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ORIGINAL ARTICLE

Effects of restoration approaches on benthic assemblages in the saltmarshes of a Mediterranean lagoon

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Abstract: Saltmarsh restoration is widely implemented in the Venice lagoon, yet the extent to which different restoration designs influence benthic and epibenthic communities remains unclear. This study compares natural and artificial saltmarshes across two lagoon basins (central and northern), accounting for large-scale environmental gradients and local habitat characteristics. Benthic and epibenthic communities were analyzed in creeks. Basin-scale conditions, particularly salinity and sediment characteristics, emerged as the main drivers of community structure, with clear differences between lagoon sectors. The central basin supported more diverse and functionally heterogeneous assemblages, whereas northern sites showed lower diversity and were dominated by deposit feeders. The effects of restoration design were context-dependent. In the northern basin, artificial and natural saltmarshes hosted similar communities, while in the central basin, artificial marshes built with sandy sediments supported distinct assemblages compared to natural sites. Overall, while environmental gradients constrain community patterns, restoration design - especially sediment characteristics - can influence ecological trajectories, highlighting the need for site-specific restoration strategies.
Keywords: Venice lagoon; ecosystem services; saltmarsh restoration; benthic assemblages; macrozoobenthos; artificial saltmarshes; restoration ecology

Sažetak: UČINCI RAZLIČITIH TIPOVA OBNOVE NA BENTIČKE ZAJEDNICE SLANIH MOČVARA MEDITERANSKE LAGUNE**.** Obnova slanih močvara uvelike se provodi u Venecijanskoj laguni, no još uvijek nije dovoljno poznato u kojoj mjeri različiti pristupi obnovi utječu na bentičke i epibentičke zajednice. U ovom radu uspoređene su prirodne i umjetne slane močvare u dvama bazenima lagune (središnjem i sjevernom), uzimajući u obzir okolišne gradijente na velikim prostornim skalama te lokalna obilježja staništa. Analizirane su bentičke i epibentičke zajednice u plimnim kanalima. Pokazalo se da su uvjeti na prostornoj skali bazena, osobito salinitet i karakteristike sedimenta, glavni čimbenici koji oblikuju strukturu zajednica, pri čemu su uočene jasne razlike između pojedinih dijelova lagune. Središnji bazen odlikovao se većom raznolikošću i funkcionalnom heterogenošću zajednica, dok su na sjevernim lokalitetima zabilježene manje raznolike zajednice u kojima su dominirale vrste koje se hrane sedimentom. Učinci različitih pristupa obnovi su ovisili o lokalnom okolišnom kontekstu. U sjevernom bazenu umjetne i prirodne slane močvare sadržavale su vrlo slične zajednice, dok su u središnjem bazenu umjetne močvare izgrađene na pjeskovitim sedimentima sadržavale zajednice koje su se razlikovale od onih u prirodnim močvarama. Iako okolišni gradijenti uvelike određuju obrasce raspodjele bentičkih zajednica, rezultati pokazuju da način provedbe obnove – osobito karakteristike sedimenta - može usmjeriti njihov ekološki razvoj, naglašavajući potrebu za strategijama obnove prilagođenim specifičnostima pojedinog lokaliteta.
Ključne riječi: Venecijanska laguna; usluge ekosustava; obnova slanih močvara; bentičke zajednice; makrozoobentos; umjetne slane močvare; ekologija obnove

INTRODUCTION

Coastal lagoons are highly productive and dynamic ecosystems, playing a key role in biogeochemical cycling, biodiversity conservation, and land–sea interactions (Cattrijsse and Hampel, 2006). Within these systems, saltmarshes are a fundamental morphological and ecological component. These habitats, characterized by low hydrodynamic energy, shallow depths, and water replacement times that vary depending on geographical location, play a key role in sediment stabilization, nutrient retention and modulation of tidal fluxes, thereby substantially contributing to the entire lagoon functioning (Molinaroli *et al.,* 2009). Venice lagoon saltmarshes, which are included within the Natura 2000 network (SACs and SPAs), are characterized by halophytic plant communities structured along elevation and inundation gradients, with pioneer species such as *Salicornia* spp. and *Spartina maritima* in low marsh areas and more complex communities including *Sarcocornia fruticosa*, *Juncus maritimus*, and *Limonium narbonense* in higher zones. Compared to natural saltmarshes, artificial ones show lower species richness, simplified community structure, and the absence of late-successional

