

Review

Marine Seagrasses Transplantation in Confined and Coastal Adriatic Environments: Methods and Results

Daniele Curiel ¹, Sandra Pavelić ² , Agata Kovačev ³, Chiara Miotti ¹ and Andrea Rismondo ^{1,*}
¹ SELC Soc. Coop., Via dell'Elettricità 3/D Marghera-VE, 30175 Venezia, Italy; curiel@selc.it (D.C.); miotti@selc.it (C.M.)

² Faculty of Health Studies, University of Rijeka, Viktora Cara Emina 5, 51000 Rijeka, Croatia; sandrakp@biotech.uniri.hr

³ Kornati National Park, Butina 2, 22243 Murter, Croatia; agata.kovacev@np-kornati.hr

* Correspondence: rismondo@selc.it

Abstract: The anthropogenic pressures of the twentieth century have seriously endangered the Mediterranean coastal zone; as a consequence, marine seagrass habitats have strongly retreated, mostly those of *Posidonia oceanica*. For this reason, over time, restoration programs have been put in place through transplantation activities, with different success. These actions have also been conducted with other Mediterranean marine seagrasses. The results of numerous transplanting operations conducted in the Northern Adriatic Sea and lagoons with *Cymodocea nodosa*, *Zostera marina* and *Z. noltei* and in the Central and Southern Adriatic Sea with *P. oceanica* (only within the project Interreg SASPAS), are herein presented and compared, taking also into account the presence of extensive meadows of *C. nodosa*, *Z. marina* and *Z. noltei*, along the North Adriatic coasts and lagoons.

Keywords: seagrass restoration; transplanting; *Posidonia oceanica*; *Cymodocea nodosa*



Citation: Curiel, D.; Kraljević Pavelić, S.; Kovačev, A.; Miotti, C.; Rismondo, A. Marine Seagrasses Transplantation in Confined and Coastal Adriatic Environments: Methods and Results. *Water* **2021**, *13*, 2289. <https://doi.org/10.3390/w13162289>

Academic Editors: Sebastiano Calvo and Agostino Tomasello

Received: 6 July 2021

Accepted: 16 August 2021

Published: 21 August 2021

Publisher's Note: MDPI stays neutral with regard to jurisdictional claims in published maps and institutional affiliations.



Copyright: © 2021 by the authors. Licensee MDPI, Basel, Switzerland. This article is an open access article distributed under the terms and conditions of the Creative Commons Attribution (CC BY) license (<https://creativecommons.org/licenses/by/4.0/>).

1. Introduction

Marine seagrasses (MS) are among the most productive and widespread ecosystems from the Tropics to the boreal coasts of any ocean [1,2]. In the sea and within transitional environments they play an important role as a carrier of the trophic chain and regulators of physical processes that control sedimentology and seabed morphology [3]. They reduce wave motion, regulate the nutrient cycle, the structure of the food web [1] and provide important ecological functions for the marine environment [4], not to mention the support for the ecosystem value of the coastal zone. The leaf component acts as a substrate for algal and zoobenthic epibionts and provides shelter and nourishment for invertebrates and fish [5–7].

However, MS, as well as the active role they play, are threatened directly and indirectly by diverse anthropogenic activities [3]. In particular, in transitional environments such as lagoons and estuaries, where disturbances are amplified, the seagrasses are negatively affected by reduced light radiation [8], extended and persistent macroalgal blooms over time [9] and anomalous meteorological trends [10–12].

MS have been included among the protected species at international level (Bern Convention 23 June 1979 and SPAMI-Barcelona Convention 1995). MS are also included among the species requiring attention in the Action Plan for the Conservation of Marine Vegetation in the Mediterranean Sea (RACs/SPAs—Regional Activity Center for Specially Protected Areas). In addition, the Water Framework Directive (EU 2000/60) gives them the utmost importance as indicators of a good ecological status.

MS meadows and other connected valuable habitats experienced multiple threats through the 20th century and into the 21st. In fact, MS are very susceptible to a series of disturbance factors (Table 1). As a consequence, a number of conservation and restoration programs have been performed in the Mediterranean Sea [3,13].

Table 1. Main factors of pressure and disturbance acting on seagrasses, identified and coded during the activities of the DG Environment and the European Environment Agency concerning the implementation of European Directives Habitat (92/43/EEC) and Birds (2009/147/EC) [14].

Code	Description
F02.02	Professional active fishing
F02.02.05	Professional active fishing with benthic dredging
F01.03	Marine and Freshwater Aquaculture with bottom culture
G05.02	Shallow surface abrasion/mechanical damage to seabed surface
H03	Marine and brackish water pollution
I01	Invasive non-native species (both animal and vegetal)
J02.02.02	Removal of sediments (by estuarine and coastal dredging)
J02.05.01	Modification of water flow (tidal and marine currents)
J02.05.06	Wave exposure changes
J02.12.01	Sea defense or coast protection works, tidal barrages
J02.11	Siltation rate changes, dumping, depositing of dredged deposits

In the Adriatic Sea five MS species have been documented. Along coastal zone and in the transitional environments, *Cymodocea nodosa* (Ucria) Ascherson, *Zostera marina* Linnaeus, *Zostera noltei* Hornemann, *Ruppia maritima* Linnaeus (including *R. cirrhosa*, now considered as a heterotypic synonym) [15] can be accordingly found. The latter colonize the most confined areas of the North Adriatic brackish lagoons and are subject to dramatic fluctuations. All species are found along the confinement gradient from the flushed areas to the most confined, but inside the lagoons many microhabitats alternate with each other, with patches of different species.

The fifth MS, *Posidonia oceanica* Linnaeus, reported up to the 1960s and 1970s in several coastal sites of the Northern Adriatic, has further retreated, with limited patches now present only in Grado [16,17] and in the Gulf of Trieste [18,19] due to its high sensitivity to turbidity, siltation and anthropization [1,3].

Very significant meadows of this species are found along the coasts of Eastern Istria and Dalmatia, all along Greece [20] or along Apulia in the west coast of Adriatic Sea [21].

This work summarizes the most significant experiences of MS transplantations carried out since the 1990s in the most extensive transitional water ecosystem of the Mediterranean, the lagoon of Venice and in other Adriatic coastal sites, as part of pilot interventions carried out for different Authorities or in the frame of European Union financed projects (LIFE or Interreg).

Specifically, most of these transplanting experiences were developed and carried out by some of the Authors in Venice Lagoon, which is characterized by the presence of widespread (over 6000 ha) and diversified seagrass meadows (four MS species).

Concerning the Venetian experiences, other restoration interventions were carried out by the University of Venice and ISPRA (The Italian Institute for Environmental Protection and Research) in the framework of a European Union project (LIFE SeResto), that we also report, by using available data.

Authors of this paper represent some of the project partners of the European Union Project (Interreg SASPAS) of Italy–Croatia collaboration.

The tests conducted in the Venice lagoon, highly diversified by type of environment (shallows, mudflats and sandflats), bathymetry (from surface to −4 m), type of sediment (from sandy to muddy), tidal range (some 120 cm from the highest to the lowest astronomical tidal level) and residence time (a few days in the flushed areas up to 40 days in the most confined ones) allowed for finalization methods that were at that point applied in the lagoon and in marine environments on limited bathymetry (−3/4 m) for *C. nodosa* and *Zostera* spp.

The work also reports transplantation experiences both in the coastal zone of the northern and in marine sectors always submerged in the central-southern Adriatic where the *Posidonia oceanica* meadows are prevalent.

2. Study Areas and Seagrass Distribution Knowledge

2.1. Venice Lagoon

The Lagoon of Venice is one of the largest coastal intertidal ecosystems of the Mediterranean Sea [22] (Figure 1). Due to the large distribution of MS meadows, regular maps have been created on a lagoon scale since 1990.

Three inlets connect the lagoon to the sea, interrupting a long and thin barrier in three points. The lagoon is about 50 km long and 10 km wide, accounting for a surface of about 550 km². Out of them 36 are saltmarshes, 30 islands (excluding the barrier islands) and the rest is covered by water. The mean depth of the water column is about 1.2 m, with only 5% of the lagoon deeper than 5 m [23]. The three inlets (Lido, Malamocco and Chioggia) allow tidal flushing twice a day, following a semi-diurnal tide scheme, exchanging daily about 400 million m³ of water with Adriatic Sea, while the daily inflow from the mainland through rivers and subsoil is about 3.7 million m³ [24].

In the Lagoon of Venice tides are the largest in the Mediterranean Sea, with an intertidal range of 121 cm from the highest to the lowest astronomical tidal level (calculated for 1986–2004) [25].

Freshwater inputs and tides produce a salinity gradient, ranging from marine (cca 37 psu) to almost fresh water. The climate classification of the lagoon is humid subtropical with hot summers. Due to limited depth, water temperature trend is strictly seasonal, ranging from zero (seldom freezing) to above 30–35° C at the surface. The salinity gradient is very compressed toward the mainland, due to the predominant tidal contribution, with an average value of some 30 psu [25].

In Venice lagoon, MS have been reported in the literature including the genera *Zostera*, *Cymodocea* and *Ruppia* since the beginning of the twentieth century, but without a specific information on distribution [26–28]. Historical but approximate indications dating back to early 1900s report a very large coverage of the lagoon bottoms, locally confirmed starting from aerial photographs made during World War II. During the twentieth century, Venice lagoon suffered from major hydro-morphological changes that significantly affected MS meadows as well. We mention in particular the construction of large jetties at the sea inlets and the progressive creation of the industrial zone by land reclamation on the mainland. Other substantial changes, mainly the excavation of new channels, resulted in a further marked alteration of hydrodynamism [29]. The important inputs from the drainage basin and the industrial wastes caused an increase in nutrients between the 1960s and 1970s [30] with the consequent macroalgal blooms in the 1980s [31,32]. The relative disappearance of these phenomena has however been followed more recently by an important entry of alien species [33,34], as a consequence of the worldwide extension of maritime traffic arriving in Venice and due to the phenomenon of marinization of the lagoon, caused by the erosion and deepening of the seabed, followed by the increase of the tidal prism [25].

The first lagoon-scale mapping of MS dates back to 1990 [35,36] with following updates in 2002, 2004 and 2010, while the last control refers to 2017 [14,37,38] (Table 2 and Figures S1–S5 in Supplementary Materials).

Table 2. Seagrass coverage reported for Venice lagoon in 1990, 2002, 2004, 2010 [38].

	1990 (ha)	2002 (ha)	2004 (ha)	2010 (ha)	2017 (ha)
Monospecific <i>Cymodocea nodosa</i>	392	1.777	1.718	2.276	3.421
Monospecific <i>Zostera marina</i>	265	2.195	1.130	1.404	2.464
Monospecific <i>Zostera noltei</i>	1.436	70	20	58	485
Monospecific <i>Ruppia</i> spp.	0	0	0	0	281
Mixed <i>Z. noltei</i> + <i>C. nodosa</i>	23	142	68	19	17
Mixed <i>Z. noltei</i> + <i>Z. marina</i>	2.157	220	75	27	107
Mixed <i>Z. marina</i> + <i>C. nodosa</i>	692	825	527	12	15
Mixed <i>Z. noltei</i> + <i>Z. marina</i> + <i>C. nodosa</i>	528	202	136	12	6
Total	5.493	5.431	3.674	3.808	6.796

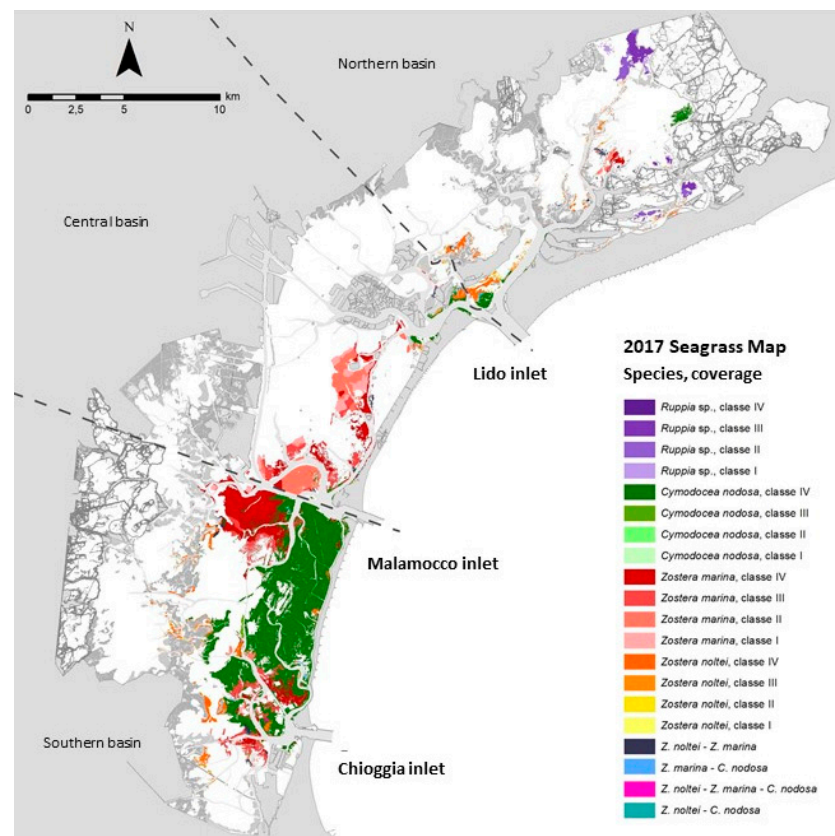


Figure 1. Marine seagrass distribution for Venice lagoon (2017 map) [38].

