalgal assemblages have also been analysed in terms of system complexity ([98] and references therein). Such an approach showed that communities switch results in loss of ecosystem components, but overall ecosystem complexity and organisation are impoverished, even if more research and further comparison are needed for the macrobenthos.

It is noteworthy that the removal of habitat-forming species results in a decline in community diversity by reducing habitat complexity. However, depending on the scale of organisms considered, it may lead to an increase in diversity, liberating other species from competition for space [99]. In many habitats, this function is highly dependent on the characteristics of the foundation species (i.e. their size, density, complexity, etc.) [88].

7. Conclusion

From the above, the following conclusions can be drawn:

(1) There is a different level of knowledge about and amount of information on macroalgae distribution and changes that have occurred along Italian Adriatic coasts. The Adriatic Sea is undergoing severe changes due to land reclamation, tourism, loss of habitats, pollution and climatic changes (the last affecting the whole east Mediterranean basin), which are acting directly or indirectly on algal benthic assemblages. Thus, long-term baseline data and updated regional lists are necessary to both detect changes and predict future effects of current human activities.

(2) The conservation of natural habitats together with the restoration of damaged habitats, in which a more or less important loss of biodiversity occurs, are primary goals that studies should address in order to better understand the ecological processes responsible for the origin and maintenance of natural communities. Because of the importance of habitat-forming species for the structure of the entire community [88], efforts must be focused on their preservation since they play an important role in facilitating associated species. It is noteworthy that most of ecological studies deal with facilitators, and do not consider other important foundation species in the ecosystem. Obviously, just preserving facilitators or mutualists is not enough to stop the decline in biodiversity. In fact, their success depends on size, density, architectural complexity and chemistry, all of which vary geographically, temporally and with local biotic and abiotic conditions [88]. In this context, it is important to understand that facilitation is essential to restore the characteristics and functions of the original systems [100]. Moreover, research is often restricted in its temporal and spatial extents such that it represents only a snapshot of the ecological processes under investigation [101]. Differences among experiments, interactions between biotic and abiotic processes and natural variation in ecosystems make generalisation difficult [78,101].

(3) At present, the occurrence of regime shifts is detected *post hoc* and relies on observations taken over time scale of years and decades. However, the hypothesis that ecological systems may undergo alternative stable states should not be taken as a rule before experimental validation [91,102]. In the context of natural resources management, there is a specific need to develop warnings and indicators of an impending regime shift with an adequate lead time to enable preventive and effective interventions [93,103]. Although diverse events can trigger such shifts, recent studies show that a loss of resilience usually facilitates the switch to an alternative state. Systems apparently absorb disturbance for a while, then suddenly collapse, suggesting that good management of the environment should concentrate on processes that preserve resilience to buffer perturbation [92].

In conclusion, there is an urgent need for the implementation of long-term and large-scale monitoring programmes on biodiversity and habitat distribution, status and trends. This should include a new integrated and cross-sector research approach that takes into account genetic, taxonomic, physiological and ecological aspects, coupled with chemical and physical assessments. This would allow a better understanding of biodiversity and its relationship with the function, processes and conservation of ecosystems.

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