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or freshwater-influenced communities, with vegetation tending to converge over time toward dominance by *Sarcocornia fruticosa* (Zorzi, 2024). Creeks and ponds are crucial structures in the saltmarsh system and host highly specialized biological communities adapted to strong environmental gradients, including fluctuations in salinity, temperature, oxygen availability, and organic matter content. Among these, benthic and epibenthic assemblages represent a central ecological compartment participating in different biological cycles, like organic matter processing, sediment reworking, and nutrient regeneration, supporting energy transfer to higher trophic levels (Tagliapietra and Sigovini, 2010). The structure and spatial distribution of benthic and epibenthic communities within lagoon saltmarshes are closely linked to local hydrological and geomorphological conditions (Dauer, 1993; Taramelli *et al.,* 2021). Gradients in confinement, distance from tidal channels, and sediment characteristics often result in distinct assemblage patterns, with opportunistic species dominating more confined and organically enriched areas and higher diversity occurring in zones with greater water exchange. These patterns emphasize the role of saltmarshes as ecological sub-units within the lagoon (Reizopoulou and Nicolaidou, 2004; Bettoso *et al.,* 2024).

The lagoon of Venice, located in the northern Adriatic Sea, is the largest Mediterranean lagoon and one of the most important wetland systems in Italy. Despite centuries of human modification, the lagoon retains essential natural features that sustain high ecological complexity and spatial heterogeneity (Dauer, 1993; Tagliapietra *et al.,* 2000). In recent decades, the Venice lagoon has undergone substantial loss and degradation of saltmarsh habitats, driven by relative sea-level rise, altered sediment dynamics mainly due to the diversion of rivers, which no longer carry sediment into the lagoon, and anthropogenic pressures such as the digging of navigation channels or the waves caused by boats (Day *et al.,* 1998; Carniello *et al.,* 2009). In order to face this decline, management actions have included the restoration of new artificial saltmarshes and the restoration of eroded or degraded ones using different techniques. Previous studies have shown that macrozoobenthic communities respond to restoration interventions, particularly to the re-establishment of aquatic angiosperms, with increases in abundance and changes in community composition, although responses are often modulated by local environmental conditions (Bonometto, 2008; Oselladore *et al.*, 2022). However, evidence on how different saltmarsh restoration approaches influence benthic and epibenthic community structure across lagoon basins remains limited.

Benthic and epibenthic communities are particularly well suited to evaluate restoration outcomes due to their limited mobility and close association with sediments (Pranovi *et al.,* 2006). This study therefore aims to address the following objectives: (i) to assess whether different saltmarsh restoration and construction approaches influence the structure of benthic and epibenthic communities in creeks surrounding artificial structures in the Venice Lagoon; (ii) to compare community composition between natural and restored saltmarshes across different lagoon basins; (iii) to evaluate the relative role of large-scale environmental gradients and local restoration design in shaping benthic assemblages; and (iv) to contribute to the assessment of restoration effectiveness and provide insights for the improved management of lagoon habitats. Additionally, given their role as prey for juvenile fish in saltmarsh nursery habitats (Franco *et al.,* 2012; Nakamura *et al.,* 2024), their distribution is also considered in relation to habitat use by juvenile fish.

MATERIAL AND METHODS

Two sites were selected within the Venice Lagoon (Northern Italy): one site located in the northern basin of the lagoon, and one located in the central basin (Fig. 1). In both sites, one natural and one artificial saltmarsh were selected in close proximity to ensure comparable environmental conditions (distance between saltmarshes: 500 m in the north, 1 km in the central). Sampling sites were coded according to lagoon sector and saltmarsh type. In the northern lagoon, sampling sites were designated as NA (artificial) and NN (natural), while in the central lagoon, they were labeled CA (artificial) and CN (natural). The two artificial saltmarshes differ in their restoration approach, although both interventions were carried out in the year 2012. The northern site was restored from a previously existing marsh through sediment replacement and channel modification, whereas the central site was constructed from scratch using dredged sediments following a morphological restoration approach.

In each saltmarsh, a representative creek was identified, and three sampling points were established along a transect (approximately of 100 m) extending from the creek mouth toward the inner terminal portion (distance between points of 30 m), to cover the entire variability related to the local morphology. The sampling campaign was conducted at the end of May 2025 as part of a series of fish fauna sampling activities carried out during the period of juvenile migration from the sea to the lagoon.