1990 mapping was carried out thanks to classic positioning, based on compass alignment and substantial marks. Since the 2002 mapping, a GPS (global positioning system) navigation, integrated with GIS software (ESRI ArcGIS, Redlands, CA, USA), was performed in the field, in order to enhance the precision degree, permit coverage evaluation and comparison among mappings. Each field team, equipped with the described system, was provided with aerial or satellite images on PPC.

Surveys were carried out accordingly to vegetation characteristic: (a) along seagrasses patches' borders, (b) along transects of appropriate distance to explore areas where irregular coverage requested an integral territorial mapping.

For each mapped seagrass patch, topologic information was collected, together with vegetation data (species and coverage degree), in accordance with the following scale (Class I = 0%, Class II = 1–5%, Class III = 6–50%, Class IV = 51–75%, Class V = 76–100%). Patches characterized by a mosaic of two or three species were classified as mixed population and different coverage values were recorded. Data gathered on the field were used to produce preliminary maps, which were subsequently checked again with a desk work thanks to aerial and satellite photos. If necessary, further field work was carried out to refine specific coverages [37,38].

This method, integrated by a correction of the 1990 mapping, permitted a high level of homogeneity among all subsequent mappings, with a standardized estimation of coverage, thanks also to the equalized training of the field team.

The most recent 2017 survey (Figure 1) highlights an extensive colonization of the genus *Ruppia* in the more inner and confined areas (+281 ha), in addition to a significant expansion of the three historical seagrasses *Cymodocea nodosa*, *Zostera marina* and *Zostera noltei*.

Cymodocea nodosa is a subtropical species that colonizes areas with high salinity and coarse sediments, on sand to silty-sand substrates, mostly nearby the sea inlets. It performs a strong seasonality, linked to the variations in water temperature, so its leaf canopy is

largely reduced in winter. In the lagoon, however, this plant is more developed than in other parts of the Mediterranean Sea, reaching a shoot height of 1.5 m, also in less turbid waters, probably due to high irradiance, nutrient-rich waters and sediments, high seasonality, with summer temperature peaks.

Zostera marina lives on silty sediments with little clay and has long leaves that can reach 1.3 m in length and are 5–6 mm wide. It forms dense populations living in shallow confined waters; at low tide the leaves often float on the surface.

Zostera noltei is characteristic of the most inner areas, with predominantly silty sediments, shallow water, and muddy flats, emerging at low tide. *Zostera marina* and *Z. noltei* grow during all year round, faster during springtime, with increased stress and reduced growth rate at temperature exceeding 25 °C [39].

Ruppia maritima colonizes fine sediments, where temperature and salinity are very variable, even in anoxic conditions, but in Venice lagoon this species prefers brackish water, especially inside salt marsh ponds, which are flooded only during particularly high tides.

A general MS reduction, especially during the period of great algal proliferation between the 1970s and the 1980s [40], occurred in the more confined areas. As shown in Table 2, the comparison between the maps shows a modest retreat of the meadows (−62 ha) between 1990 and 2002, and significant losses between 2002 and 2004 (−1.759 ha) with a slight but significant increase between 2004 and 2010 (+136 ha). In 2017, both a marked recolonization of the lost areas since 1990 and the colonization of new areas (+2.988 ha) were recorded. The last map (2017) shows a strong recolonization of sites already colonized in 1990.

Based on the general literature data and personal long-term observations, we attribute the main causes that led to the disappearance of *Z. marina* observed from 2002 to 2004 to the anomalous meteo-climatic conditions with summer water temperatures close to 35–40° C, compared to the average value of the period 1962–1999 [41]. The scientific literature underlines how the optimum temperature for this species is around 10–20 °C and that values above 25 °C strongly increase its retreat and mortality (about 12 times), reduce photosynthesis by 50%, and compresses its growth of new leaves (−50%) and their elongation (−75%) [39,42].

2.2. Adriatic Sea

Current and historical information on the distribution of seagrasses for the other locations subject to transplantations, as the Venetian and North Adriatic coast, the Interreg SASPAS Project sites (Bay of Panzano, near Monfalcone and Trieste, Kornati National Park in Dalmatia and the Regional Natural Park of Coastal Dunes, near Brindisi, Apulia) are less detailed (Figure 2).

Along the North Adriatic coasts, from Venice to Trieste, MS are present but fragmented, with small spots of *C. nodosa* or *Z. marina* up to a depth of 3 or 4 m and *Z. noltei* beds in the emerging tidal flats (Habitat 1110 of Natura2K network) [43–45]. *P. oceanica*, with the exception of little spots in the Northern Adriatic (Gulf of Trieste) [17], is widespread in the Eastern Adriatic and precisely along the eastern Istrian coast, Quarner Islands, Dalmatian coasts and archipelagos, in Albania [20]. Along western Adriatic coasts, *P. oceanica* meadows only occur as south as the Apulia littoral [21].

In the Bay of Panzano (Gulf of Trieste), where a transplantation was carried out as part of the Interreg SASPAS Project, *C. nodosa* is the most abundant seagrass species, which sometimes forms mixed meadows together with *Z. marina* and/or *Z. noltei*. The conditions observed show that although anchoring boats are numerous in summertime, their impact is scarce due to the thick and dense underground compartment and strong plasticity and recovery capacity after physical damage and retreat [45,46].



Figure 2. The sites where SASPAS partners performed transplantation tests, as part of the project concrete actions: Panzano Bay, in Monfalcone, nearby Trieste; Kornati National Park, in Dalmatia; Regional Natural Park of Coastal Dunes, nearby Brindisi.

In Kornati National Park, on an overall view, *P. oceanica* meadows are widespread down to depths of 30 m and more, with an irregular distribution that mainly follows the heterogeneous bathymetric pattern of the archipelago. A rough available distribution map was produced based on orthophoto and bathymetric data and mostly represents a potential distribution range. A *P. oceanica* transplantation test was carried out in a previously disturbed site, defined as an “Anchoring site” in Kravljачica Bay, after a buoy limited area was protected from navigation and anchoring. In the transplanting site, signs of disturbance were expectedly reported and observed. In some areas, coverage is discontinuous and patchy and the damage to MS seems caused by anchors and chains which drag and scrape along the seabed. The site, due to its morphology and exposure to the wind, behaves like a sedimentation basin [45,46], where sand and silty sand is suspended by continuous anchoring.

In the Regional Natural Park of Coastal Dunes, the presence of *P. oceanica*, along the coast of the park, has been detected at a few hundred meters offshore, at a depth of about 7 m, while the lower limit is positioned at a depth of about 20–25 m. Several surfaces of mattes have been observed where MS have certainly retreated, for reasons not directly connectable to anthropogenic pressure. Meadow coverage was about 70–75%, on matte, with the presence of numerous areas of sandy deposition inter-matte [46].

3. Seagrass Transplantations in Venice Lagoon

Over the last 25 years, various authorities in Venice Lagoon have supported MS transplantations, both for technical experiments and for proper environmental restoration. Many of these transplantations were followed by monitoring with a short-term perspective (one vegetative season or one year). Their goal was to adapt the methods of literature [47–49] to the different environmental and morphological conditions that characterize the Venice lagoon.

The numerous mappings conducted in the last 30 years in the lagoon and the historical data have made it possible to select the replanting sites in coherence with different species, with their past presence/absence in the sites. Furthermore, before the restoration, it was

always assessed whether the disturbing factors that negatively affected the meadows were still in place or had subsided.

Whenever possible, outside the project framework, the restoration interventions were subsequently followed up with a 2-to-3-year monitoring, including evaluating of coverage, shoot density, patch size, biomass, rhizome elongation at the end of the growing season (September–October for *Cymodocea nodosa* and *Zostera marina*).

The last two reviews we report below refer to transplantation interventions performed by Venetian University Teams (Sections 3.1.2 and 3.1.3).

3.1. Manual Transplantations

The City of Venice supported (1992–1997), with a pragmatic approach, a series of small-scale (4–5 m² plots) experiments of MS transplantations in the central and southern basin of the lagoon that allowed the identification of edaphic and hydrological requirements of seagrass species living in the lagoon (*Zostera marina*, *Zostera noltei* and *Cymodocea nodosa*). These experiments, together with phenological surveys conducted alongside, provided the necessary background for application and adaptation in the lagoon of various transplantation techniques reported in the literature such as, for example, sod transplantation (vegetated units where the plant with leaves, roots and rhizomes is taken together with the native sediment that surrounds it) and cutting transplantation (manual collection of shoots with rhizomes and bare roots).

For these first transplantations, the evolution was followed in terms of the survival of the sods or of enlargement of its colonized area.

The transplantations with the sod method were carried out by manually picking the plants from donor sites with high leaf density (about 1000–2500 shoots/m² for *C. nodosa*; from 400 to 600 shoots/m² for *Z. marina*; from 1500 to 2500 shoots/m² for *Z. noltei*) and experimenting with different diameters and heights in core drills. On the basis of literature and experience in the field, a reference core drill has been created (diameter of 22 cm and height of 28 cm) also taking into account other aspects such as (a) the manual management of sods by weight, (b) the sediment component compared to shoots and rhizomes, (c) the size of the rhizomes and the presence of terminal rhizomes, (d) the ease of storage and transport of the sods in the boat at a distance, (e) the ability to operate on sandy or muddy shallow bottoms.

The experiments have also allowed development of the sod removal procedure, enabling the maximum efficiency of operators without underwater devices up to bathymetry of the order of one m with an operational capacity of explantation/implantation estimated at about 100–150 sods/day (3.8–5.7 m²/day).

With a spaced arrangement of 0.5 to 1 m between sods, which varies in relation to the growth rate of the rhizomes of the species to be transplanted (greater for *C. nodosa*, less for *Z. marina*), the replanting operation may involve an area of 25–100 m². With regard to the sod arrangement scheme, based on the species, the size of the area to be restored and the number of sods envisaged, it is possible to evaluate an arrangement of the sods at a regular distance or a system of nuclei composed of about 10 sods spaced apart.

The basic operational procedure for explantation and implantation developed over the years involves the use of a four operators' team and two boats (one boat and a support raft for portable equipment) to support the crew and for the temporary storage and transport of sods. After collection, the sods are transferred into semi-rigid plastic pots with a jute bag inside that allows (a) to keep the plants moist until they are transferred to the donor site, (b) to give compactness to the sod during manual handling, (c) to limit the loss of sediment during transportation and placing, especially if water column is more than 1 m. To speed-up the replanting phase, the hole in the sediment is made with a water pump, directed by an operator equipped with a snorkel or scuba equipment in relation to the bathymetry.

For the cutting technique (also referred as “rhizome method” or “rhizome transplantation”), no significant changes were made to the methods reported in the literature [47]. To

speed up the collection of rhizomes and more easily intercept the apical shoots, a surface of donor bed of about 1–2 m² is largely freed of the surface sediment, by means of a water pump, until the rhizomes and roots are exposed. This method allows to easily select apical rhizomes by evaluating their length in relation to the species.

In the recipient sites, the cuttings were inserted directly into the substrate by staples: single cuttings or bundle of cuttings were attached to staples by inserting the root-rhizome portion of the group under the bridge of the staple that was inserted in the sediment so that the rhizomes and roots were buried. Operators worked in a partial immersion mode, considering the depth and the tide.

