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Environmental factors affecting Phragmites australis *litter decomposition in Mediterranean and Black Sea transitional waters*

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ABSTRACT

1. Leaf litter decomposition rates in aquatic ecosystems are known to be related to many abiotic and biotic factors.
2. Field experiments were carried out during spring 2005 in 16 ecosystems, each with four sampling sites, using the litter bag technique to investigate the influence of abiotic factors on patterns of reed litter breakdown in different physiographic, hydrological and physico-chemical gradients occurring in transitional water ecosystems in the Eastern Mediterranean and Black Sea.
3. Significant differences in leaf litter decomposition were observed among the studied ecosystems along univariate gradients of tidal range, water temperature, salinity and sinuosity index.
4. Overall, 71% of variance in the litter breakdown rate was explained by the hydrological, physico-chemical and physiographic components. Specifically, tidal range, salinity and sinuosity index are among the key factors in the most commonly used typological schemes for classifying transitional water ecosystems (i.e. Confinement Concept and Venice System), due to their influence on abundance and distribution of benthic macroinvertebrates and other guilds.
5. The patterns observed at the regional scale of the study suggest that certain key abiotic factors are likely to play a major role as drivers of plant detritus decomposition processes, through their influence on the overall metabolism of microorganisms and benthic macroinvertebrates.

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6. These observations have implications for the identification of reference conditions for transitional water ecosystems in the studied area, on which all processes of classification and conservation of their ecological status are based.

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KEY WORDS: decomposition process; *Phragmites australis*; transitional waters; abiotic factors

INTRODUCTION

Submerged and littoral macrophytes, especially reed stands, are important contributors to primary production in freshwater and transitional water ecosystems (Mann, 1972).

In transitional aquatic ecosystems, only a small part of aquatic macrophyte production is directly consumed by herbivores (Mann, 1975), and a large part of the macrophyte biomass has a major function in the detritic pathway (Cummins *et al*., 1973; Webster and Benfield, 1986). Inputs of litter from littoral-emerged macrophytes are made available through decomposition processes and have been cited as a major source of energy for transitional aquatic environments (Mann, 1972; Valiela, 1984), which are ecotones, functionally connecting the land and its rivers on one side and the sea on the other (Wiegert and Pomeroy, 1981).

The intrinsic heterogeneity of transitional waters has given rise to a number of attempts to develop classifications based on potential forcing factors such as lagoon salinity (Venice System; Battaglia, 1959), lagoon confinement (Confinement Concept; Guelorget and Perthuisot, 1983), lagoon mechanical energy (Ergocline Theory; Legendre and Demerse, 1985) and lagoon surface area (Basset *et al*., 2006). Such schemes have gained fresh impetus as a result of the EU Water Framework Directive (WFD 2000/60/EC).

Plant breakdown rates in aquatic ecosystems have been found to be affected by internal factors such as physico-chemical characteristics of the leaves (Kok *et al*., 1990; Canhoto and Graça, 1996), and by external environmental factors such as water temperature and salinity (Carpenter and Adams, 1979; Reice and Herbst, 1982; Vought *et al*., 1998), pH (Thompson and Bärlocher, 1989), nutrients (Elwood *et al*., 1981; Sharma and Gopal, 1982), or regional characteristics, such as climate (Murphy *et al*., 1998) and solar radiation (Denward and Tranvik, 1998). Moreover, plant decomposition rates have been described in relation to biotic factors, highlighting the role of microfungi and invertebrates (Rossi, 1985; Gessner and Chauvet, 1994; Albariño and Balseiro, 2002). Abiotic factors can have a direct effect on decomposition, through leaching and fragmentation (Triska and Sedell, 1976), and an indirect effect, by determining the conditions of the environmental niche, filtering the traits of potential colonizers and affecting their metabolism (Suberkropp and Chauvet, 1995; Pascoal *et al*., 2003).

Litter breakdown has been widely studied in streams and rivers (Graça and Pereira, 1995; Diez *et al*., 2002; Pinna *et al*., 2003) and lakes (Gupta *et al*., 1996; van Dokkum *et al*., 2002); in contrast, studies of leaf litter decomposition in transitional aquatic ecosystems, such as coastal lagoons or river mouths, are less common (Rossi and Costantini, 2000; Menéndez *et al*., 2004; Bayo *et al*., 2005). In this type of ecosystem, plant litter decomposition may vary considerably from site to site in relation to many factors (Mendelssohn *et al*., 1999; Sangiorgio *et al*., 2004) such as water nutrient concentration (Menéndez *et al*., 2003, 2004; Bayo *et al*., 2005), and water salinity (Mendelssohn *et al*., 1999).