Benthic infauna samples were collected using a hand-operated Van Veen grab (surface 30 x 20 cm, height 10 cm). The retrieved sediment was sieved through two nested meshes of 1 mm and 0.5 mm, and the retained material was stored at –20 °C. Epifaunal samples were collected by towing a modified plankton net with a 160 µm mesh size and a square mouth opening (35 × 35 cm) along a 4 m transect directly on the sediment surface. Collected samples were preserved in 5% formalin for subsequent taxonomic identification in the laboratory. The species of infauna and epifauna, together with their respective densities, have been compiled in the same database (Supplementary Table 1), and therefore all the analyses were carried out on the combined database containing the densities for both categories. In order to

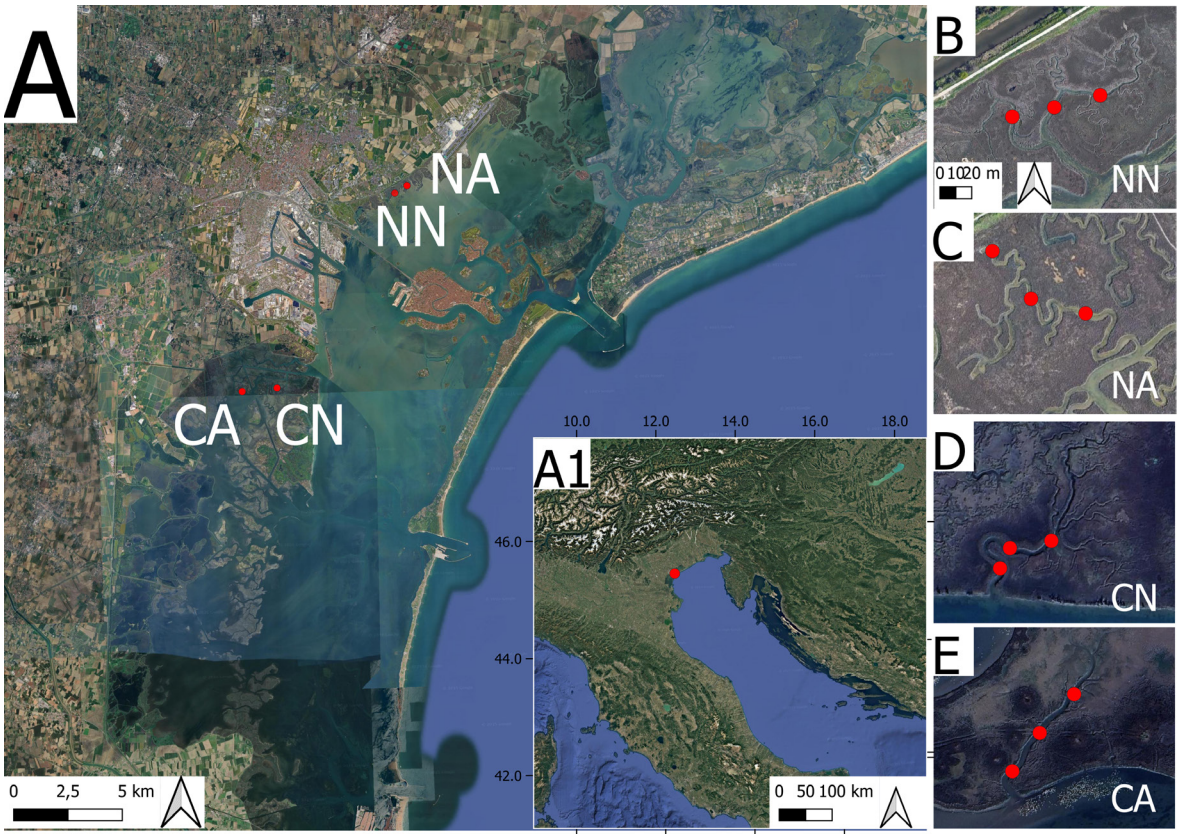

Fig. 1. Location of the sampling sites (CA = Central Artificial, CN = Central Natural, NA = North Artificial, NN = North Natural). The Venice Lagoon with the sampling sites **(A)** and its location within the Adriatic Sea **(A1)** are shown. The individual sampling sites are NN **(B)**, NA **(C)**, CN **(D)**, and CA **(E)**. The three red dots in panels B–E indicate the three sampling points at each site.