This technique in Venice Lagoon has not been used consistently because it often does not respond to the extensive result perspective when transplanting is requested in the context of mitigation or compensatory projects, where large areas of MS are to be mobilized or restored and significant colonization is asked after 2–3 years, with a formal and bureaucratic approach which does not take into account the real natural conditions and an in-depth assessment of the existence of environmental requirements for development and macrophytes. Furthermore, this method is not performed in environments with high tidal hydrodynamics (0.5–1.0 m/s) or strong prevailing winds which are able to impact the sediment and erode installations. This technique, on the other hand, appears well suited in our experience (a) for restoration interventions of a widespread nature (hectares) in the lagoon areas of where the hydrodynamic effect and the prevailing winds have little impact on the seabed and (b) in projects where high performance is not required in the short term.

3.1.1. Manual Transplantations (Water Authority of Venice)

In 1996–1997, the possibility of explanting seagrass sods from a donor site without damaging the meadow vitality was tested in the southern basin of Venice lagoon. Two different techniques, sod transplantation and rhizome method (bundles of rhizomes with shoots held in the superficial sediments with plastic clips), were tested in five stations with *C. nodosa* and five stations with *Z. marina* (Table 3 and Figure 3).

Table 3. Average values of parameters monitored for *C. nodosa* and *Z. marina* [50].

<i>Cymodocea nodosa</i>	Beginning		After Two Growing Seasons	
	Sod	Rhizome	Sod	Rhizome
Survival (%)	100	100	74	73
Coverage (%)	4.1	1.2	86	76
Density (shoots/m ²)	45	13.4	681	563
Biomass transplantation (g.d.w./m ²)	-	-	402.9	177
Biomass control (g.d.w./m ²)	-	-	1116.9	
<i>Zostera marina</i>	Beginning		After Two Growing Seasons	
	Sod	Rhizome	Sod	Rhizome
Survival (%)	100	100	48	60
Coverage (%)	4.1	1.2	70	74.4
Density (shoots/m ²)	16.2	7.8	107.5	130.6
Biomass transplantation (g.d.w./m ²)	-	-	167.2	107.8
Biomass control (g.d.w./m ²)	-	-	308.3	

Survival rate, coverage, shoot density and biomass were measured at the 10 sites for both methods (total 20 plots 5 × 5 m each, hosting 25 sods or bundles). After two growing seasons, both transplanting methods showed good successful results. Statistically significant differences between the two transplantation methods ($p < 0.001$, ANOVA) were observed only for *C. nodosa* biomass, which performed best with the sod technique [50] (Table 3).

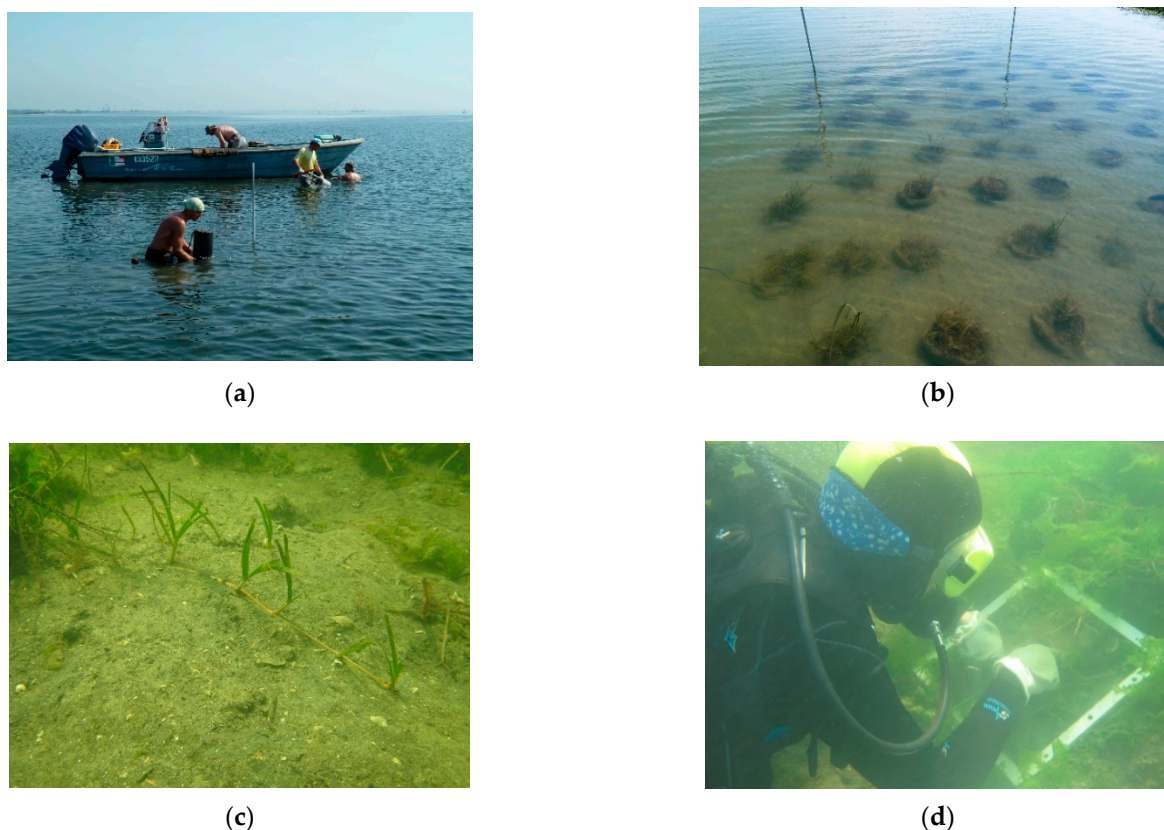


Figure 3. Manual seagrass transplantation: (a) replanting of the sods in the sediment, (b) transplanted sods, (c) rhizome colonizing the bare sediment adjacent to the transplantation area and (d) seagrass growth monitoring.

With both methods, the Venice Water Authority supported several restoration works as part of the compensation, conservation and environmental development measures of the SACs of Venice lagoon [51–54]. In some cases, these interventions were performed after the morphological remodeling of the sites with the ex-novo creation of morphological structures or mudflats that have also positively changed hydrodynamics, enhancing water circulation and recreating a more homogeneous gradient of biological confinement. These interventions have reported success already in the short term (1–2 vegetative years) and in the following years, while in other situations, the results of the intervention were already negative from the first year.

A critical analysis, but useful for understanding the errors not to be repeated in the future, finds that the negative performance of transplantations can be attributed to errors in the project design or errors in the execution of the transplantation. Below we report a series of situations that we have recorded in the context of restoration interventions that might have a negative impact on the transplantation outcome (decreasing order of importance):

- the morphological interventions envisaged by the project did not eliminate or reduce the stress on the habitat;
- effects of climate change with high summer temperatures, together with prolonged low tide and emersion;
- macroalgal blooms events with consequent anoxic crises;
- execution of the intervention on morphological structures not yet stabilized or not consistent to the project goals (e.g., bathymetry, type of sediment);
- seasonality of the intervention not in accordance with the characteristics of the species;
- incorrect leveling of the transplanted sods to surrounding substrate;
- errors in the choice of species.

3.1.2. Manual Transplantations (Venice Architecture School (IUAV) and Water Authority of Venice)

In 1994 the Venice Architecture School (IUAV) and the Consorzio Thetis, Venice, conducted a pilot study for the transplantation of some square meters of *Zostera noltei* in a shallow basin in Northern Venice Lagoon, once rich in seagrasses. At the beginning the experiment gave positive results both in the survival and recolonization capability of the implanted sods [55] but after some year the transplantation failed due to the anoxic conditions due to severe summer macroalgal blooms. It is in fact important to highlight that in the beginning of 1990s Venice lagoon had experienced the peak of a macroalgal overgrowth of *Ulva*, *Gracilaria* and other nitrophilic genera [31,32]. This phenomenon was about to end in these years, but low hydrodynamics areas still showed extensive macroalgal proliferations in the spring-summer months (average 5–10 kg/m² fresh weight) [56], with consequent anoxic phenomena and strong stress for the phyto-zoobenthic community and fish.

3.1.3. Manual Transplantations (Life SERESTO—SEagrass RESTOration)

In order to favor a faster MS colonization in the northern part of the North lagoon basin, where they had almost completely disappeared, the European Community funded the project SeResto “Habitat 1150* (Coastal lagoon) recovery by SEagrass RESTOration in 2012 [57,58]. The aim was to recover the ecological status of this area by restoration and preservation of the habitat 1150* (coastal lagoon) in the site of Community Interest (SCI) Laguna Superiore di Venezia (IT3250031) where this habitat in 2010 covers approx. 3660 ha, by means of a wide transplantation action of MS.

Referring to the lagoon mapping data [38], it is noted that in the northern lagoon there was a regression of the meadows from 684 ha to 56 ha from 1990 to 2010, mostly of *Zostera noltei*. The area is almost completely enclosed amongst saltmarshes and the mainland and without the widespread transplantation of small sods (15–30 cm) and rhizomes the recolonization would have required much longer times. In-field activities were supported by fishermen, hunters, and sport associations assisted by the scientific partners (University Venice and ISPRA—Istituto Superiore per la Ricerca e la Protezione Ambientale). Transplantations involved four species, particularly *Z. marina* and *Z. noltei*, whereas *R. cirrhosa* and *C. nodosa* were only transplanted in some stations with suitable ecological conditions.

The larger rhizomes of *Z. marina* and *C. nodosa* have been transplanted through a handle of approximately 1 m length. *Zostera noltei* and *R. cirrhosa*, given their small size, have been transplanted with 15 cm diameter cores.

These transplantation techniques allowed for a large area intervention, following, as far as possible, the morphology of sites, where depth of the intervention area was generally less than one meter on the average tide level. Angiosperm sods and rhizomes were supplied by managers of closed fishing ponds, where ecological conditions are good and aquatic angiosperms are abundant. Hundreds of full-grown rhizomes were transplanted individually at each station using pliers with a handle of approximately 1 m length.

As general overview, plant rooting was successful where the waters were clear and the organic matter in sediment and column was moderate. However, near the outflows of freshwater, rich in nutrients and suspended particulate matter, the action failed. Results demonstrate the effectiveness of small, widespread interventions and the importance of engaging the population in the recovery of the environment, which makes the action economically cheaper and replicable in other similar environments. The good outcome benefited from a general condition of good quality of the area and a resumption of the colonization dynamics of the MS in Venice lagoon, as shown by the recent mappings.

The rhizome growth of the transplanted plants, recorded to be 0.16–0.22 cm day^{−1}, i.e., 58–80 cm y^{−1}, and the reproduction capacity (approx. 50 seeds per shoot) supported by sea tides and winds favored the plant dispersion and a progressive re-colonization of the area. The first 3 years of results show that rhizome transplantations were successful

in 33 sites out of 35, where the colonization has exceeded 60% with a high dispersion along saltmarshes and channel edges. In the successful sites, the overall ecological status recorded by the Macrophyte Quality Index (MaQI) [59] and the Habitat Fish Bioindicator Index (HFBI) [60] changed from “Poor” to “Good”.

At the end of the project, it was estimated that in the intervention area the seagrasses have colonized, with different degrees of coverage, an area equal to about 10 km² (Figure 4).

