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Trace element (Al, As, B, Ba, Cr, Mo, Ni, Se, Sr, Tl, U and V) distribution and seasonality in compartments of the seagrass *Cymodocea nodosa*

Paraskevi Malea [a,*], Theodoros Kevrekidis [b]

[a] *Department of Botany, School of Biology, Aristotle University, Thessaloniki GR-54124, Greece*
[b] *Laboratory of Environmental Research and Education, Democritus University of Thrace, Nea Hili, Alexandroupolis GR-68100, Greece*

HIGHLIGHTS

- The biological fate of rarely researched elements in a seagrass bed was examined.
- As,Ba,Sr and Tl did not markedly vary among Cymodocea nodosa compartments.
- B content was higher in blades, Cr in sheaths; Al,Mo,Ni,Se were less in rhizomes.
- Elements in leaf tissues showed a seasonality associated with leaf growth cycle.
- Blades reflected V in sediment, thus C. nodosa could be regarded as biomonitor for V.

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ABSTRACT

Novel information on the biological fate of trace elements in seagrass ecosystems is provided. Al, As, B, Ba, Cr, Mo, Ni, Se, Sr, Tl, U and V concentrations in five compartments (blades, sheaths, vertical rhizomes, main axis plus additional branches, roots) of the seagrass *Cymodocea nodosa*, as well as in seawater and sediments from the Thessaloniki Gulf, Greece were determined monthly. Uni- and multivariate data analyses were applied. Leaf compartments and roots displayed higher Al, Mo, Ni and Se annual mean concentrations than rhizomes, B was highly accumulated in blades and Cr in sheaths; As, Ba, Sr and Tl contents did not significantly vary among plant compartments. A review summarizing reported element concentrations in seagrasses has revealed that *C. nodosa* sheaths display a high Cr accumulation capacity. Most element concentrations in blades increased in early mid-summer and early autumn with blade size and age, while those in sheaths peaked in late spring–early summer and autumn when sheath size was the lowest; elevated element concentrations in seawater in late spring and early–mid autumn, possibly as a result of elevated rainfall and associated run-off from the land, may have also contributed to the observed variability. Element concentrations in rhizomes and roots generally displayed a temporary increase in late autumn, which was concurrent with high rainfall, low wind speed associated with reduced hydrodynamism, and elevated sediment element levels. The bioaccumulation factor based on element concentrations in seagrass compartments and sediments was lower than 1 except for B, Ba, Mo, Se and Sr in all compartments, Cr in sheaths and U in roots. Blade V concentration positively correlated with sediment V concentration, suggesting that *C. nodosa* could be regarded as a bioindicator for V. Our findings can contribute to the design of biomonitoring programs and the development of predictive models for rational management of seagrass meadows.

1. Introduction

Seagrasses occur widely in all coastal areas of the world, except along the Antarctic, by developing extensive beds in tidal or subtidal environments (Hemminga and Duarte, 2000). Seagrasses are important primary producers; they supply organic food to a variety of dependent food webs, stabilize the seabed, and structure the seabed into a complex environment which provides trophic and reproductive niches to many commercially-caught species (Costanza et al., 1997). However, seagrass decline is now a common phenomenon. This decline has been attributed to many factors that include natural causes, but in more than 70% of the cases anthropogenic factors are thought to be responsible (Hemminga and Duarte, 2000). Eutrophication has possibly the most widespread impact, but toxic chemicals such as trace elements are also suspected to be a major factor (Ralph et al., 2006). However, scientific knowledge on the biological fate of trace elements in seagrass meadows and their effects on seagrasses is limited, thus restricting a realistic assessment of the trace element

* Corresponding author. Fax: +30 2310 998389.
E-mail addresses: malea@bio.auth.gr (P. Malea), tkebreki@eled.duth.gr (T. Kevrekidis).

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role in seagrass decline (see review in Lewis and Devereux, 2009). For instance, bioaccumulation data are more available for a few seagrass species, mainly *Posidonia oceanica*, *Zostera marina* and *Thalassia testudinum,* and a few trace element species, particularly zinc (Zn), copper (Cu), cadmium (Cd) and lead (Pb) (see review in Pergent-Martini and Pergent, 2000 and Lewis and Devereux, 2009). Data on trace element concentrations in surface water over seagrass beds and in seagrass-rooted sediments are also more available for the same few elements (Lewis and Devereux, 2009). Therefore, additional information for the most commonly researched trace elements is needed, but research also needs to be extended to several other trace elements for which data are scarce or missing.