characterize sampling sites conditions, the main physico-chemical parameters of the water were measured: salinity with a portable digital refractometer (Hanna Instruments, HI96822), temperature (±0.1 °C) and dissolved oxygen (% saturation, ±0.1) with a LDO optical probe (Hanna Instruments, HI98198). At each sampling site, three sediment cores were also collected to determine chlorophyll *a* concentration, following the method proposed by Lorenzen (1966), organic matter content (LOI method, Heiri *et al.,* 2001), and the sand content of the sediment using a Malvern Mastersizer 3000. Any grain larger than 63 µm is defined as sand, whilst anything smaller than this is considered fine material. Taxonomic identification of the collected specimens was carried out using a microstereoscope at the lowest possible taxonomic level. To ensure comparability between grab and plankton net data, they were standardized as densities (number of individuals *per* square meter), considering the sampling area of each (0.08 m² for the grab, 1.4 m² for the plankton net)

All identified species were assigned to a trophic category (deposit feeders, herbivores, predators, scavengers, surface deposit feeders, and suspension feeders) (see Supplementary Table 2). The taxonomic identification and the assignment of trophic categories to the collected specimens were carried out using several reference manuals and identification keys (Cesari, 1994; Hayward and Ryland, 1995; Ruffo, 1998; Munari *et al.,* 2016).

All univariate statistical analyses were conducted in the R computational environment (RStudio version 2025.09.2) and the software PRIMER (version 7). Univariate community descriptors, Shannon diversity index (H′) and Pielou's evenness (J′), were calculated for each sample. All univariate analyses were performed at the replicate level, with each sample treated as an independent observation. Differences among sampling groups were tested using the non-parametric Kruskal–Wallis test due to deviations from normality and homoscedasticity. Analyses were conducted on groups defined by sampling site codes (combining lagoon sector and saltmarsh type). All indices were computed using the *vegan* package in R, and results were summarized as mean values ± standard error for each group.

The PRIMER software (version 7) was also used for a multivariate approach by means of distance-based Redundancy Analysis (dbRDA), in order to relate biological patterns to a set of explanatory environmental variables through linear combinations (Capblancq and Forester, 2021). Species abundance data were not used directly in the analysis; instead, they were first aggregated to obtain the number of species *per* trophic group at each sampling point. This transformation allowed the

analysis to focus on trophic structure rather than individual species abundances. Prior to analysis, the trophic group data were fourth-root transformed to down-weight the influence of dominant groups. A Bray–Curtis similarity matrix was then calculated based on the transformed data using all samples. Environmental variables were included as predictors and were normalized prior to analysis. The dbRDA was conducted using the set of samples and variables to identify linear relationships between trophic group composition and environmental gradients.

RESULTS

The main physico-chemical parameters measured during the sampling campaigns are reported in Table 1. The most pronounced differences were observed in salinity and sediment grain size. Salinity was the primary factor distinguishing the northern site from the central one, with higher values recorded in the central lagoon. Sediment grain size represented the main factor differentiating the two artificial saltmarshes without a common trend: sediments at the CA sampling site were predominantly sandy, whereas in the northern sites, the artificial saltmarshes generally present a higher proportion of fine materials compared to the natural one.

The complete list of species and their corresponding trophic categories is provided in the supplementary material (Supplementary Table 2), whilst Supplementary Table 1 shows the abundance of each species at each site. Based on this dataset, barplots were produced to illustrate the proportional contribution of each trophic group and taxonomic class within each sampling site (Figs. 2 and 3). Analysis of these bar plots showed many differences among sampling sites: in the CA sampling site, herbivores constituted the dominant group but decreased toward the inner sampling site, where scavengers became more frequent. As is possible to notice, in the NA sampling site, deposit feeders represented the main trophic group, with herbivores increasing and predators decreasing along the channel gradient. The NN sampling site was characterized by an almost complete dominance of deposit feeders, while the CN sampling site displayed a more heterogeneous trophic composition, with multiple trophic groups contributing more evenly to the community.

