Science of the Total Environment 605–606 (2017) 559–568

Contents lists available at ScienceDirect

Science of the Total Environment

journal homepage: www.elsevier.com/locate/scitotenv

Macrophyte assemblage composition as a simple tool to assess global change in coastal areas. Freshwater impacts and climatic changes

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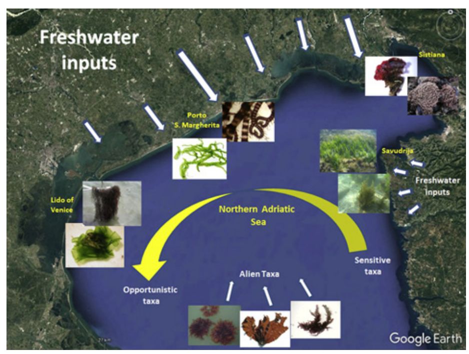
HIGHLIGHTS

- Macrophyte allows a rapid assessment of environmental changes in the coastal areas.
- The main causes of species variations are anthropogenic pressures and climatic changes.
- The study overlaps hydrosphere, anthroposphere and biosphere.
- Macrophytes and hydrologic parameters were recorded along the northern Adriatic coasts.
- River outflows are the main factors governing macrophyte communities in the northern Adriatic Sea.

GRAPHICAL ABSTRACT



ARTICLE INFO

Article history:
Received 21 March 2017
Received in revised form 27 May 2017
Accepted 23 June 2017
Available online 30 June 2017

Editor: D. Barcelo

Keywords:
Macrophytes
Biodiversity
River outflows
Nutrient concentrations
Ecological indices
Northern Adriatic Sea

ABSTRACT

Macrophyte assemblages are one of the most sensitive biological communities to assess anthropogenic impacts and climate changes. Community composition responds very quickly to environmental changes driving towards a predictable composition. The increase or decrease of the trophic status (i.e. nutrient concentrations, suspended particulate matter, Chlorophyll-*a*) and temperature are the most important factors responsible for the replacement of taxa of high ecological value (sensitive taxa) with opportunistic species. A qualitative and quantitative study of macrophytes in 4 areas along the coasts of the Northern Adriatic Sea, from Venice (Italy) to Savudrija (Croatia) and the analysis of river outflows in this region during one year (May 2012–April 2013) provided information about their spatial variability. The coasts of the Veneto Region and Friuli-Venezia Giulia, which are affected by significant freshwater inputs, showed a strong biodiversity reduction or a dominance of thionitrophilic taxa. No seagrasses colonized these areas. On the other hand, the coasts of Croatia had negligible fresh water inputs and macrophyte communities were dominated by sensitive taxa such as the seagrass *Cymodocea nodosa* and some species belonging to genus *Cystoseira*.

1. Introduction

Macrophyte (macroalgae and seagrasses) assemblages have a key role in the environmental quality of all the different types of aquatic ecosystems, such as lakes, reservoirs, wetlands, streams, rivers, transitional and marine environments. The colonization of aquatic environments by macrophytes is the result of adaptive strategies achieved over evolutionary time (Sujana et al., 2015). Macroalgae take on a wide variability of forms, ranging from simple crusts, foliose (leafy) and filamentous (threadlike) forms with simple branching structures, to more complex forms with highly specialised structures for light capture, reproduction, support, flotation, and attachment to the seafloor. From the ecological point of view, as described by MacArthur and

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http://dx.doi.org/10.1016/j.scitotenv.2017.06.196

Wilson (1967), annual species adopt mainly a "r" strategy, while perennial species adopt a "k" strategy. The former "r" are opportunistic and thionitrophilic taxa characterized by faster growth rates and short life cycles (for example Ulvaceae and Cladophoraceae, Sfriso and Facca, 2007). In contrast, the latter "k" show low growth rates and long life cycles and in general are more sensitive to environmental stressors (Orfanidis et al., 2001). These include many small calcareous macroalgae and seagrasses, particularly important for marine ecosystems. They ensure many ecosystem functions such as food, habitat and nursery areas for several benthic organisms and fish species. Seagrasses stabilize the sea floors and abate erosion processes. In addition, they are perennial species which permanently trap CO_2 and affect nutrient cycles, for example through the transfer of chemical elements from surface sediments to the water column, both by active and passive processes (Camargo et al., 2003). Similarly, calcareous algae, especially the small encrusting taxa of the genera *Hydrolithon* and *Pneophyllum*, are strongly affected by the physico-chemical variation of water parameters, particularly pH that when it decreases below mean marine values (approx. 8.0–8.3) hampers carbonate formation and the presence of these taxa. Furthermore, larger species such as *Lithophyllum stictaeforme* (Areschoug) Hauck, *Mesophyllum alternans* (Foslie) Cabioch & M.L. Mendoza, *Neogoniolithon mamillosum* (Hauck) Setchell & L.R. Mason and *Peyssonnelia rosa-marina* Boudouresque & Denizot which form thick coralligenous concretions and occupy large portions of the deep infralittoral and circalittoral zone, reduce their range of expansion and may disappear (Ballesteros, 2006).