Reed (*Phragmites australis* [Cav] Trin ex Steud.) decay rates were studied in the Eastern Mediterranean and Black Sea, searching for indirect abiotic drivers of plant detritus decomposition in transitional waters.

The aims of the project were: (1) to identify regional spatial patterns of *P. australis* leaf decomposition among ecosystems; (2) to analyse the relationships between reed decomposition and certain key physiographic, hydrological and physico-chemical characteristics of the studied ecosystems; (3) to evaluate the relevance of these abiotic factors as potential indirect drivers of decomposition processes in transitional waters.

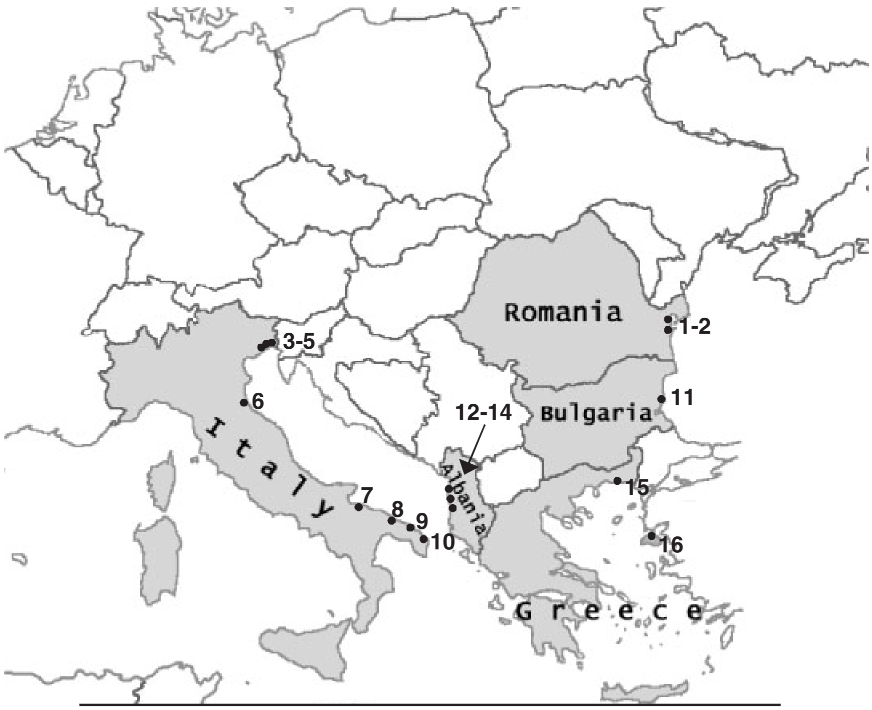
MATERIAL AND METHODS

Study sites

The study took place in 16 transitional aquatic ecosystems of the Central, Adriatic, Danubian and South-eastern European Space (CADSES area), from 45°42′59″N and 13°08′15″E at the most northernly site (Grado Marano, Italy) to 39°06′35″N and 26°10′57″ at the most southernly one (Kalloni, Greece). In this study, the transitional aquatic ecosystems included lagoons, coastal lakes and estuaries; three salt pans, in Albania, Greece and Italy, were also studied. The list is as follows: Leahova and Sinoe in Romania; Grado Marano, Grado fish farm, Grado Cavanata, Pialassa Baiona, Margherita di Savoia, Torre Guaceto, Cesine and Alimini in Italy; Varna in Bulgaria; Patok, Karavasta and Narta in Albania; Agiasma and Kalloni in Greece (Figure 1).

Field experiments

The study was carried out during spring in 16 ecosystems, each with four sampling sites, selected according to an intra-habitat typology classification, and with five replicates per site. Data on the physiographic and hydrological features of each ecosystem (area, depth, index of sinuosity, outlet length, outlet width and tidal range) were provided by each partner involved in the EU-funded TWReferenceNet Project (Interreg IIIB-CADSES), of which this study is a part. Abiotic water parameters (dissolved oxygen, pH, water salinity and temperature) were monitored during sampling activities at