A non-parametric Kruskal–Wallis test was used to compare univariate indices among groups, as a conservative approach commonly adopted for ecological diversity data, which may deviate from normality and homoscedasticity assumptions. Benthic community diversity indices showed differences in the values among sampling sites (Kruskal-Wallis test for Shannon index: $H = 9.36$, $df = 3$, $p = 0.025$) (Fig. 4). Shannon diversity was highest in the central lagoon sites (CA: 2.04 ± 0.08; CN: 2.01 ± 0.19), and lower in the northern lagoon (NA: 1.44 ± 0.04; NN: 1.03 ± 0.07). Pielou's evenness (Kruskal-Wallis test: $H = 9.36$, $df = 3$, $p = 0.025$) showed a similar pattern, with higher values in the central lagoon (CA: 0.79 ± 0.02; CN: 0.79 ± 0.04) and lower values in the northern lagoon (NA: 0.63 ± 0.02; NN: 0.41 ± 0.02), with differences in particular in the comparison between basins (Fig. 4). The highest values for both indices were observed in the central lagoon (CA and CN), with CN showing slightly higher median diversity than CA. In contrast, the northern saltmarshes (NA and NN) displayed lower diversity, with NN exhibiting the lowest values overall for both Shannon and Pielou indices. Within each lagoon basin, artificial and natural saltmarshes followed a similar pattern: as shown by the values, CA and CN had comparable diversity levels, while NA and NN were both characterized by reduced diversity, particularly pronounced at NN. This pattern was statistically supported by post-hoc Dunn's tests (Holm correction) following Kruskal–Wallis analysis, which did not detect significant differences between CA and CN ($p = 0.91$), while comparisons involving NN approached significance (e.g., CA vs NN: $p = 0.055$; CN vs NN: $p = 0.064$).

The distance-based redundancy analysis (dbRDA) performed on trophic community data (Bray–Curtis similarity on fourth-root–transformed abundances) and normalized environmental variables revealed patterns in community distribution among sampling sites (Fig. 5). The first dbRDA axis explained 54.43% of the total variation and represented the main environmental gradient. Environmental vectors were fitted onto the ordination, and the reported r values correspond to the correlation coefficients between each environmental variable and the dbRDA axes. Salinity showed a strong correlation with the first axis ($r = 0.967$), suggesting that this gradient is largely associated with salinity variation. The

Table 1. Average values of temperature, chlorophyll *a* (Chl*a*), % sand, % organic matter and salinity measured in the field during the sampling procedure. The data is expressed as the average ± standard deviation of the three replicates carried out at each site (CA= Central Artificial, CN= Central Natural, NA= North Artificial, NN= North Natural).

Site	Temperature (° C)	Chl*a* ($\mu g\ g^{-1}$)	% Sand	% Organic matter	Salinity
CA	25.4±0.8	2.7±0.9	64.7±7.6	10.8±8.6	23.2±0.8
CN	23.9±0.5	6.4±1.4	36.2±2.3	13.5±1.1	25.8±0.1
NA	29.7±3.1	8.3±3.8	25.7±3.7	14.1±3.4	18.2±0.9
NN	28.7±0.4	5.5±0.9	43.4±1.4	16.7±1.6	19.4±1.9