In the Mediterranean Sea, *Cymodocea nodosa* (Ucria) Ascherson along with *P. oceanica* (L.) Delile are the most important and widespread seagrass species. *Cymodocea nodosa* can colonize open coastal waters, estuaries and coastal lagoons and forms monospecific and mixed stands; it is considered as a species with great phenotypic plasticity and a high capacity to adapt to environmental variability and, thereby, to colonize new substrates (Terrados and Ros, 1992; Cancemi et al., 2002). Most of the studies that deal with trace element accumulation in *C. nodosa* have focused on determining element distribution among the basic plant compartments (leaves, rhizomes, roots) in locations with a different degree of contamination (Catsiki et al., 1987; Catsiki and Panayotidis, 1993; Nicolaidou and Nott, 1998; Sanchiz et al., 1999; Marín-Guirao et al., 2005; Llagostera et al., 2011); in some cases, the spatial variation in trace element concentrations in the basic plant compartments has been related to sediment element concentrations and/or to sediment physico-chemical characteristics (Sanchiz et al., 2000, 2001; Marín-Guirao et al., 2005). A few research efforts have been centered on describing the seasonal variation of trace element concentrations in whole plant tissues, in the basic plant compartments or in specific compartments of *C. nodosa* (Malea, 1993; Malea and Haritonidis, 1995, 1999; Malea et al., 2013b). Data are available more frequently for Zn, Cu, Cd, Pb and nickel (Ni), less frequently for chromium (Cr), iron (Fe), manganese (Mn) and even less frequently for mercury (Hg), cobalt (Co) and aluminum (Al) (Catsiki et al., 1987; Catsiki and Panayotidis, 1993; Malea, 1993; Malea and Haritonidis, 1995, 1999; Kozanoglou and Catsiki, 1997; Nicolaidou and Nott, 1998; Sanchiz et al., 1999; Marín-Guirao et al., 2005; Llagostera et al., 2011; Malea et al., 2013b). In particular, as far as we are aware, there are no available data on the distribution of trace elements such as Al, Cr and Ni among specific compartments of *C. nodosa*, as well as on the monthly variability of their concentrations in these compartments. In addition, no information is also available on the accumulation in *C. nodosa* tissues of several other elements, such as arsenic (As), boron (B), barium (Ba), molybdenum (Mo), selenium (Se), strontium (Sr), thallium (Tl), uranium (U) and vanadium (V).

The main goal of this study is to provide novel information on the accumulation of trace elements in seagrasses by investigating (1) the distribution of a wide set of elements (Al, As, B, Ba, Cr, Mo, Ni, Se, Sr, Tl, U and V) in several compartments (leaf blades, leaf sheaths, vertical rhizomes, main axis plus additional branches, roots) of *Cymodocea nodosa*, (2) the monthly variation in all twelve element concentrations in these plant compartments all year round and (3) the potential influence of element concentrations in surface water and sediment on this variation, in the Gulf of Thessaloniki, Northern Aegean Sea.

2. Materials and Methods

2.1. Study Area

Thermaikos Gulf is a water mass located in northwestern Aegean Sea at 40°30′N and 22°55′E. The area, volume and maximum depth of this gulf are 518 km^2, 11.33 km^3 and 36 m, respectively. To the north, the gulf becomes narrow and continues into the Gulf of Thessaloniki (Fig. 1), which receives industrial, partially treated domestic and agricultural effluents (Nikolaidis et al., 2006; Christophoridis et al., 2009). In the Gulf of Thessaloniki, meadows of *P. oceanica* (at depths of 12 m), *Cymodocea nodosa* (at depths of 0.4–2 m) and *Zostera noltii* (at depths of 0.5 m) have been recorded (Haritonidis et al., 1990; Haritonidis, 1996; Lazaridou et al., 1997; Orfanidis et al., 2010).

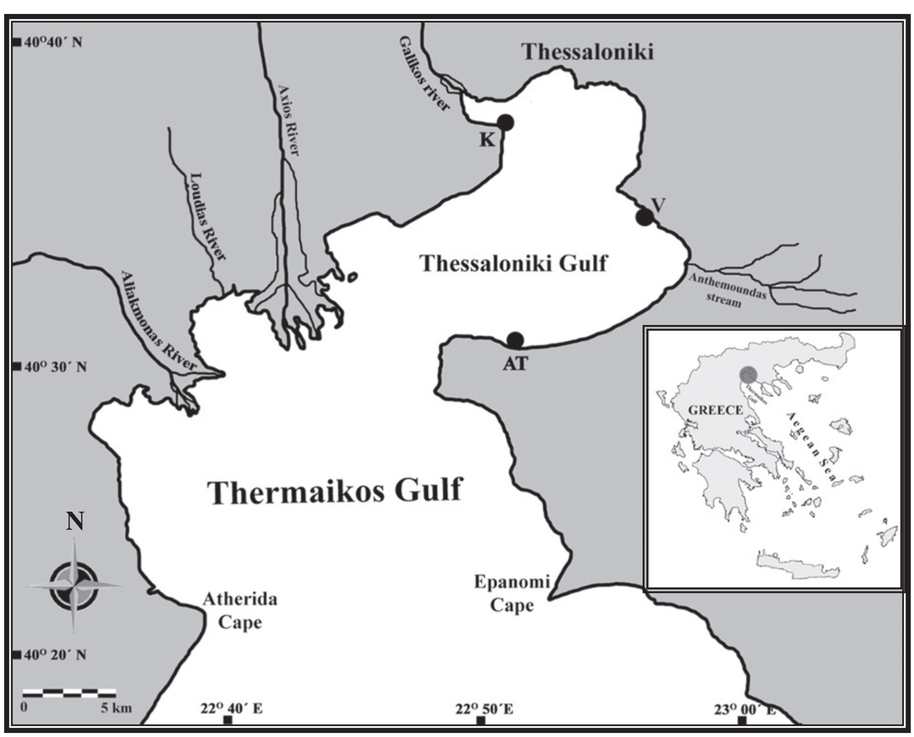

Fig. 1. Geographical location of the study site and map of the Gulf of Thessaloniki indicating the sampling station (V).