Country		Name	Latitude	Longitude
Romania	1	Leahova	N 44° 43' 49"	E 29° 01' 44"
	2	Sinoe	N 44° 35' 51"	E 28° 51' 55"
Italy	3	Grado Marano	N 45° 42' 59"	E 13° 08' 15"
	4	Grado fish farm	N 45° 42' 33"	E 13° 22' 27"
	5	Grado Cavanata	N 45° 42' 24"	E 13° 28' 21"
	6	Pialassa Baiona	N 44° 29' 19"	E 12° 14' 41"
	7	Margherita di Savoia	N 41° 23' 47"	E 16° 02' 56"
	8	Torre Guaceto	N 40° 42' 44"	E 17° 47' 32"
	9	Cesine	N 40° 21' 26"	E 18° 19' 51"
	10	Alimini	N 40° 11' 43"	E 18° 27' 09"
Bulgaria	11	Varna	N 43° 10' 40"	E 27° 47' 46"
Albania	12	Patok	N 41° 37' 23"	E 19° 36' 11"
	13	Karavasta	N 40° 55' 01"	E 19° 29' 48"
	14	Narta	N 40° 31' 46"	E 19° 25' 29"
Greece	15	Agiasma	N 40° 52' 36"	E 24° 37' 26"
	16	Kalloni	N 39° 06' 35"	E 26° 10' 57"

Figure 1. Geographic localization of studied transitional waters within the CADSES area (in grey). Latitude and longitude are reported for each ecosystem.

each site using a hand-held multi-probe meter (YSI 556). Samples were taken from the water column surrounding the litter bags in a subset of sites representing all the bottom types (up to three) of each ecosystem, identified before the start of the experiment, two sites being chosen per type. Water nutrients (ammonium, nitrite, nitrate and phosphate) were determined in the laboratory as inorganic dissolved concentrations (Strickland and Parsons, 1972).

Detritus processing was studied on leaves of *P. australis* using the litter bag technique (Bocock and Gilbert, 1957; Shanks and Olson, 1961). Leaves were collected simultaneously and from the same area at the beginning of autumn; the basal and apical parts of all leaves were cut off and only the central leaf section was used for leaf packs. An estimate of the initial ash free dry weight of leaves was determined on sub-samples of leaves. In spring, litter bags (0.5 cm mesh size) were filled with 3.000 ± 0.005 g of oven-dried leaves (60°C, 72 h), five leaf bags being placed at each sampling site. It was planned to retrieve all bags after 30 days immersion but because of poor weather conditions, the immersion period varied slightly among ecosystems. Seven ecosystems were sampled after 30 days (Agiasma, Kalloni, Karavasta, Narta, Pialassa, Sinoe, Varna); seven after 35 days (Alimini, Cesine, G. Marano, G. fish farm, Leahova, M. di Savoia and T. Guaceto); and two after 40 days (G. Cavanata and Patok). In the laboratory, the leaves were gently washed with tap water, dried (60°C, 72 h), weighed and combusted (500°C, 6 h) to obtain the ash content.

Data analysis

To account for the differences in the duration of field experiments in the various ecosystems, dry mass loss per day, calculated assuming an exponential decay model (Petersen and Cummins, 1974), was used to estimate litter breakdown rates of *P. australis* leaves. Percentage mass loss per day and percentage mass remaining at the end of the experiment were found to be strictly related (ordinary least squares regression: $y = 8.94e^{-0.03x}$; d.f. = 70; $r^2 = 0.91$).

Analysis of structural abiotic similarity among ecosystems was performed using multi-dimensional scaling (MDS) based on Euclidean distances on square-root transformed abiotic data. Analysis of similarity of reed detritus breakdown rates among ecosystems was performed using hierarchical clustering by the average linkage method and analysis of similarity among groups (ANOSIM) was then computed (Primer v.5, Clarke and Gorley, 2001).

One-way analysis of variance (ANOVA) (Sokal and Rohlf, 2001) was performed on leaf breakdown data, grouped according to transitional water type classifications. Ordinary least squares regressions between leaf mass loss per day and each abiotic characteristic of the ecosystems were calculated. Stepwise multiple regression analysis (Statistica v.6) was carried out on all ecosystems and on a subset of ecosystems selected from the MDS analysis, in order to select potential sources of variation of reed breakdown rates among the abiotic characteristics considered.

Data were tested for conformity to assumptions of variance homogeneity (Cochran's test) and transformed when necessary to fulfil assumptions of normality.

RESULTS

Site characterization

Physiographic and hydrological features varied widely across the water bodies studied. Surface area varied from 0.3 km^2 in Grado fish farm to 142.0 km^2 in Grado Marano; depth ranged from a minimum of 0.4 m in Margherita di Savoia and Kalloni to a maximum of 11.7 m in Varna. Three ecosystems, Leahova, Sinoe and Cesine, were only temporarily connected to the sea; both outlet length and width were occasionally equal to zero, depending on freshwater pressures and wave action. Outlet length was maximum in Varna (3.09 km) and outlet width was greatest in Grado Marano (3.30 km) (Table 1).