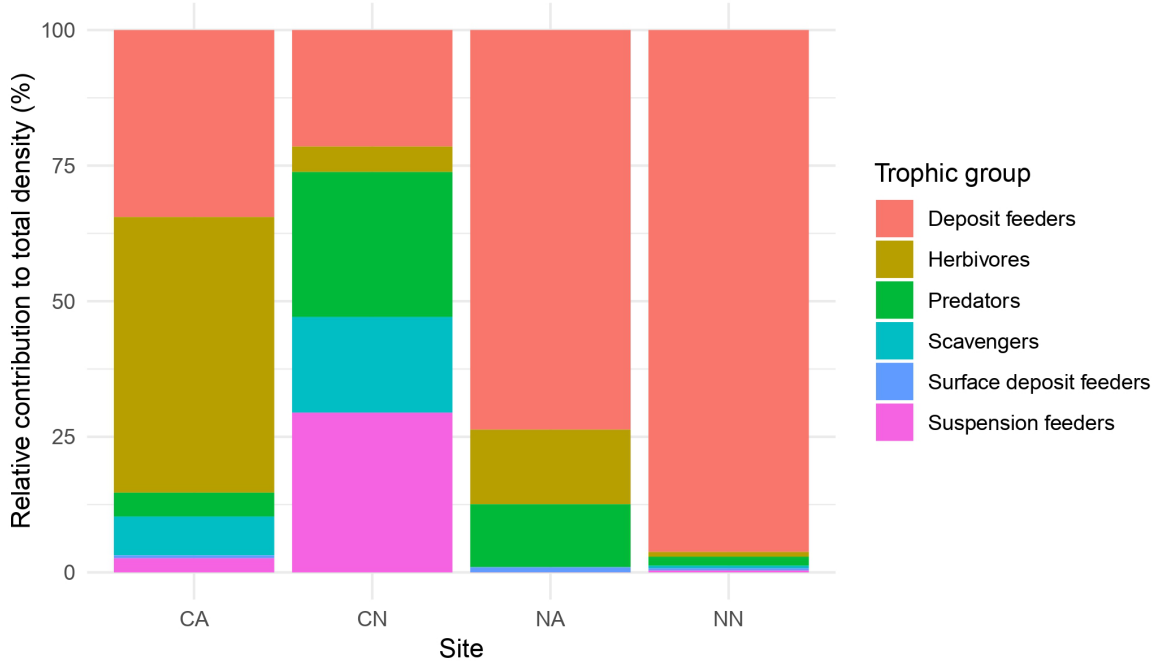

Fig. 2. Bar plots showing the percentage composition of trophic groups at each sampling site. CA= Central Artificial, CN= Central Natural, NA=North Artificial, NN = North Natural.

Fig. 3. Bar plots showing the percentage composition of taxonomic class at each sampling site. CA= Central Artificial, CN= Central Natural, NA=North Artificial, NN = North Natural.

second axis accounted for an additional 7.21% of the variation and was dominated by the sand content of the sediment (% sand, r = 0.980), distinguishing sampling sites characterized by coarser, sand-rich substrates, particularly those in the CA cluster. Chlorophyll *a* showed a weak correlation with the first dbRDA axis (r = −0.156), indicating a limited contribution to the observed community patterns compared to salinity and the sand con-

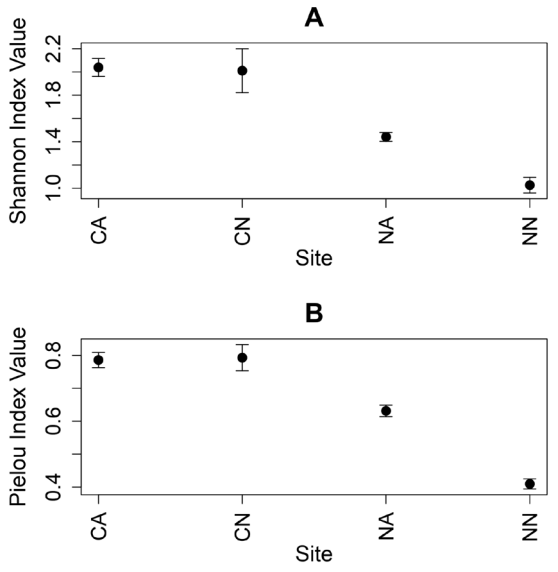

Fig. 4. Shannon (A) and Pielou (B) indices results for the four sample sites (mean ± st. error). Shannon: CA=2.04±0.07, CN=2.01±0.2, NA=1.44±0.03, NN=1.03±0.06; Pielou: CA=0.78±0.02, CN=0.79±0.03, NA=0.63±0.02, NN=0.41±0.01.

tent of the sediment. The spatial arrangement of samples in the dbRDA ordination showed clustering of sampling site within the same lagoon basin, suggesting internally consistent faunal assemblages, while broader separations among basins highlighted the combined influence of salinity and sediment characteristics on community structure. The environmental parameters included in the graph were selected a priori based on the combination that yielded the best condition for community development (Darr *et al.,* 2014; Saad and Wade, 2017; Carrier-Belleau *et al.,* 2021; Chauvel *et al.,* 2025), providing a high percentage of explained variance.

DISCUSSION

Due to the significant loss of saltmarshes, 11 km² of artificial saltmarshes have been created in connection with the MOSE system (Tagliapietra *et al.,* 2018). Previous studies in the Venice Lagoon have shown that artificial saltmarshes are rapidly colonized and effectively support breeding waterbirds, with several species reaching high abundances. This success is largely attributed to the environmental heterogeneity of these habitats, which provides a mosaic of substrates and conditions (Scarton *et al.,* 2009). Information on the overall ecological effectiveness of these restoration techniques remains limited. In this context, benthic communities represent a valuable tool for assessing restoration outcomes, due to their limited mobility and strong dependence on local environmental conditions (Pranovi *et al.,* 2006). Our results indicate that spatial setting within the lagoon, together with marsh origin (natural *vs* artificial), plays a key role in shaping the benthic community. Significant differences in community structure emerged among lagoon basins and between saltmarsh types, highlighting the influence of environmental gradients and restoration strategies. Higher Shannon diversity values were generally observed in the central lagoon, with site CN exhibiting the most heterogeneous community. This pat-