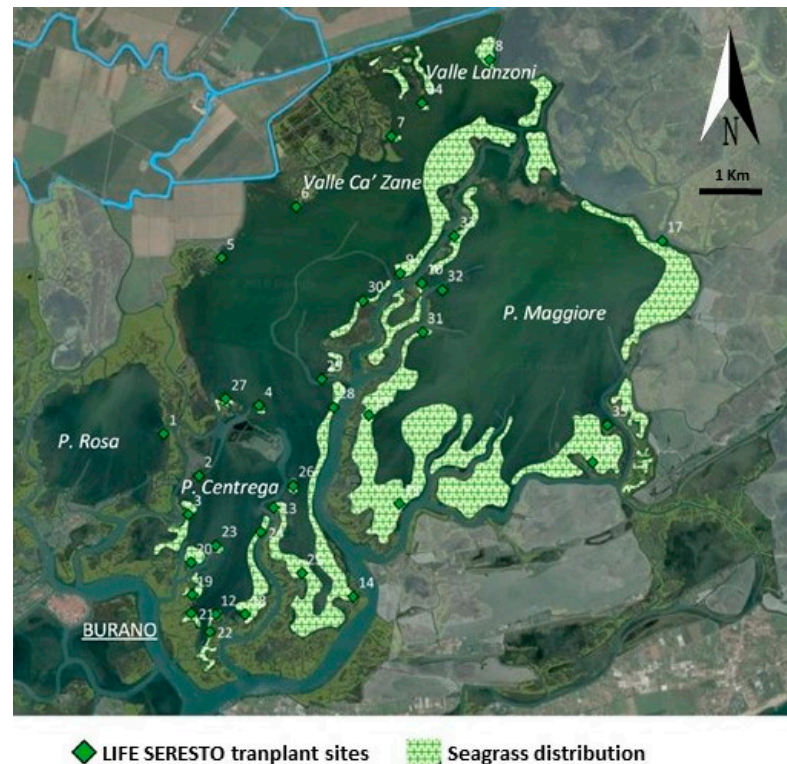


Figure 4. Map of seagrass distribution in the LIFE SERESTO project area (spring 2018) [58], modified.

3.2. Mechanized Transplantations

In addition to the manual transplantation technique, mechanized transplantation techniques were also experimented and applied in the frame of projects supported by the Water Authority of Venice. These techniques allowed the transplantations to be more resilient because of the larger size of the implanted turf compared to manually transplanted ones.

The technique of collecting and repositioning large sods with a mechanized methodology was developed after a series of pilot experiments carried out on MS meadows of *Cymodocea nodosa* and *Zostera marina* on sandy or silty-sandy sediments, on average bathymetry of about 2–3 m. This technique was developed to meet the requests of the various Authorities for large-scale restoration interventions or replanting of extensive MS meadows in the framework of large morphological interventions. For the execution of these interventions, a specific hydraulic bucket has been designed, mounted on a servo-assisted arm capable of picking up sods of about 2 m² and 40–60 cm thick (Figures 5 and 6).

The bucket is divided into two areas, a front with a square blade shape (about 2 × 2 m) for the collection of the sod from the donor site and a rear one for positioning in the host site. Sod is reloaded into the bucket and transferred to the rear part of the bucket, which, during the deposition on the seabed, by means of hydraulically pushed jaws, creates a trench and guarantees good leveling with the surrounding seabed. The construction of the bucket was inspired by the work of Uhrin et al. [61] which with a clamshell bucket was able to remove and transport only one sod at a time, limiting the rate at which sods may be transplanted (approximately 12 sods could be transplanted in one 8-h workday). Our

bucket, modified for the Venice lagoon, is able to pick up numerous sods and temporarily place them in an area of a pontoon, to then reload them at a later stage and deposit them on the seabed at the receiving site.

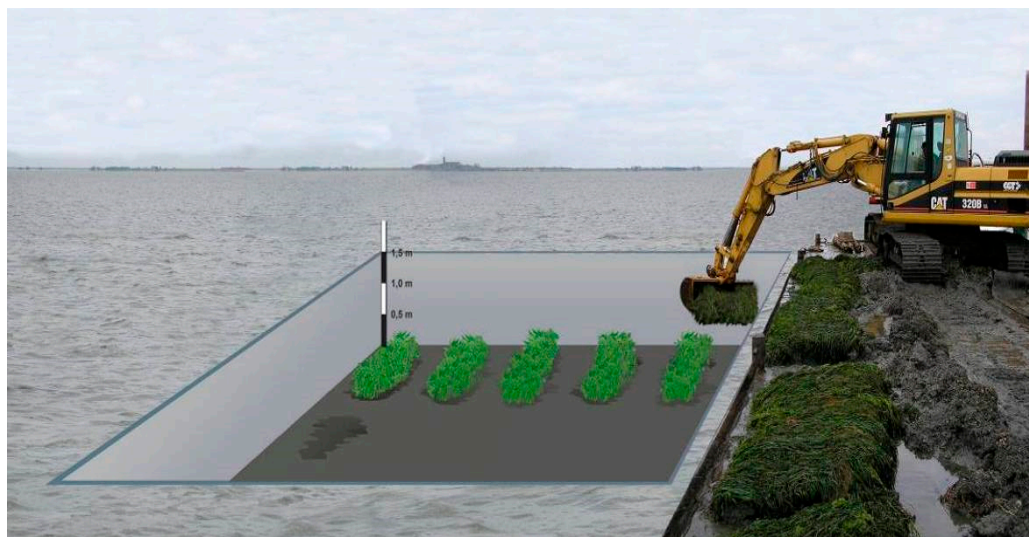
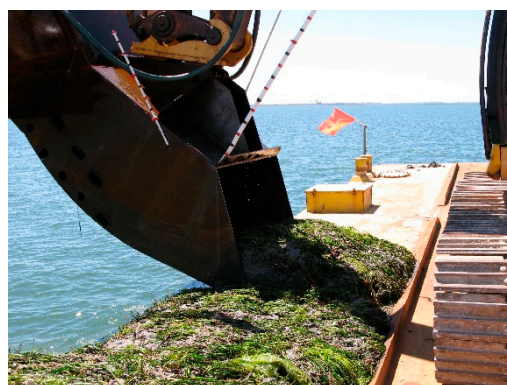


Figure 5. Representative diagram of the sods transplantation by power assisted means, pontoon and servo-assisted arm.



(a)



(b)



(c)



(d)

Figure 6. Mechanized transplantation procedure: (a,b) harvesting of sods from the donor site, (c) temporary storage of sods on the pontoon and (d) deposition of the sods in the transplantation site.

The developed procedure has an operational capacity of about 60 sods/day (some 120 m² of meadow). In relation to the transplanted species (*Cymodocea nodosa* or

Zostera marina) and to the typology of the area, with a spacing of the center/center sods of 3.0–3.5 m in both directions, the replanting area can have an overall extension of 3–4 times (360–480 m²).

A large seagrass mechanized transplantation was carried out for the first time for the conservation and upgrading of the Sites of Community Importance and Special Protection Areas of the Venice Lagoon (spring to summer 2010) [54]. The activity allowed to obtain 2250 m² of *Cymodocea nodosa* sods, from donor sites with high seagrass coverage. The seagrasses have been re-implanted in the Southern lagoon basin in plots of approximately 350 m² each; sods were deployed at about 1.30 m from each other. Site monitoring at the end of the third vegetative season showed coverage of 80–100%, and an increase in the vegetated area of 3.2–3.8 times beside low mortality rates of transplanted sods (6% to 13%). The donor sites after three years returned to a coverage of about 100%, recolonizing the explanations [62].

A second intervention with the mechanized methodology was carried out in May 2016 in the central basin of the lagoon in order to restore an area of about 0.6 ha with *Cymodocea nodosa* [63]. The intervention involved the removal of a total of 450 sods of about 2 m² each from two donor sites and the subsequent replanting on a sandy-muddy bottom on a 1.5–3.0 m head.

At the end of the first growing season, the sod mortality rate was estimated at 4–5%. After the end of the third growing season, sods gave rise to an almost continuous meadow with a coverage of 75–100% that did not allow the single sods to be recognized each other anymore. Average shoots density has progressively increased over the years, varying from an average of 739 shoots/m² in the second year to an average of 1034 shoots/m² in the third year, very close to the values of the neighboring donor meadow (about 1200–1600 shoots/m²).

The positive outcome of the transplantations is mainly due to the vegetative growth capacity of the rhizomes of *Cymodocea nodosa* which in the last 2 years has been estimated on average in the order of 60–70 cm on an annual basis, with minimums of 20–45 cm and maximums of 120 cm of rhizome elongation. Five years after the intervention, thanks to the high capacity of vegetative growth and production of *C. nodosa* seeds, the transplantation area is completely recolonized, and the meadow was comparable in density and degree of coverage (80–100%) to the neighboring donor one.

As well as for monitoring at the recipient sites, during the mechanized transplantations checks were also conducted at the donor sites of *C. nodosa*, to verify the recovery times in respect of the leveling of holes where the sods were collected and of re-colonization of the meadow. Excellent results were observed already at the end of the second vegetative season to reach a total recovery in the third season, when the leveling of the sod marks was almost completed (97–100%) and the colonization close to 100%, which is comparable to the unaffected meadow from explant.

Preliminary mechanized transplantation tests of authors with *Zostera marina*, carried out in 2014 in Venice lagoon, showed very low success and rapid degradation of the underground compartment. Practical problems, as the difficult in transportation and underwater placement of large sods, made of soft and fine sediment, together with rapid growth of summer temperature, affected the results.

4. Seagrass Transplantations in the Adriatic Sea

4.1. Manual Transplantations (Water Authority of Venice in Marine Areas)

In the early 2000s The Water Authority of Venice promoted the experimentation of a seagrass transplantation at sea, in front of Venice (Pellestrina) on a depth of about 4 m. The intervention, designed to facilitate the triggering of the consolidation and environmental improvement processes of the coasts, was part of a wide project which involved the construction of a 9 km sub-emerged barrier parallel to the coastline with 18 emerged breakwaters and 18 sub-emerged ones, forming 17 cells to host a nourishment performed with 4,600,000 m³ of sand.

The MS transplantation intervention had the objective of (a) defending and consolidating the sandy bottom, (b) triggering the processes of enrichment of the organic substance in the sediments, (c) increasing benthic biodiversity. The choice of transplantation siting within the cell was evaluated on the basis of the evidence of erosive processes, of macroalgae accumulation points and of the presence of currents parallel to the sub-emerged barrier [64].

To achieve these objectives, 12 transplantation plots measuring 22×30 m were created between the sub-emerged barrier and the coastline (ca 290 m). In each one, 300 sods with regular distribution (1 m distance) and 240 sods with distribution in nuclei of 20 (0.5 m distance between sods) were transplanted for a total of about 2700 sods. The intervention therefore involved the laying of 10,080 sods for a total plant of about 380 m^2 of seagrass. The choice of the species fell on *Cymodocea nodosa*, the only one reported even if sporadically in the marine sector in front up to a depth of 3–4 m. The intervention was performed in the months of May and June 2001 (Figures 7 and 8).

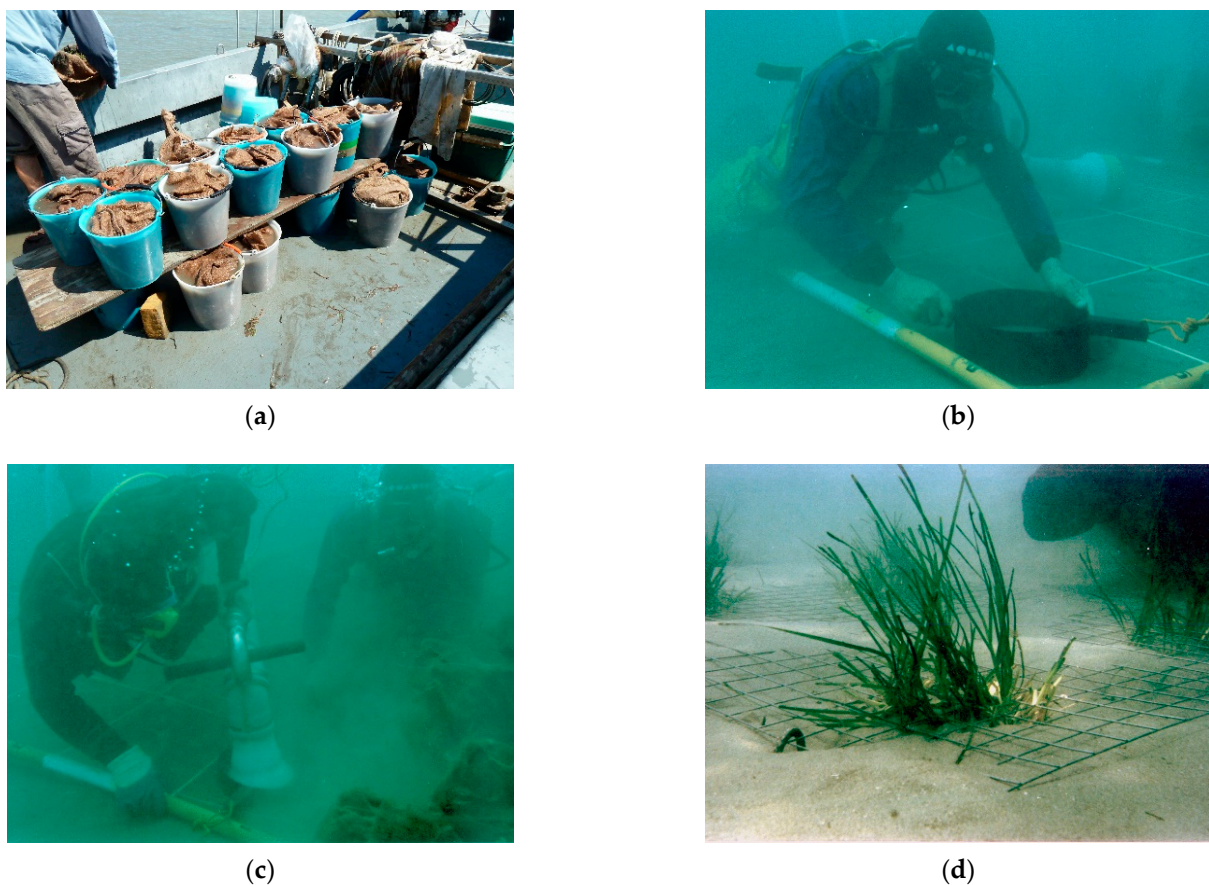


Figure 7. Manual transplantations: (a) temporary storage of sods on boat, (b,c) transfer and deposition of the sods in the transplantation site and (d) sods protected with 10 cm mesh metal nets.