Physico-chemical parameters also varied considerably among ecosystems; the lowest water salinity (0.2‰) was recorded in Leahova and Sinoe, and the highest (64.8‰) in Margherita di Savoia. However, nutrients had higher variability than physical water parameters such as water temperature, pH and dissolved oxygen (Table 2).

Considering both physiographic and hydrological features on the one hand and physico-chemical parameters on the other, three groups of ecosystems were derived from MDS analysis (ANOSIM, $R = 0.97$, $P < 0.01$). Grado Marano and Sinoe, with the highest surface areas (average = 135.8 km^2), were separated from the other ecosystems in one group; Leahova, Torre Guaceto and Cesine (which together with Sinoe were the four ecosystems) with the lowest water salinity (average = 2.93‰), comprised a second group, and the remaining 11 ecosystems formed a third group (Figure 2).

Leaf decomposition

Leaf mass loss per day of *P. australis* leaves varied significantly across all the ecosystems (one-way ANOVA, $F_{15,56} = 7.1$; $P < 0.001$). On average, litter mass loss per day was equal to $1.93 \pm 0.28\%$, ranging from 1.39 to 2.81% (Table 3). Average linkage clustering of similarity identified three groups of ecosystems characterized by different litter breakdown rates (ANOSIM, $R = 0.97$, $P < 0.01$) (Figure 3). The highest leaf mass loss per day (2.81%) was observed in Pialassa Baiona where *P. australis* breakdown was significantly faster than in

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Table 1. Main physiographic and hydrological characteristics of studied transitional waters

Country	Ecosystem	Area (km^2)	Depth (m)	Index of sinuosity	Outlet length (km)	Outlet width (km)	Tidal range (m)
Romania	Leahova	22.9	1.0	1.8	0.00	0.00	0.15
	Sinoe	129.6	0.7	1.9	0.00	0.00	0.15
Italy	Grado Marano	142.0	1.2	2.1	0.55	3.30	0.65
	Grado fish farm	0.3	0.7	1.4	0.05	0.03	0.10
	Grado Cavanata	2.1	1.0	1.3	0.50	0.30	0.10
	Pialassa Baiona	8.4	2.5	3.8	1.96	0.16	0.40
	Margherita di Savoia	12.0	0.4	1.9	0.34	0.08	0.10
	Torre Guaceto	1.6	0.5	1.4	0.08	0.04	0.20
	Cesine	0.9	1.1	3.6	0.00	0.00	0.15
	Alimini	1.4	1.1	2.3	0.17	0.02	0.19
Bulgaria	Varna	26.2	11.7	2.7	3.09	0.73	0.15
Albania	Patok	7.1	0.6	1.5	0.05	0.48	0.30
	Karavasta	45.0	1.2	1.9	0.66	0.33	0.20
	Narta	29.9	0.5	1.3	0.52	0.13	0.10
Greece	Agiasma	3.2	0.7	2.1	0.24	0.02	0.50
	Kalloni	2.8	0.4	1.4	0.65	0.06	0.10

Ecosystems are listed from north to south in each country.

Table 2. Physico-chemical characteristics of studied transitional waters

Country	Ecosystem	Salinity (‰)	Temperature (°C)	DO (mg/l)	pH	Ammonium (μM)	Nitrite (μM)	Nitrate (μM)	Phosphate (μM)
Romania	Leahova	0.2	18.5	7.8	8.3	0.03	0.03	20.25	0.00
	Sinoe	0.2	18.5	9.3	8.4	0.02	0.02	16.25	0.10
Italy	Grado Marano	27.5	21.6	7.2	8.3	5.49	1.22	39.16	0.14
	Grado fish farm	32.0	23.2	6.8	8.3	1.59	1.29	5.61	0.03
	Grado Cavanata	26.3	21.7	9.7	8.7	6.28	0.55	9.94	0.15
	Pialassa Baiona	30.3	24.6	9.0	8.5	32.64	3.35	10.32	0.52
	Margherita di Savoia	64.8	21.1	6.9	8.4	17.67	0.30	8.05	0.07
	Torre Guaceto	6.6	19.8	3.3	7.4	2.47	0.15	25.45	0.11
	Cesine	4.75	19.9	8.3	9.0	0.84	0.07	1.94	0.09
	Alimini	27.0	17.9	7.1	8.1	9.50	0.84	41.99	0.07
Bulgaria	Varna	16.9	15.8	11.3	8.3	3.96	1.21	8.54	0.70
Albania	Patok	28.0	15.7	8.0	8.7	1.14	0.15	11.59	0.19
	Karavasta	32.2	15.4	8.2	8.9	3.23	0.13	13.96	0.12
	Narta	28.7	16.5	6.8	8.3	8.01	0.19	7.94	0.07
Greece	Agiasma	28.8	27.5	6.0	8.3	1.88	0.95	2.57	0.88
	Kalloni	46.7	29.5	7.0	8.4	4.71	0.06	0.60	0.29

Ecosystems are listed from north to south in each country.

all other ecosystems except Grado Marano, Cesine, Leahova and Agiasma (Tukey HSD test, $P < 0.05$).