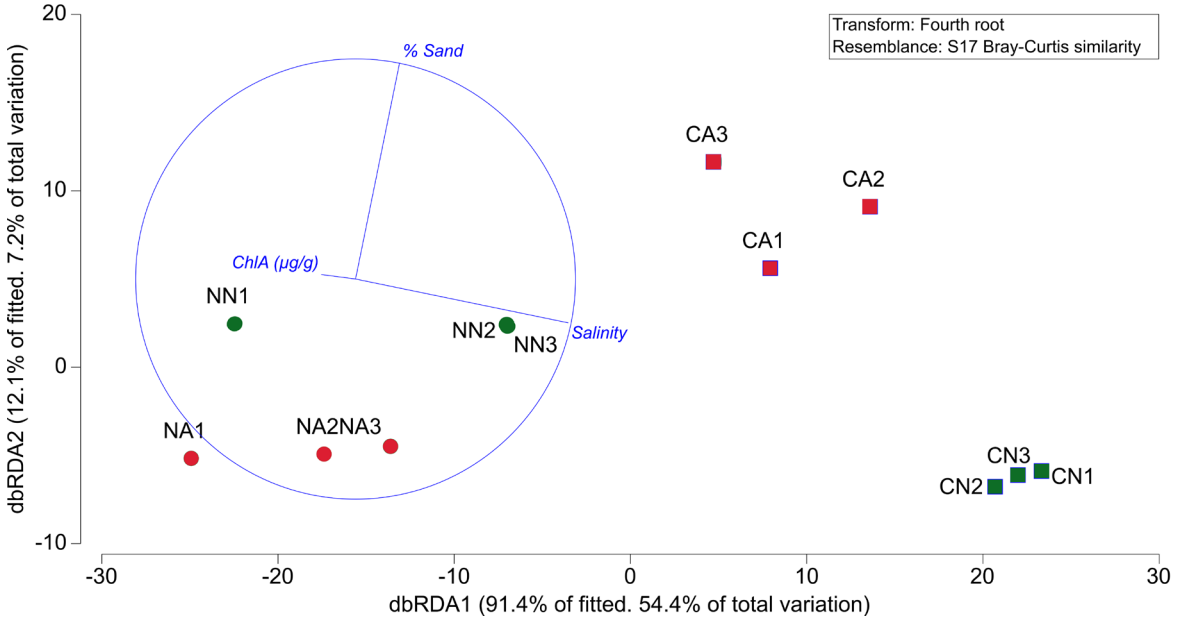

Fig. 5. dbRDA of trophic communities based on Bray–Curtis similarity of fourth-root transformed abundances showing site separation driven by salinity and the sand content of the sediment, with basin-level clustering.

tern suggests that central lagoon saltmarshes provide a wider range of ecological niches, likely associated with stronger marine influence and more stable environmental conditions. Conversely, site NA was characterized by the dominance of a limited number of species, as indicated by an intermediate Shannon index combined with low variability. This dominance-driven structure was further supported by Pielou's evenness index, which revealed a more balanced distribution of individuals in central lagoon communities compared to the northern basin sampling site. The distance-based redundancy analysis suggested that salinity was one of the main environmental parameters explaining differences between the central and northern lagoon basins. The natural saltmarsh of the central lagoon was associated with the highest salinity values, reflecting the substantial marine water input from the sea through the Petroli Channel (Cucco and Umgiesser, 2006). Due to its proximity to the lagoon margin and freshwater inputs, it was further distinguished by its sandy sediment composition. This artificial marsh further differed in sediment characteristics, being mainly composed of sandy material, a feature likely related to the restoration techniques employed, which involved the placement of predominantly coarse sediments (Bonometto, 2008). The two saltmarshes in the northern basin appeared more similar, likely due to their geographic proximity and shared environmental conditions. Their location near the lagoon margin exposes them to comparable and generally lower salinity regimes, driven by freshwater inflows from rivers. Additionally, similarities in restoration approaches—primarily based on morphological reshaping without substantial sediment addition—may have contributed to the observed homogeneity in both abiotic conditions and biological assemblages. Within these northern saltmarshes, consistent internal gradients were observed, with salinity increasing landward, potentially as a consequence of enhanced evaporation and reduced water exchanges, and chlorophyll concentrations decreasing toward inner marsh areas, likely reflecting progressively less favorable environmental conditions.