The sods, with a diameter of 22 cm and a height of 25 cm, after being taken from donor sites with a manual core drill, were placed in plastic pots with jute bags that allowed them to be transported and properly humidified before replantation with boats. A team of scuba divers carried out the transfer of the sods. The positioning design (regular or with cores) as per project was carried out by setting up a mobile frame at the bottom with a specific reference grid.

To defend the sods from the erosion action caused by the waves due to the prevailing winds (NE in autumn-winter rising up to 70 kn; SE dominant in spring summer with maximum intensity of 55 kn), the transplantations were protected with 10 cm mesh metal nets.

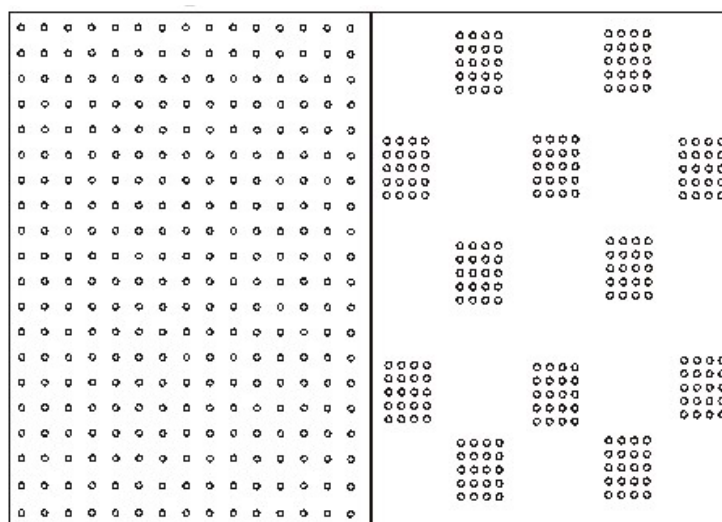


Figure 8. The sods positioning design: on the left, regular, and on the right, with cores.

The three-year monitoring provided for the control of the following parameters: (a) sod mortality, (b) shoot density, (c) leaf length, (d) colonization in inter-sod spaces, (e) general conditions (e.g., sediment leveling, erosion phenomena), (f) triggering of the colonization processes, “prairie effect” (e.g., sessile and vagile benthic component).

The transplantation had a very positive trend until the end of the vegetative season (November) of the first year, in particular for the density estimated at about 900 shoots/m², a value slightly lower than the natural prairie conditions for the same period (1000–1200 shoots/m²). Furthermore, in the first transplantations the longer period that has elapsed has also allowed a significant centrifugal growth of the rhizomes and the development of new shoots. Overall, at the end of the first growing season (November), even after the first storms, the transplantation showed a good course in terms of density and growth, with stability and compaction of the sedimentary surface affected by the sods [64].

The outcome of the transplantation in the following 2 years was strongly compromised by two extraordinary storm surges, June and November 2002, which occurred in conjunction with very high tides and caused an extensive and high mobilization of the superficial sandy layers within the cells, with accumulations of +20 cm and erosions of −15 cm with resentment of the sods that have undergone burial (Table 4).

Table 4. Average values of density, leaf length and sod loss in the monitoring plots.

Density Average Value (Shoots/m ²)		Shoot Length Average Value (cm)				Sod Loss Average Value (%)	
Core Distribution	Regular Distribution	Core Distribution		Regular Distribution		Core Distribution	Regular Distribution
		Min	Max	Min	Max		
2001		2001				2001	
816	817	21.4	55.4	20.8	55.4	9	7
2002		2002				2002	
255	521	12.58	45.04	10.74	39.52	82	81
2003		2003				2003	
43	544	15.6	46.2	14.45	45.3	96	92

The meteorological events also led to the detachment from the surface of the rocks of the suffused barrier of large quantities of algal thalli (*Ulva*, *Dictyopteris*, *Cystoseira*) which also settled among the sods of seagrasses or were trapped between the meshes of the protective nets.

The loss of sods following these two meteorological events estimated, for the different cells, between 70% and 80%. Although negatively marked by this occurrence, the transplantation in the third year, however, also showed good growth capacity of *Cymodocea nodosa* in the absence of extreme weather events. Regarding the quality of the residual sods, the morphometric parameters recorded in the third year highlight the presence of shoots in excellent condition, with growth parameters similar to those of *C. nodosa* of natural meadows. At the same time, we believe it is important to emphasize, as reported by [65], that the process for biodiversity development of benthic and epibenthic fauna hardly reaches the natural meadow levels.

The marked mobilization of the sandy bottoms, however, has shown an insufficient cohesion of the superficial sediments, not yet perfectly able to host a submerged macrophytic flora in the presence of significant meteorological events.

Regarding the objectives of increasing benthic biodiversity, a field survey has shown that the transplanted meadow played a role of nourishment and protection. Among *C. nodosa*, a more abundant and heterogeneous fauna developed in comparison to the surrounding bare areas where the benthic community was characterized by the dominance (in density and biomass) of the decapod crustacean *Diogenes pugilator*. On the contrary, among *Cymodocea*, in addition to *D. pugilator*, other organisms resulted also frequent (in density and biomass), such as gastropods (e.g., *Tritia reticulata*), decapod crustaceans (e.g., *Liocarcinus depurator*), some amphipod crustaceans and sedentary polychaetes.

As observed up to 2002, the presence of MS, where not limited to a few scattered shoots, appeared important in structuring the benthic population compared to the adjacent vegetate stations.

4.2. Manual Transplantations (Interreg Project SASPAS)

4.2.1. Panzano Bay (Gulf of Trieste)—*Cymodocea nodosa* Transplantation

In September 2020 and April 2021, a *Cymodocea nodosa* pilot transplantation was performed in Panzano Bay, located near the site (SAC SPA) Foce dell'Isonzo—Isola della Cona [66]. This area is characterized by shallow depth (some 1.2 m above mean sea level), and the presence of *Cymodocea nodosa* meadows mixed with other species (*Zostera noltei* and *Z. marina*). In this area anchoring pressures occur due to the presence of small leisure boats, mostly in summer season and fine weather. The donor site was selected in an adjacent area with continuous meadow, with no visible signs of disturbance.

Four square transplantation areas (m 10 × 10 each) were selected, where the manual transplantation of vegetated *C. nodosa* sods and cuttings was carried out.

The first manual transplanting technique, prevalent, involved the collection and planting of sods. The second manual transplanting methods involved the manual collection of shoots and their subsequent re-planting, thanks to anchoring staples.

Technique n. 1—Manual harvesting from donor sites and transplantation by sods: sediment intact transplantation units (sods) were extracted from the donor site (the whole plant, with leaf blades, roots, rhizomes and surrounding native sediment) and transported to the host site where specific holes were excavated to receive them. Combined units of leaf blades, roots, rhizomes and sediment were collected from the donor site, using a round cylinder corer (core tube, 25 cm diameter) to harvest them. In the recipient site, sods were planted into the substrate by means of hessian bags (made from biodegradable jute fiber) (Figure 9).

Technique n. 2—Manual harvesting from donor sites and transplanting by bare-root transplantation cuttings (cutting—terminal rhizome with roots and shoots with leaves attached which are usually at least 10–20 cm long): cuttings were selectively collected from the donor site by hand and washed free of sediment. They were inserted directly in the substrate by the use of staples: single cutting or bundle of cuttings were inserted in the sediment and stopped by staples so that the rhizomes and roots were buried (Figure 10).

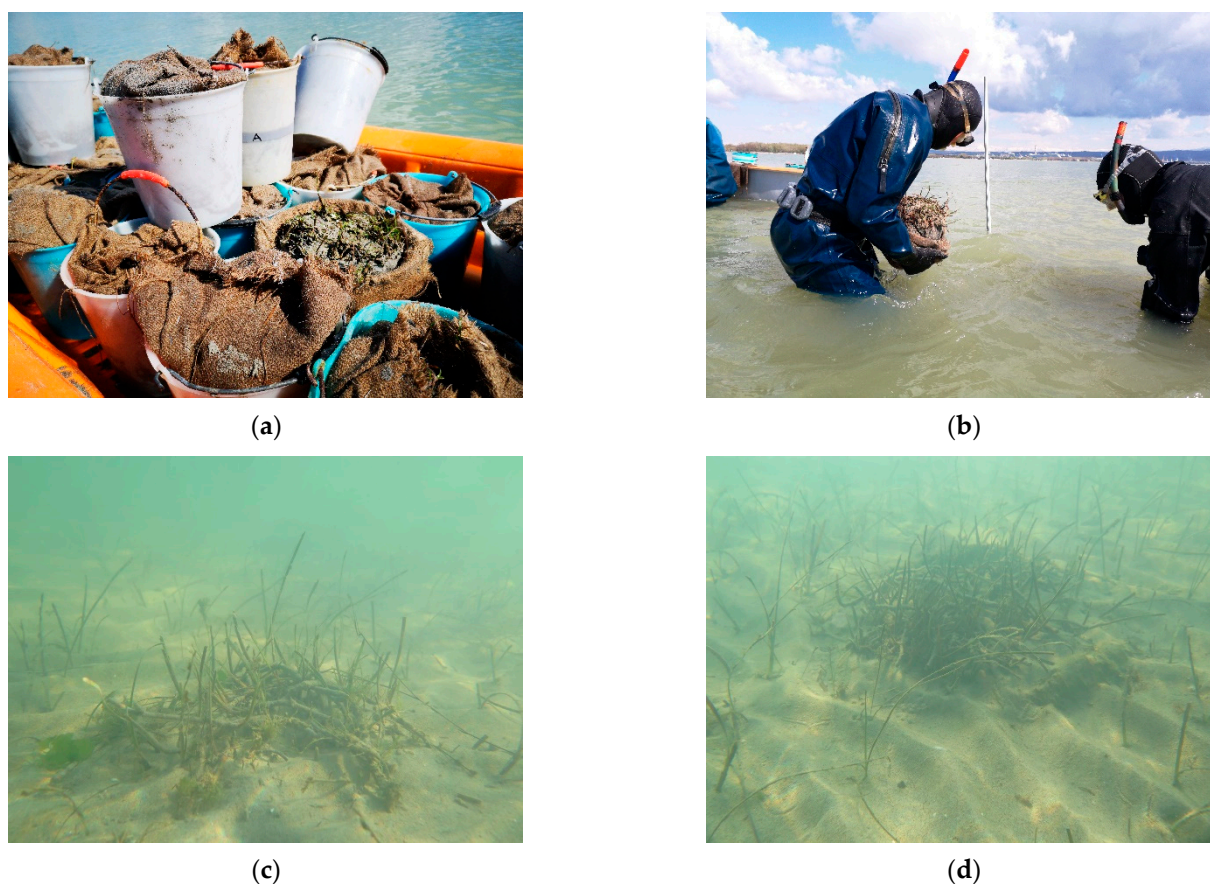


Figure 9. Panzano Bay (Gulf of Trieste) pilot transplantation by sods: (a) temporary storage of sods and their transport to the site to be reforested, (b) sods planting into the substrate by means of jute bags and (c,d) sods planted into the substrate.