The ecosystems studied were grouped according to geographic coordinates and the main factors included in typological classifications of transitional waters (tidal range, surface area and water salinity). Average *P. australis* leaf breakdown rates, expressed as mass loss per day, were found to vary significantly as a function of geographic coordinates

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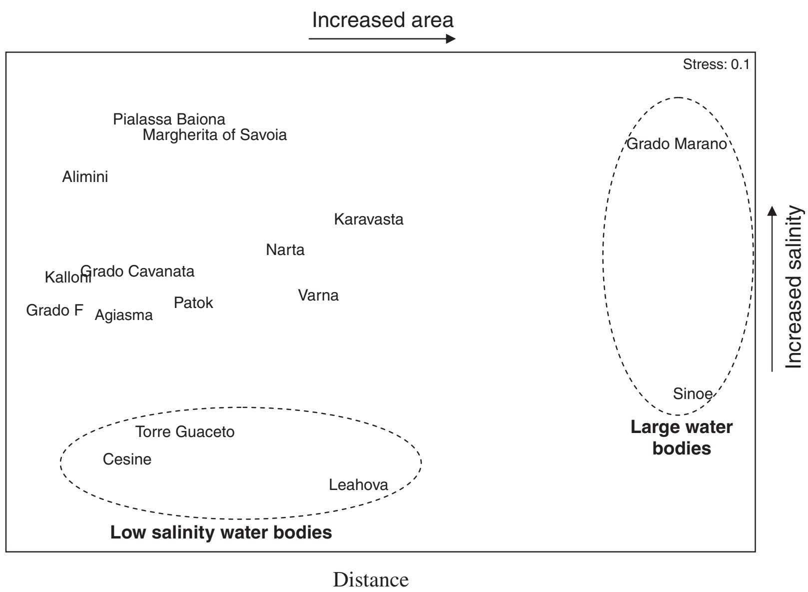

Figure 2. MDS ordination of the 16 ecosystems based on Euclidean distances of physiographic and hydrological (area, depth, sinuosity index, tidal range, outlet length and outlet width) and physico-chemical data (DO, pH, salinity, temperature, ammonium, nitrite, nitrate and phosphate) (stress = 0.1). Ecosystem arranged according to increased salinity (except Kalloni) and increased area.

Table 3. Decomposition parameters of *P. australis* leaf packs

Ecosystem	Mass loss per day (%)	C.V. (%)	t_{50} (days)
Pialassa Baiona	2.81	18.8	24
Grado Marano	2.52	1.1	27
Cesine	2.36	14.2	29
Leahova	2.13	9.8	33
Agiasma	2.03	19.3	34
Kalloni	2.03	16.2	34
Patok	1.98	20.7	35
Sinoe	1.98	11.6	35
Grado fish farm	1.77	11.0	39
Torre Guaceto	1.77	15.0	39
Alimini	1.71	22.1	41
Karavasta	1.64	15.7	42
Grado Cavanata	1.63	8.3	42
Margherita di Savoia	1.60	11.9	43
Varna	1.52	36.5	45
Narta	1.39	3.3	49

Mass loss per day (%), coefficient of variation (%) and half-life (days) are reported. The ecosystems are ordered according to decreasing mass loss per day.

($P<0.01$), tidal range ($P<0.01$) and water salinity ($P<0.01$) (Figure 4).

Regression analyses showed that reed leaf mass loss per day increased with tidal range ($P<0.01$), index of sinuosity ($P<0.05$) and water temperature ($P<0.01$), and decreased with water salinity ($P<0.05$) (regression analysis, OLS) (Figure 5). Taking account of the subset of sampling sites in which nutrients were analysed, reed mass loss per day co-varied positively with reduced inorganic nitrogen compounds (regression analysis, OLS; $P<0.05$).