For this reason, the structure and composition of macrophyte assemblages can provide information on trophic and environmental health, its alteration and evolution. The anthropogenic impacts on the biogeochemical cycles (especially nutrient enrichments and carbon emissions) and the increase of temperature, changing freshwater inputs mostly in terms of abundance and periodicity of rainfall, can have strong effects on the biodiversity and ecosystem functioning. As described by McQuatters-Gollop et al. (2009), European coastal areas that suffer the most from eutrophication are the coasts of the North Sea, the Baltic Sea, the northwest shelf of the Black Sea and the northern Adriatic Sea. In particular, the northern Adriatic Sea is a shallow and semi-enclosed marine basin that has experienced a strong increase in anthropogenic stress and global environmental alterations over the last 50 years. Waters have a cyclonic circulation pattern, from East to West and convey river outflows, pollutants and nutrients southwards, along the western Adriatic coasts (Gasparović et al., 2011). In addition the recent population increase along the coastal areas and the growing technology development have discharged into the environment a great amount of nutrients and pollutants (Cossarini et al., 2012; Kourafalou, 2001; Marcus, 2004). The combined effects of the anthropogenic stressors and regional climate changes are causing modifications to the physico-chemical characteristics of the Adriatic Sea affecting its biological communities (Giani et al., 2012). In particular, macrophyte assemblages tend to change their structure and taxonomic composition according to environmental stressors. Worldwide, studies have considered macrophytes valuable biological indicators of the water quality (Ballesteros et al., 2007; Orfanidis et al., 2011; Nikolic et al., 2013; Sfriso et al., 2014) because they mainly consist of sessile organisms with a relatively long life span. Along coastal areas, macrophytes, and in particular seagrasses, play a key role in primary production and constitute the basic structure of benthic communities. As stated in the Water Framework Directive (WFD, 2000/60/EC) and the Marine Strategy Framework Directive (WFD, 2008/56/EC), macrophyte assemblages are a good descriptor to assess the ecological status of coastal waters.

The main objective of this study was to show how macrophyte assemblage composition reflects the presence of anthropic stressors in a predictable way. We prove this by sampling macrophytes and some parameters affecting their presence at four coastal sites: Lido of Venice (Lido), Porto Santa Margherita (PSM), Sistiana and Savudrija, from the Veneto Region to Croatia. These areas have very different coastal morphology, anthropic stressors and are differently affected by river and lagoon outflows. Their waters convey large amounts of nutrients and particulate matter that are mainly responsible for the floral differences that characterize these coastal areas.

The impact of anthropogenic pressures that govern the trophic status of coastal areas; climatic changes, that reduce or concentrate rainfall events over short periods (Easterling et al., 2000) and increasing water temperature (Lejeusne et al., 2009), that favours the spreading of non-native species (Zenetos et al., 2010, 2012), can be rapidly assessed by the analysis of the structure and composition of macrophyte communities. At the same time, an increase of sensitive taxa provides immediate information on an ongoing environmental recovery.

2. Materials and methods

2.1. Study area

The four selected sites along the coast of the Northern Adriatic Sea (Fig. 1), from West to East are: Lido of Venice (sexagesimal coordinates: 45°22′15″ N, 12°20′41″ E), PSM (45°35′11″N, 12°51′59″ E), Sistiana (45°46′08″ N, 13°37′20″ E) and Savudrija (Croatia) (45°29′30″ N, 13°29′48″ E). The coastal area of Sistiana has high karst cliffs while shallow rocky cliffs characterize the Savudrija coastline. Sistiana is affected by the presence of a number of submarine springs, mainly connected to one of the most important karst rivers in the world, the Timavo river, which discharges waters from a karstic area of 700–1000 km^2 (Furlani et al., 2009). Savudrija receives waters from the small karst streams: Dragonja, Drnica, Badasevica, Rizana, that have a negligible impact on the coast. The two Veneto areas (Lido and PSM) have sandy shores protected by perpendicular breakwater panels and submerged artificial reefs parallel to the coastline. These areas are affected by the outflows of large above-ground rivers (Isonzo, Tagliamento, Livenza, Piave) and by water exchange with Grado-Marano (approx. 84.5 $m^3\ s^{-1}$, Bettoso et al., 2013; Acquavita et al., 2015) and Venice (approx. 35 $m^3\ s^{-1}$ (Sfriso et al., 1994; Zuliani et al., 2005) lagoons which convey significant loads of nutrients and pollutants into the sea.

2.2. Macrophyte sampling and identification

Macrophytes were sampled randomly by scuba divers in a linear transect of ca. 100 m per site each month from May 2012 to April 2013 collecting every different specimen in order to find the highest possible number of taxa. Samples were preserved in 4% formaldehyde sea-water until the taxonomic identification at specific and intra-specific level by a stereo-zoom microscope and a light microscope by using the most common floras available in literature. The cover of each taxon was determined by sampling macrophytes in spring and autumn through 6 sub-samples per stations by a frame of 40 × 40 cm (1600 cm^2) according to Curiel et al. (2000). Sampling was carried out taking into account station depth, that at Sistiana and Savudrija reaches 5–6 m whereas at Lido and PSM it is 2–3 m. The relative species cover (RSC) of each sub-sample was obtained by resuspending macrophytes in a transparent PVC container filled with tap water and with the bottom divided in a cm^2 grid in order to measure the vertical projection of macroalgae (Orfanidis et al., 2001, 2003, 2011; Panayotidis et al., 2004). With that procedure the sum of the cover of all taxa can overcome the 100% because the superimposition of erected, bushy and crusted taxa. The total in field species cover was obtained by multiplying the cover of each taxon of the 6 sub-samples by a number ranging from 0 to 1 to take into account the macrophyte cover of the total area. That number was the mean of in situ observations carried out by two operators by applying the Visual Census Technique (ISPRA - Istituto Superiore per la Protezione e la Ricerca Ambientale, 2011). The final result is a good approximation of the relative cover of each species.