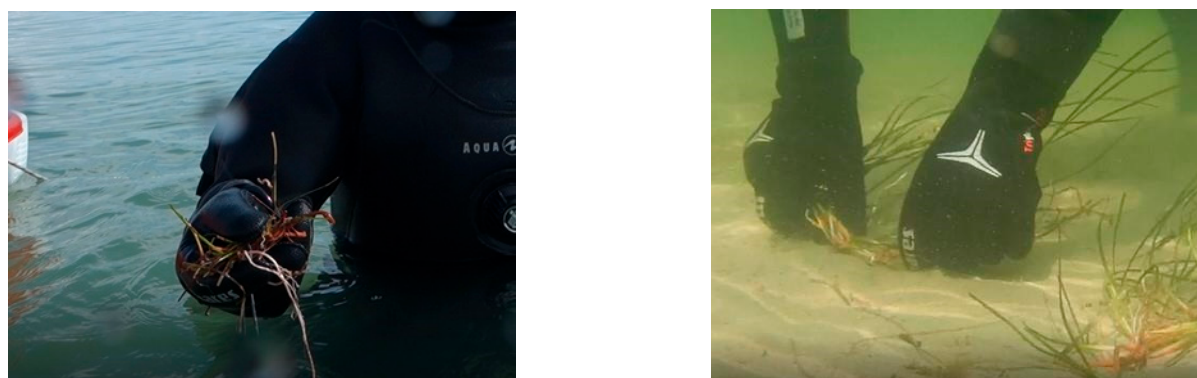


Figure 10. Panzano Bay (Gulf of Trieste) pilot transplantation by plant cuttings, inserted into the substrate by means of staples.

A special inspection of the restored site was carried out in January 2021 and showed that approximately 95% of the sods transplanted in September were still present. Regarding the transplanted cuttings, the small leaf size of *Cymodocea nodosa*, due to the very slow growth during the winter months, hampered their identification and observation. The controls of May 2021 showed a survival of the sods of the 80% in the transplantation of September 2020 and of the 95% in the transplantation of April 2021.

4.2.2. Kornati National Park and Regional Natural Park of Coastal Dunes—*Posidonia oceanica* Transplanting

As part of the ongoing Interreg Italy–Croatia SASPAS project, pilot transplantations were carried out with *Posidonia oceanica* in two sites: Kornati National Park

in Dalmatia (October 2019) and Regional Natural Park of Coastal Dunes, in Apulia (February 2021) [67,68].

Restoration of *P. oceanica* beds is performed by transplantation of the cuttings on sandy substrate or on dead matte, as the sod technique is not suitable for this species [69]. Evidence suggests that plagiotropic rhizomes (rhizomes growing horizontally) are more successfully transplanted than orthotropic ones (rhizomes growing vertically). Artificial holders, such as metal stakes and grids, concrete frames inside which is inserted a wire net, bioengineering materials and partially biodegradable structures have been employed to anchor propagules to the bottom [69–72]. However, restoration success appears highly variable, depending on the transplantation site, local environmental conditions (e.g., hydrodynamics, sediment instability) and the recovery of degraded conditions [69–73].

After an examination of the methods reported in the literature and their results [69,74,75], the timing of the project, the small scale of the Interreg intervention, the characteristics of the restoration sites and costs, the transplantation method proposed by Calvo et al. [74], was evaluated as the more appropriate, considering: (a) the limited impact for the donor grasslands, (b) reduced use of nautical and personal means, especially in diving, (c) consistency with the aims of the project, considering the use of biodegradable materials for anchoring rhizomes. In transplantation tests, price appears to be relatively high in terms of the cost/transplanted surface ratio (about EUR 150.00/sq.m. of transplanted area, with a peak of about EUR 200/sq.m.), based on the Interreg Project experience. The costs for larger-scale interventions, certainly cheaper, must take into account the type of site and logistical aspects.

In both sites, the transplantation was carried out in two contiguous parcels, in relation to the area's bathymetry, each of which represented approximately an area of about 100 square meters, for a total of about 200 square meters of transplanted area.

Kravljacića Bay is situated on the western side of Kornat Island and represents 1 of the 19 preferred anchoring sites in Kornati National Park. After a preliminary survey, this bay has been selected as an appropriate area for the first pilot transplantation. On a general overview, the *P. oceanica* meadow in the Kravljacića Bay shows signs of disturbance, clear regression phenomena, probably due to a high sedimentation of mainly muddy material. Many years of continuous anchoring caused the partial depletion of this marine habitat. A check by the use of sediment traps is ongoing. The meadow is settled on matte, it is discontinuous and shows low density. The upper limit of the meadow is at a depth of 9 m. On the contrary, the donor meadow, in an undisturbed site, was continuous with no visible signs of pressures or significant over-sedimentation.

In the Regional Natural Park of Coastal Dunes, the transplantation site is located inside a discontinuous meadow that shows the upper limit to a depth of 8 m, characterized by the presence of patches of *P. oceanica*, dead matte and sand. The distribution of the dead matte is fragmented and is partially localized on sub-superficial rocky layers.

Transplanting action was run by a team of scientific divers following the method of Calvo et al. [74], who performed the search for plant supply in donor sites, the treatment of cuttings, and replantation. In both sites, the collection of *Posidonia* shoots was carried out selecting plagiotropic cuttings, about 15 cm long, carrying at least three shoots. Cuttings were collected from donor site according to sustainability criteria (1% of meadow density), minimizing the impact on donor meadow. Each shoot was attached to a biodegradable plastic support (The modular biodegradable system (patent pending by Biosurvey Srl) is a polymer (Mater Bi®) for the rapid, effective, and low-cost positioning of *Posidonia oceanica* cuttings on the seabed, to ensure its rooting and growth and to facilitate the natural dynamics of development of the meadow). A total of 10 cuttings for each support were fixed and then transferred by means of a boat to the receiving site for assembling operation on the sea-bed, thanks to a screw fixing system to the dead matte.

The used structure is modular, with five arms on which a variable number of clips for optimal fixation of *P. oceanica* cuttings occurs (Figure 11). According to Scannavino et al. [76],

P. oceanica transplanting modular system allows the rapid attachment and expansion as evidenced by high survival rates and density increasing.



(a)



(b)



(c)



(d)

Figure 11. Pilot transplantation procedure: (a) identification of the donor meadow and (b) harvesting of cuttings, fixing of cuttings to arms (biodegradable support), (c) transport of the supports with cuttings to the site to be reforested and (d) monitoring of the transplantation.

Altogether, in Kornati National Park 720 cuttings and about 2160 shoots were placed, at a depth of some 10 m, in the Kravljaci Bay. First monitoring was carried out in October 2019 immediately after transplantation (zero control) and later in June 2020. The results of the monitoring campaigns (Figure 12) underline that, since October 2019, all transplantations are in good conditions and there are no signs of damage. More recent controls highlight a survival rate varying from 50% to 75% and a persistent pressure due to over-sedimentation, that was a known aspect from the beginning and that is part of the boundary conditions.

The total number of shoots shows a decrease in four out of six measured supports; however, the leaf length shows no major fluctuations, highlighting a good vitality of the shoots that survived the transplanting phase from donor to transplantation area.

In the Regional Natural Park of Coastal Dunes 14 patches were arranged in the area consisting of a total of 84 anchoring modules and about 2500 rhizomes. The transplantation, originally planned in October 2020, was postponed (due to difficulties in obtaining permits from the competent authorities and due to the COVID-19 emergency) and carried out only at the end of February 2021.

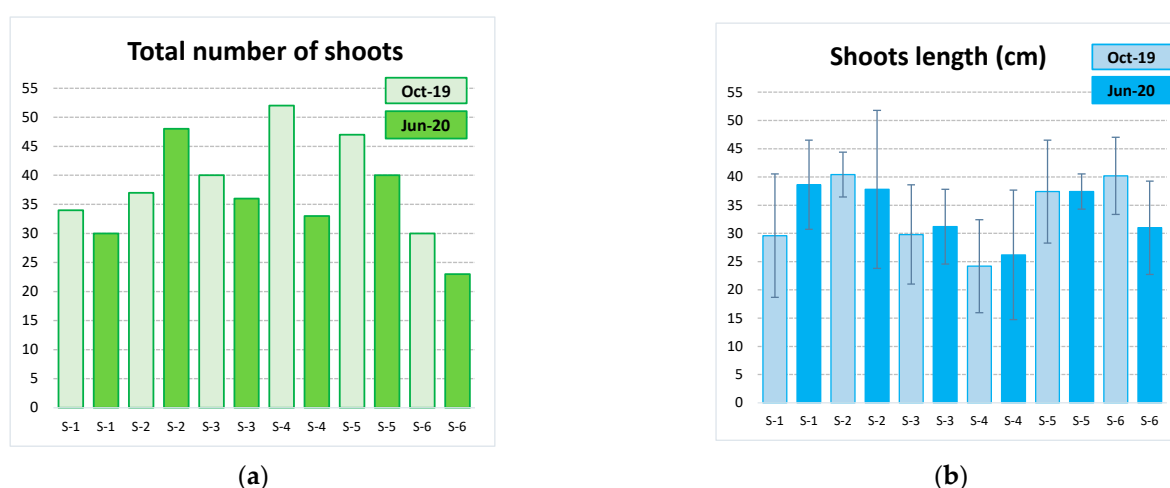


Figure 12. Total number of shoots (a) and average values of shoot length (b) of the 6 monitored supports in October 2019 and in June 2020.

The first control, carried out in May 2021 3 months after the intervention, highlighted good conditions of all modules in terms of rooting, state of the leaves, length, signs of mortality, but evident signs of disturbance due to tools of an unregulated fishing.

The monitoring plan envisaged by the *Posidonia* transplantation project provides for two annual checks, in summer and autumn, to specific labelled modules. In each of the five brackets (arms) of each module, the following variables are to be evaluated for each monitoring campaign:

- Evidence of eroded leaf apex (ER);
- Length of rhizome (LR-LR);
- Total number of shoots in the arm (FT);
- Number of shoots of the external cutting (FE);
- Longest leaf length, in the outer cutting (LF).

5. Discussion and Conclusions

The application of different methodologies for MS transplantations in the transitional environments required a long fine-tuning experience. Nevertheless, both success and failure were achieved.

The results from assessment and evaluation led to construction of a toolbox for intervention in coastal environments with such a variability as for example Venice lagoon and other North Adriatic lagoons. In these contexts, transplantations must take into account the different typology of the sediments, the bathymetry, ranging from almost 0 up to 4 m, the daily tide excursion, and the different residence times of the waters, not to mention other aspects of conservation and protection, of fishing regulation, of pleasure craft traffic.

In relation to the species, *Cymodocea nodosa* offers the greatest chance for success in transplantation procedures, given the quick growth of the rhizomes in the favorable season [77,78], rather than the production of seeds which is limited in time and sites [79].

On the contrary, *Zostera marina* is the most critical species due to the slower growth of rhizomes [77,80] and because of the stress it can experience when water temperatures exceed 25–30 °C [39,42] and when anoxic conditions occur, as it often happens in confined environments. Mappings of MS, carried out in the last 20 years in the Venice lagoon, for example, confirm several events, which alternated in time between retreat and recolonization for this species [38].

With regard to the planting methodology, the various gathered experiences have shown that the sod technique allows for better results, being fundamental in the seabed when water current is high (more than 1 m/s) or when winds and waves cause erosion and resuspensions, impacting the shallow seabed. In these conditions, the cuttings technique does not appear effective because plants get easily eroded. Such a technique, as reported

in Sfriso et al. [57], appears to be well suited for wide surface restoration interventions, in protected or semi-enclosed areas where little impact on the seabed can occur. The low hydrodynamics of these sites also favors the retention of seeds locally or shortly away from the intervention site.

The mechanized solution for transplantations applied in the Venice lagoon, using a servo-assisted bucket mounted on a pontoon, despite having higher equipment costs than the manual one, allows a low use of personnel and the mobilization of large surface sods (about 2 m²) which start propagating rhizomes around very shortly, once replanted. While believing that it is an invasive and not very ecologically friendly method, this solution has a high percentage of success and efficiency and is suitable to avoid success uncertainties even when the intervention is included in the framework of large hydro-morphological works. In addition, the monitoring of the re-leveling process in the donor site, where large holes are produced, showed that, due to the high sediment availability, levelling occurs after 3 months, and a significant plant recolonization is reached after one favorable growth season.