Stepwise regression showed that at least 71% of reed breakdown variance was explained by five abiotic characteristics (Stepwise multiple regression analysis, adjusted $r^2=0.71$, $P<0.01$; $n=16$); tidal range ($\beta=0.40$), index of sinuosity ($\beta=0.55$), depth ($\beta=-0.30$), temperature ($\beta=0.29$) and salinity ($\beta=-0.27$) (Table 4).

In the group of 11 ecosystems selected on the basis of MDS analysis, i.e. excluding the largest ecosystems and the more freshwater ones (Figure 2), at least 65% of reed breakdown rate variance was explained by the same abiotic characteristics, with the exclusion of water salinity (stepwise multiple regression analysis, adjusted $r^2=0.65$, $P<0.05$; $n=11$) (Table 4); tidal range ($\beta=0.26$), temperature ($\beta=0.33$), index of sinuosity ($\beta=0.63$), and depth ($\beta=-0.30$).

DISCUSSION AND CONCLUSIONS

The results obtained in this study highlight two principal points: (1) patterns of reed decomposition processes can be

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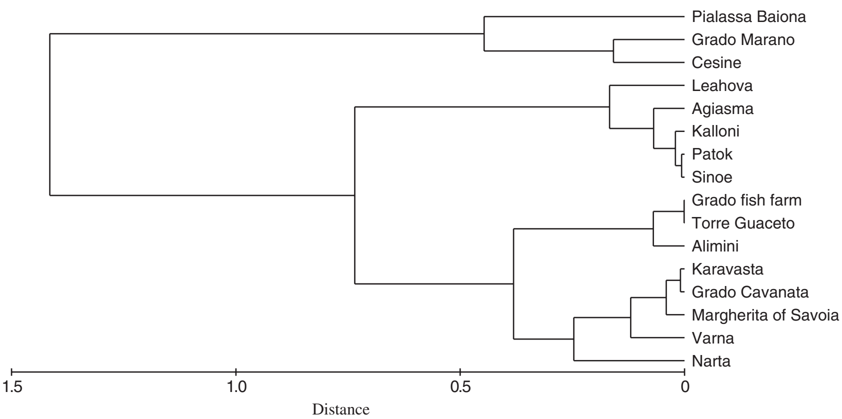

Figure 3. Cluster analysis (average linkage) of decomposition data, expressed as leaf mass loss per day (%), in all studied ecosystems.

observed at the regional scale; (2) spatial patterns appear to show indirect influence of key abiotic factors on reed decay rates in transitional waters.

Concerning the first point, comparative studies of organic matter decomposition rates have been conducted for many years, mainly in terrestrial ecosystems (Jenny *et al.*, 1949; Anderson, 1991; Aerts, 1997) and rivers (Stout, 1980; Covich, 1988; Sponseller and Benfield, 2001). In a study of the geographic variations of decomposition rates in Canada and USA, Meentemeyer (1984) observed that on the continental scale of analysis, climate overwhelmed all other factors in litter decomposition rates, while the physico-chemical nature of the organic matter and other factors became more relevant when the geographic scale was reduced. Similarly, in cool temperate and humid tropical regions, climate (expressed as actual evapotranspiration) was the best predictor of k-values at the global scale, while litter chemistry parameters explained a high percentage of variance in k-values within a particular climatic region (Aerts, 1997). In tropical streams, comparisons of leaf breakdown demonstrated that decay rates were faster than those reported for colder, high-latitudinal streams (Verghese and Furtado, 1987).

In the present study, even though all ecosystems were included in the fast category of litter breakdown rates (Petersen and Cummins, 1974), significant patterns of variation in litter decomposition were seen on the regional scale. Here, spatial patterns described for *P. australis* leaf breakdown were unlikely to be due to methodological biases arising from the experimental treatment of the leaf material (Newell, 1996), the timing of leaf collection (Gessner, 1991), the use of oven-dried leaves instead of fresh leaves or air-dried leaves (Barlöcher, 1991; Gessner, 1991) and the use of different parts of the reed plants (Kufel and Kufel, 1988).

As regards the second point, the effects of many abiotic and biotic factors on plant detritus decay rates in aquatic ecosystems have been considered (see Webster and Benfield, 1986 for a review). At the community and ecosystem levels, the importance of microorganisms and benthic invertebrates as immediate agents of decomposition is well established (Saunders, 1980); however, the distribution and activity of these two groups of organisms are affected by various abiotic variables, which in turn can be considered indirect but crucial agents of decomposition. Abiotic conditions set up the physical template to which communities (either microbial or inverts) are forced to adapt, and thus, litter breakdown is the result of the combined effects of abiotic and biotic processes. Therefore, in terms of conservation at a regional scale, studying the influence of the environmental niche (abiotic conditions) on plant decomposition processes represents a potentially fruitful approach to defining reference conditions in transitional waters.