The functional analysis of trophic group composition confirmed basin-level differences observed in taxonomic patterns. The natural central saltmarsh showed the most functionally heterogeneous assemblages, with no dominant trophic group, consistent with its high evenness and strong marine influence, which likely promotes filter feeders like *Glycimeris nummaria*. In contrast, saltmarshes of the northern basin were dominated by deposit feeders, a pattern consistent with the higher sediment organic matter content and finer grain-size composition (Taghon, 1982), since these conditions favor taxa exploiting organic-rich sediments. Artificial saltmarshes, irrespective of basin, were further characterized by a relatively high contribution of herbivores.

Overall, these findings highlight how restoration practices, environmental drivers, and spatial setting jointly influence both the taxonomic and functional organization of saltmarsh communities. Although salinity emerged as a key factor structuring assemblages across the lagoon, the effects of restoration were not uniform between basins. In the northern basin, where restoration primarily involved morphological reshaping without substantial modifications to sediment composition, artificial and natural saltmarshes retained similar environmental characteristics. Consequently, the associated biological communities did not exhibit marked differences, maintaining similar structural and functional features. In contrast, the construction methods adopted for the artificial saltmarsh in the central basin, particularly with respect to sediment grain-size composition, had repercussions on community assemblages. The predominance of sandy substrates, resulting from the use of coarse material during restoration, promoted a community structure distinct from that observed in the natural marsh. These findings highlight that, beyond broad environmental gradients, restoration design choices—especially those affecting key habitat properties—can strongly influence the trajectory of community development. In addition, benthic communities may not yet have reached a fully stable configuration, especially in recently restored sites, where colonization processes may still be ongoing. This highlights the importance of long-term monitoring to assess whether initial differences persist, attenuate, or intensify over time, and to better understand the trajectory of recovery in restored saltmarsh system.

Overall, these findings highlight that restoration outcomes depend on the interaction between environmental gradients and site-specific design choices. While salinity strongly structures community composition at the basin scale, restoration interventions can significantly modify habitat conditions and redirect ecological trajectories. In the northern basin, limited intervention led to restored saltmarshes similar to natural ones, suggesting low-impact restoration may be effective under suitable conditions, whereas in the central basin, coarse-sediment placement produced distinct communities, highlighting the strong influence of restoration design on ecological outcomes. From a management perspective, these results emphasize the need for context-dependent restoration strategies that explicitly consider how design choices affect key habitat properties and, consequently, community structure and ecosystem functioning. Incorporating trophic linkages into planning, such as supporting prey availability for juvenile fish, which rely heavily on copepods during early life stages (Franco *et al.,* 2012; Pepin, 2023; Nakamura *et al.,* 2024), may further enhance ecosystem services, while acknowledging potential trade-offs among restoration objectives.

CONCLUSION

This study highlights how benthic and epibenthic community structure in Venice lagoon saltmarshes is primarily shaped by large-scale environmental gra-

dients, particularly salinity, together with restoration strategies that contribute to relevant drivers. Clear differences were observed between the central and northern lagoon basins, reflecting contrasting hydrological conditions and sediment characteristics. Saltmarshes in the central lagoon supported more diverse and functionally heterogeneous communities, especially in the natural site, likely due to stronger marine influence and more stable environmental conditions. In contrast, northern lagoon saltmarshes were characterized by lower diversity and a strong dominance of deposit feeders, consistent with finer sediments, higher organic matter content, and reduced salinity. Comparisons between natural and artificial saltmarshes showed that restoration outcomes strongly depend on the type of intervention. In the northern basin, where restoration involved limited morphological modifications, artificial and natural saltmarshes hosted similar communities, indicating a limited ecological differentiation. Conversely, in the central basin, the artificial saltmarsh constructed with predominantly sandy sediments supported a community structure distinct from the adjacent natural marsh, emphasizing the role of sediment properties in shaping benthic assemblages. Overall, these results indicate that while basin-scale environmental conditions set the primary constraints on community structure, restoration design choices, particularly those affecting substrate characteristics, can significantly influence ecological trajectories. Effective saltmarsh restoration in the Venice Lagoon, therefore, requires site-specific approaches that explicitly consider local environmental gradients and the ecological implications of restoration techniques. Future long-term monitoring will be essential to assess temporal changes, as variation in sediment granulometry or other environmental parameters and associated shifts in benthic community structure may occur.

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