The following table (Table 5) shows a comprehensive comparison between techniques with pro/contra or benefit/short-comings of different transplantation techniques, considering the main specific factors (environmental and morphological variables and managerial evaluations) that can influence the choice of one over another. For example, considering the costs, manual techniques are preferable to the mechanized one; instead, if we consider the presence of a sand to silty-sand sediment, the manual cutting technique shows a poor response (low possibility of transplantation success).

Table 5. List of the main factors (environmental and morphological variables and managerial evaluations) that can affect the transplantation choice and/or success.

	Manual Sod Technique (Corer 20–25 cm Ø)	Manual Cutting Technique (20–30 cm Long)	Mechanized Sod Technique (about 2 m ²)
Costs	low	low	high
Response to possible erosion with high water current	good	poor	good
Response to possible erosion with low water current	good	good	good
N. of employed technical operators	high	high	low
Response to bathymetry 0–1.5 m	good	good	poor
Response to bathymetry >1.5 m	poor	poor	good
Response to a transplantation extension >2500 m ²	medium	poor	good
Use of environmentally friendly transplantation method	good	good	poor
Rapid area colonization (within 2–3 years)	medium	low	good
Level of resilience	low	low	high
Possibility of involving the local population	medium	high	low
Response to the presence of sand to silty-sand sediment	good	poor	good
Response to the presence of predominantly silty sediment	good	good	poor

The authors agree with the recent review by Boudouresque et al. [49] on MS restoration in the Mediterranean. A deep analysis of the environmental conditions and the maintenance of the MS environmental requirements are fundamental, and they must take into consideration both the efforts for the recovery of degraded conditions (sewage outputs, turbidity production, etc.) and actions to favor further colonization of the macrophytes.

The wide surface transplantations of small sods and single cuttings (mainly *Z. marina* and *Z. noltei*) in large, confined lagoon areas are a good solution when help is received by local population, fishermen, local stakeholders, together organized, for example, in university projects, regional and municipality activities, EU programs, etc.

Low-scale projects, in the framework of an involvement of local stakeholders, represent a point of success especially when an extended temporal range and vision are possible. The continuous monitoring of the dynamics of MS coverages and of the ongoing trends must be combined with a coherent program of transplantation at least in the middle time scale. In this way, interventions can be crucial to trigger and strengthen natural spots of colonization that are just developing, working in same direction as nature and not against it.

Some examples meet the requirements of the code of conduct, as defined by Boudouresque [49], as they consist in wide operations which engaged population interested in the recovery of the quality of environment, with consequent reduction of costs.

Greater difficulty is encountered when transplantations are part of larger morphological restoration interventions, where change of bathymetry and modification of coast profile ask for a deep assessment to choose the best design solution to apply. Our experience shows that such an assessment is not often sufficiently planned at the design stage by the competent administration in a proactive perspective.

Taking into account the experience gained through the herein described field actions, the techniques tested, and the documented mistakes, as well as reiterating the importance of a serious a-priori analysis of the boundary conditions, we list some points that we consider important and conclusive, to summarize the main conceptual outputs:

- Avoidance of carrying out interventions on morphological structures not yet stabilized or without correspondence between bathymetry and sediment typology with the environmental requirements of the macrophyte to be replanted;
- Considering that changes in the distribution of MS in lagoon and coastal environments are a normal and physiological fact e that they can account for up to the 30% of coverage distribution each year;
- Avoidance of transplantation if the stress factors on the population exist or have not been eliminated, with particular emphasis on the sediment condition and on the sedimentation pattern;
- Taking special care of the leveling of the sods in the sediment to avoid erosion and rapid rejection;
- Avoidance of areas or contexts characterized by macroalgal blooms or anoxic phenomena;
- Avoidance of periodicity with temperature and other characteristics that do not correspond to the seasonal requirements of the macrophyte.

Supplementary Materials: The following are available online at <https://www.mdpi.com/article/10.3390/w13162289/s1>, Figure S1: Marine seagrass distribution for Venice lagoon (1990 map) [38], Figure S2: Marine seagrass distribution for Venice lagoon (2002 map) [38], Figure S3: Marine seagrass distribution for Venice lagoon (2004 map) [38], Figure S4: Marine seagrass distribution for Venice lagoon (2010 map) [38], Figure S5: Marine seagrass distribution for Venice lagoon (2017 map) [38].

Author Contributions: Conceptualization, A.R. and D.C.; writing, A.R. and D.C.; review of text, literature, editing, A.R., D.C., S.K.P., C.M. and A.K.; involvement in SASPAS field actions, A.R., D.C., S.K.P. and A.K. All authors have read and agreed to the published version of the manuscript.

Funding: This review was funded by the EU Interreg SASPAS Project (<https://www.italy-croatia.eu/web/saspas>) (accessed on 5 July 2021).

Institutional Review Board Statement: Not applicable.

Informed Consent Statement: Not applicable.

Data Availability Statement: Row data we referred to in this review are available on reasonable request from the corresponding author. No new data were created or analyzed in this review.

Acknowledgments: The authors would like to thank the EU Interreg SASPAS Project Lead Partner (Municipality of Monfalcone) and the other Project partners (CoNISMa—National Interuniversity Consortium For Marine Sciences/University of Trieste; CORILA—Consortium for the Co-

ordination of Research Activities Concerning the Venice Lagoon System/University of Venice; SUNCE—Association for Nature, Environment and Sustainable Development; Regional Natural Park “Coastal Dunes from Torre Canne to Torre San Leonardo”) for their collaboration in the project activities. A special thanks to A.K. colleagues of the Park Kornati organization for supporting field activities. The authors would like to thank BIOSURVEY srl (Palermo, Italy), that allowed to apply their patented transplantation methodology for *P. oceanica* and personally led transplanting field activities for SASPAS Project, in collaboration with Project partners.

Conflicts of Interest: The authors declare no conflict of interest.

References

- Hemminga, M.A.; Duarte, C.M. *Seagrass Ecology*; Cambridge University Press: Cambridge, UK, 2000; p. 298.
- Duarte, C.M.; Cebrián, J. The fate of marine autotrophic production. *Limnol. Oceanogr.* **1996**, *41*, 1758–1766. [\[CrossRef\]](#)
- Orth, R.J.; Carruthers, T.J.B.; Dennison, W.C.; Duarte, C.M.; Fourqurean, J.W.; Heck, K.L., Jr.; Randall Hughes, A.; Kendrick, G.A.; Kenworthy, W.J.; Olyarnik, S.; et al. A global crisis for seagrass ecosystems. *Bioscience* **2006**, *56*, 987–996. [\[CrossRef\]](#)
- Costanza, R.; D’arge, R.; De Groot, R.; Farber, S.; Grasso, M.; Hannon, B.; Limburg, K.; Naeem, S.; O’Neill, R.V.; Paruelo, J.; et al. The value of the world’s ecosystem services and natural capital. *Nature* **1997**, *387*, 253–260. [\[CrossRef\]](#)
- Heck, K.L., Jr.; Orth, R.J. Seagrass habitats: The roles of habitat complexity, competition and predation in structuring associated fish and motile macroinvertebrate assemblages. In *Estuarine Perspectives*; Kennedy, V.S., Ed.; Academic Press: New York, NY, USA, 1980; pp. 449–464.
- Orth, R.J.; Heck, K.L.; Van Montfrans, J. Faunal communities in seagrass beds: A review of the influence of plant structure and prey characteristics on predator–prey relationships. *Estuaries* **1984**, *7*, 339–350. [\[CrossRef\]](#)
- Phillips, R.C.; Mc Roy, C.P. *Handbook of Seagrass Biology: An Ecosystem Perspective*; Garland STPM Press: New York, NY, USA, 1980; p. 353.
- Short, F.; Carruthers, T.; Dennison, W.; Waycott, M. Global seagrass distribution and diversity: A bioregional model. *J. Exp. Mar. Biol. Ecol.* **2007**, *350*, 3–20. [\[CrossRef\]](#)
- Boesch, D.F.; Anderson, D.M.; Horner, R.A.; Shumway, S.E.; Tester, P.A.; Whittedge, T.E. Harmful algal blooms in coastal waters: Options for prevention; control and mitigation. In *NOAA Coastal Ocean Program Decision Analysis Series No. 10*; NOAA Coastal Ocean Office, Silver Spring: Montgomery, MD, USA, 1996; p. 46.
- Boesch, D.F.; Field, J.C.; Scavia, D. The Potential Consequences of Climate Variability and Change on Coastal Areas and Marine Resources. In *Report of the Coastal Areas and Marine Resources Sector Team*; U.S. National Assessment of the Potential Consequences of Climate Variability and Change; U.S. Global Change Research Program; NOAA Coastal Ocean Program Decision Analysis Series No. 21; NOAA Coastal Ocean Office, Silver Spring: Montgomery, MD, USA, 2000; p. 181.
- Carlton, J.T.; Geller, J.B.; Reaka-Kudla, M.; Norse, E.A. Historical extinctions in the sea. *Annu. Rev. Ecol. Syst.* **1999**, *30*, 515–538. [\[CrossRef\]](#)
- Jackson, J.B.C.; Kirby, M.X.; Berger, W.H.; Bjorndal, K.A.; Botsford, L.W.; Bourque, B.J.; Bradbury, R.H.; Cooke, R.G.; Erlandson, J.; Estes, J.A.; et al. Historical overfishing and the recent collapse of coastal ecosystems. *Science* **2001**, *293*, 629–638. [\[CrossRef\]](#) [\[PubMed\]](#)
- Marbà, N.; Díaz-Almela, E.; Duarte, C.M. Mediterranean seagrass (*Posidonia oceanica*) loss between 1842 and 2009. *Biol. Conserv.* **2014**, *176*, 183–190. [\[CrossRef\]](#)
- Curiel, D.; Checchin, E.; Miotti, C.; Pierini, A.; Rismondo, A. Praterie a fanerogame marine della Laguna di Venezia—Aggiornamento cartografico al 2010 e confronto storico. *Lav. Soc. Ven. Sc. Nat.* **2014**, *39*, 55–66.
- Guiry, M.D.; Guiry, G.M. *AlgaeBase*; World-Wide Electronic Publication, National University of Ireland: Galway; Ireland; 2020. Available online: <https://www.algaebase.org> (accessed on 24 June 2021).
- Giaccone, G.; Pignatti, S. Studi sulla produttività primaria del fitobenthos nel Golfo di Trieste. II. La vegetazione del Golfo di Trieste. *Nova Thalass.* **1967**, *3*, 1–28.
- Caressa, S.; Ceschia, C.; Orel, G.; Treleani, R. Popolamenti attuali e pregressi nel Golfo di Trieste da Punta Salvatore a Punta Tagliamento (Alto Adriatico). In *La Posidonia oceanica*; Cinelli, F., Fresi, E., Lorenzi, C., Mucedola, A., Eds.; Supplemento alla Rivista Marittima: Rome, Italy, 1995; Volume 12, pp. 160–173.
- Vuković, A.; Turk, R. The distribution of the seagrass *Posidonia oceanica* (L.) Del. in the Gulf of Koper: Preliminary report. *Rapp. P-V. Reun. Comm. Int. Explor. Sci. Mer. Mediterr.* **1995**, *34*, 49.
- Ruggiero, M.; Turk, R.; Procaccini, G. Genetic identity and homozygosity in North-Adriatic populations of *Posidonia oceanica*: An ancient, post-glacial clone? *Conserv. Genet.* **2002**, *3*, 69–72. [\[CrossRef\]](#)
- Telesca, L.; Belluscio, A.; Criscoli, A.; Ardizzone, G.; Apostolaki, E.T.; Frascchetti, S.; Gristina, M.; Knittweis, L.; Martin, C.S.; Pergent, G.; et al. Seagrass meadows (*Posidonia oceanica*) distribution and trajectories of change. *Sci. Rep.* **2015**, *5*, 1–14. [\[CrossRef\]](#) [\[PubMed\]](#)
- REGIONE PUGLIA. Inventario e Cartografia Delle Praterie di *Posidonia* nei Compartimenti Marittimi di Manfredonia, Molfetta, Bari, Brindisi, Gallipoli e Taranto. POR Puglia 2000–2006. 2006, p. 105. Available online: <https://www.yumpu.com/it/document/view/15363912/relazione-generale-file-pdf-28-mb-pugliamareit> (accessed on 5 July 2021).