Patterns of variation of *P. australis* decomposition in relation to certain abiotic ecosystem characteristics, including water temperature, salinity and tidal range were observed. In the transitional waters studied, reed litter breakdown rates varied with water temperature, although variations in reed breakdown rates along a latitudinal gradient were not observed. Results obtained in this work were consistent with comparative observations of decomposition processes in various streams in Costa Rica, Michigan and Alaska (Irons *et al.*, 1994). They showed no significant changes in litter decay rates of different tree species with increasing latitude; indeed, rather than the expected relationship of a negative correlation between decay rate and latitude (i.e. slower breakdown with increasing latitude and decreasing temperature), little or no correlation was found. In this study, water temperature did not show latitudinal variation, probably due to the limited range

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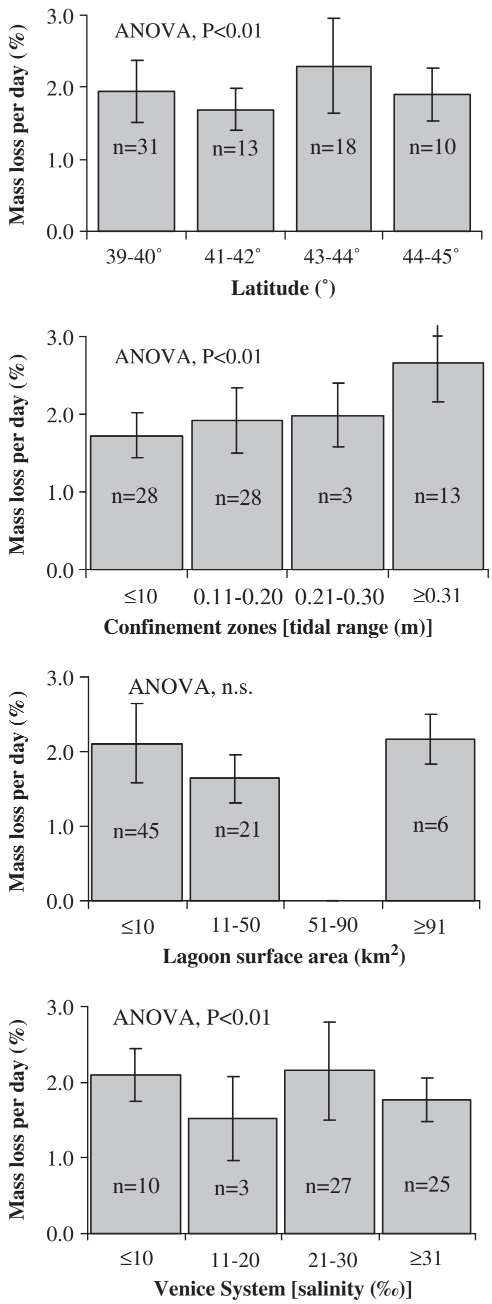

Figure 4. Mass loss per day (%) of *P. australis* leaf packs (average ± S.D.) in the studied ecosystems, grouped by latitude, tidal range (m), surface area (km^2) and water salinity (‰).

of latitudes within which the studied ecosystems were located or to the highly dynamic nature of the transitional waters in which the experiments were carried out; for example the limited sampling times may not reflect the variation in temperatures resulting from the exchange of fresh and marine waters in these environments.

Moreover, the link between transitional waters and terrestrial and marine ecosystems, and the spatial or temporal variations of their boundaries, may indirectly affect litter breakdown, through an influence on water parameters, especially salinity. The literature on relationships between litter decomposition and salinity in aquatic ecosystems is limited, mainly because most studies have focused on rivers and streams in mesic areas of temperate zones. Water salinity negatively affected leaf litter breakdown on the regional scale and this pattern is consistent with previous results obtained for aquatic ecosystems: Reice and Herbst (1982) highlighted lower decomposition rates at sampling sites with higher salinity in desert streams; similarly, Mendelssohn *et al.* (1999) observed decreased litter decay rates with increasing salinity in a *P. australis* wetland.

The influence of temperature and salinity on the metabolism and distribution of the agents of decomposition is also well established. Various equations have been proposed to incorporate the influence of temperature on microorganism metabolism (Moorhead and Sinsabaugh, 2006); similarly, the role of water salinity in establishing the range of many benthic invertebrate species has been investigated (Basset *et al.*, 2004; Piscart *et al.*, 2005). In particular, Dudgeon (1982) showed that high water temperature increased microbial processing during decomposition, and the leaves served as a major energy source for invertebrates in aquatic ecosystems. As suggested by Irons *et al.* (1994), temperature probably has an important influence on processing rates within an individual aquatic ecosystem or geographical area, whereas different biological processes operate at different efficiencies or rates in widely separated areas with differing biotas and thermal regimes. Similarly, the effect of salinity on decomposition is probably mediated by the microbial populations as high salinity may impede the growth of bacteria and fungi on detritus; moreover, these extreme conditions may also limit the presence of invertebrates among which are the shredders.

The present work emphasizes the importance of abiotic ecosystem characteristics in litter decomposition, highlighting their role as indirect drivers of reed litter breakdown in transitional waters. Moreover, the results of the selection of key abiotic factors regulating litter breakdown in transitional water ecosystems are in agreement with proposed typological classifications of these ecosystems (Basset *et al.*, 2006). Water salinity and tidal range, two of the driving factors of reed decomposition in the studied ecosystems, are also key structural factors in two major proposed typological classifications of transitional waters (the Venice System and Confinement). This aspect probably constitutes the main result of the present study because the selection of abiotic ecosystem

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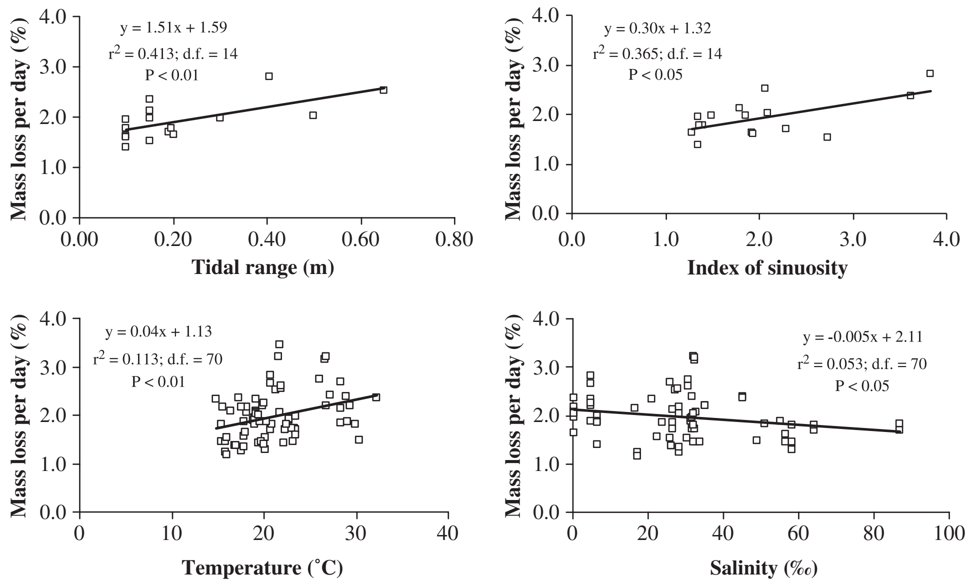

Figure 5. Analysis of regression between leaf mass loss per day (%) and tidal range (m), index of sinuosity, water temperature (°C) and water salinity (‰), in all ecosystems.

Table 4. Stepwise multiple regression analysis between leaf mass loss per day (%) and abiotic parameters, considering all ecosystems (top) and ecosystems selected by MDS analysis (below)

Variable	Adjusted r^2	F	P
All ecosystems			
Tidal range	0.37	9.86	0.007
Tidal range, sinuosity	0.55	10.02	0.002
Tidal range, sinuosity, depth	0.65	10.29	0.001
Tidal range, sinuosity, depth, temperature	0.66	8.33	0.002
Tidal range, sinuosity, depth, temperature, salinity	0.71	8.67	0.002
Selected ecosystems			
Tidal range	0.42	8.39	0.018
Tidal range, temperature	0.51	6.18	0.023
Tidal range, temperature, sinuosity	0.62	6.41	0.020
Tidal range, temperature, sinuosity, depth	0.65	5.55	0.032

characteristics as forcing factors of litter decomposition on the regional scale and their inclusion among the key factors in the most commonly used typological schemes of transitional waters may be an important aspect in the monitoring and conservation of these ecosystems. Management of transitional waters can include direct control of the abiotic variables regulating litter breakdown, acting as a filter on the combination of conditions characterizing the environmental niche in which the agents of decomposition operate. Moreover, the results of this work may contribute to WFD-driven efforts to draw up a classification scheme useful for determining the ecological status of transitional water ecosystems, for which litter decomposition data may provide valuable support.

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