22. Tagliapietra, D.; Sigovini, M.; Ghirardini, A.V. A review of terms and definitions to categorise estuaries, lagoons and associated environments. *Mar. Freshw. Res.* **2009**, *60*, 497–509. [CrossRef]
23. Molinaroli, E.; Guerzoni, S.; Sarretta, A.; Masiol, M.; Pistolato, M. Thirty-year changes (1970 to 2000) in bathymetry and sediment texture recorded in the Lagoon of Venice sub-basins, Italy. *Mar. Geol.* **2009**, *258*, 115–125. [CrossRef]
24. Bernstein, A.G.; Montobbio, L. La gestione dei sedimenti in laguna di Venezia. Quaderni Trimestrali. *Consorzio Venezia Nuova* **2011**, *1*, 41–71.
25. Tagliapietra, D.; Baldan, D.; Barausse, A.; Buosi, A.; Curiel, D.; Guarneri, I.; Pessa, G.; Rismondo, A.; Sfriso, A.; Smania, D.; et al. Protecting and restoring the salt marshes and seagrasses in the lagoon of Venice. In *Management and Restoration of Mediterranean Coastal Lagoons in Europe. Included in the Project “LIFE Pletera (LIFE13 NAT/ES/001001); Càtedra d’Ecosistemes Litorals Mediterrànies i LIFE Pletera: Venice, Italy, 2018; pp. 39–65. Available online: https://www.researchgate.net/profile/Miguel-Canedo-Arguelles/publication/325038829_Management_and_restoration_of_Mediterranean_coastal_lagoons_in_Europe/links/5af2e200a6fdcc0c03050548/Management-and-restoration-of-Mediterranean-coastal-lagoons-in-Europe.pdf (accessed on 5 July 2021).*
26. Bèguinot, A. *La Vita Delle Piante Superiori Nella Laguna di Venezia e nei Territori ad Essa Circostanti*; Studio Biologico e Fitogeografico. Pubbl. n. 54. Dell’Ufficio Idrografico del R. Magistr. Delle Acque; Ferrari: Venice, Italy, 1913; p. 348.
27. Benacchio, N. Osservazioni sistematiche e biologiche sulle Zosteraceae dell’Alto Adriatico. *Thalassia* **1938**, *3*, 1–41.
28. Vatova, A. Caratteri di alcune facies bentoniche della Laguna veneta. *Nova Thalass.* **1949**, *1*, 3–14.
29. Solidoro, C.; Bandelj, V.; Aubry Bernardi, F.; Camatti, E.; Ciavatta, S.; Cossarini, G.; Facca, C.; Franzoi, P.; Libralato, S.; Melaku Canu, D.; et al. Response of Venice Lagoon Ecosystem to Natural and Anthropogenic Pressures over the Last 50 Years. In *Systems of Natural and Anthropogenic Change Coastal Lagoons*; Paerl, H., Kennish, M., Eds.; CRC Press: Boca Raton, FL, USA, 2010; pp. 483–511, ISBN 9781420088304.
30. Cossu, R.; De Fraja Frangipane, E. *Stato Delle Conoscenze Sull’inquinamento Della Laguna di Venezia*; Technical Report; Consorzio Venezia Nuova—Servizio Informativo: Venice, Italy, 1985; Volume 4.
31. Sfriso, A.; Facca, C.; Ghetti, P.F. Rapid Quality Index (R-MaQI), based mainly on macrophyte associations, to assess the ecological status of Mediterranean transitional environments. *Chem. Ecol.* **2007**, *23*, 1–11. [CrossRef]
32. Curiel, D.; Rismondo, A.; Bellemo, G.; Marzocchi, M. Macroalgal biomass and species variations in the Lagoon of Venice (Italy; North Adriatic Sea), 1981–1998. *Sci. Mar.* **2004**, *68*, 57–67. [CrossRef]
33. Zenetos, A.; Gofas, S.; Verlaque, M.; Cinar, M.E.; Garcia Raso, J.E.; Bianchi, C.N.; Morri, C.; Azzurro, E.; Bilecenoglu, M.; Frogia, C.; et al. Alien species in the Mediterranean Sea by 2010. A contribution to the application of European Union’s Marine Strategy Framework Directive (MSFD), Part. I. Spatial distribution. *Medit. Mar. Sci.* **2010**, *11*, 381–493. [CrossRef]
34. Sfriso, A.; Buosi, A.; Wolf, M.A.; Sfriso, A.A. Invasion of alien macroalgae in the Venice Lagoon; a pest or a resource? *Aquat. Invasions* **2020**, *15*, 245–270. [CrossRef]
35. Caniglia, G.; Borella, S.; Curiel, D.; Nascimbeni, P.; Paloschi, F.; Rismondo, A.; Scarton, F.; Tagliapietra, D.; Zanella, L. Cartografia della distribuzione delle fanerogame marine nella laguna di Venezia. *Giorn. Bot. Ital.* **1990**, *124*, 212.
36. MAGISTRATO ALLE ACQUE DI VENEZIA (Venice Water Authority) (ora Provveditorato Interregionale alle OO. PP. del Veneto–Trentino Alto Adige–Friuli Venezia Giulia)—SGS ECOLOGIA. *Nuovi interventi per la salvaguardia di Venezia. Composizione delle Comunità Biologiche. 1a Fase. Rilievi sui Popolamenti delle Barene ed Aree Circostanti e Sulla Vegetazione dei Bassifondi*; Studio, A.3.16. Rapporto Finale e Cartografia; Concessionario Consorzio Venezia Nuova: Venezia, Italy, 1991.
37. Rismondo, A.; Curiel, D.; Scarton, F.; Mion, D.; Caniglia, G. A new seagrass map for the Venice Lagoon. In *Proceedings of the Sixth Conference on the Mediterranean Coastal Environment, MEADCOAST, Ravenna, Italy, 7–11 October 2003; Volume 2, pp. 843–852.*
38. Curiel, D.; Miotti, C.; Checchin, E.; Rismondo, A.; Pierini, A. Distribuzione delle fanerogame marine nella Laguna di Venezia (Nord Adriatico) al 2017 e confronto storico con il passato. *Boll. Mus. Stor. Nat. Venezia.* **2020**, *71*, 7–19.
39. Den Hartog, C. *The Seagrasses of the World*; North Holland Publishing Co.: Amsterdam, The Netherlands, 1970; p. 275.
40. Sfriso, A.; Marcomini, A.; Pavoni, B. Relationship between macroalgal biomass and nutrient concentrations in a hypertrophic area of the Venice lagoon. *Mar. Environ. Res.* **1987**, *22*, 297–312. [CrossRef]
41. MAGISTRATO ALLE ACQUE DI VENEZIA (Venice Water Authority) (ora Provveditorato Interregionale alle OO. PP. del Veneto–Trentino Alto Adige–Friuli Venezia Giulia). Monitoraggio dell’Ecosistema Lagunare (MELa2)–2° stralcio triennale. In *Linea G: “Meteo”*. Concessionario Consorzio Venezia Nuova; Three Technical Reports, 2003, 2004, 2005; SELC: Firenze, Italy, 2002.
42. Nejrup, L.B.; Pedersen, M.F. Effects of salinity and water temperature on the ecological performance of *Zostera marina*. *Aquat. Bot.* **2008**, *88*, 239–246. [CrossRef]
43. Molin, E.; Bruno, S. Presenza di prateria di *Cymodocea nodosa* (Ucria) Ascherson lungo il litorale del Lido di Venezia: Risultati preliminari. *Boll. Mus. Civ. Nat. Venezia* **2013**, *64*, 7–19.
44. Mazzella, L.; Guidetti, P.; Lorenti, M.; Buia, M.C.; Zupo, V.; Scipione, M.B.; Rismondo, A.; Curiel, D. Biomass partitioning in Adriatic ecosystem (*Posidonia oceanica*, *Cymodocea nodosa*, *Zostera marina*) XXXV Congress CIESM. *Rapp. Comm. Int. Mer. Médit.* **1998**, *35*, 562–563.
45. SASPAS. *Drivers and Pressures Identification and Assessment*; Final Report. 2014–2020 Interreg V-A Italy-Croatia CBC Programme; SASPAS: Venice, Italy, 2020; p. 78.

46. SASPAS. *Environmental Preliminary Survey-WP3 Activity 1*; 2014–2020 Interreg V-A Italy-Croatia CBC Programme; SASPAS: Venice, Italy, 2019; p. 78.
47. Fonseca, M.S.; Kenworthy, W.J.; Thayer, G.W. Guidelines for Conservation and Restoration of Sea Grasses in the United States and Adjacent Waters. In *National Oceanic and Atmospheric Administration*; Silver Spring: Montgomery, MD, USA, 1998; Volume 12.
48. Seddon, F. Going with the flow: Facilitating seagrass rehabilitation. *Ecol. Manag. Restor.* **2004**, *5*, 16–176. [\[CrossRef\]](#)
49. Boudouresque, C.-F.; Blanfuné, A.; Pergent, G.; Thibaut, T. Restoration of Seagrass meadows in the Mediterranean Sea: A Critical Review of Effectiveness and Ethical Issues. *Water* **2021**, *13*, 1034. [\[CrossRef\]](#)
50. Curiel, D.; Scarton, F.; Rismondo, A.; Marzocchi, M. Transplanting Seagrasses in the Lagoon of Venice: Results and Perspectives. In *Proceedings of the Sixth International Conference on the Mediterranean Coastal Environment, MEDCOAST 03*, Ravenna, Italy, 7–11 October 2003; Volume 2, pp. 853–864.
51. Interregional Superintendency for Public Works for Veneto, Trentino Alto Adige, Friuli Venezia Giulia; SELC Soc. Coop. Work Code OP 501-2. Plan of compensation measures, conservation and environmental requalification of the SCI and the SPA of Venice lagoon. Restoration of the tidal flat habitats in the southern lagoon-Millecampi Valley. In *Transplantation of Marine Seagrasses in Newly Created Mudflats*; Final Report. State of Progress 2016; Execution: Thetis and SELC: Venice, Italy, 2016; p. 55.
52. Interregional Superintendency for Public Works for Veneto, Trentino Alto Adige, Friuli Venezia Giulia; SELC Soc. Coop. Work Code OP 506-2. Monitoring of the morphological and environmental restoration of the Bastia Canal—Venice Lagoon. First section. In *Monitoring of Seagrass Transplantation (Art. 3C)*; 3rd Year Final Report; Execution: Thetis and SELC: Venice, Italy, 2016; p. 35.
53. MAGISTRATO ALLE ACQUE DI VENEZIA (Venice Water Authority) (now Interregional Superintendency for Public Works for Veneto, Trentino Alto Adige, Friuli Venezia Giulia). Plan of compensation measures, conservation and environmental requalification of the SCI and the SPA of Venice lagoon. In *Marine Seagrasses Transplantation (Annex 1)*; Technical Specifications. Concessionaire: Consorzio Venezia Nuova; Execution: Thetis: Venice, Italy, 2009; p. 10.
54. MAGISTRATO ALLE ACQUE DI VENEZIA (Venice Water Authority) (now Interregional Superintendency for Public Works for Veneto, Trentino Alto Adige, Friuli Venezia Giulia); SELC Soc. Coop. B.6.85/II Study: Continuation of the environmental enhancement interventions of the Venetian coasts and triggering of colonization processes at the Malamocco and Chioggia lagoon inlets. In *Transplantation of Marine Seagrasses in the Nearby Areas*; Final Report; Concessionaire: Consorzio Venezia Nuova: Venice, Italy, 2009; p. 33.
55. Zitelli, A.; Rossetto, P. Techniques in the environmental restoration programme of the Venice Lagoon: The “Palude della Rosa” pilot project. *Quad. Trimest.* **1996**, *4*, 71–79.
56. Solazzi, A.; Curiel, D.; Chiozzotto, E. Flora macroalgale di fondali mobili (paludi e velme) della laguna di Venezia. *Nova Thalass.* **1994**, *12*, 59–68.
57. Sfriso, A.; Buosi, A.; Tomio, Y.; Juhmani, A.S.; Facca, C.; Sfriso, A.A.; Franzoi, P.; Scapin, L.; Bonometto, A.; Ponis, E.; et al. Aquatic Angiosperm Transplantation: A Tool for Environmental Management and Restoring in Transitional Water Systems. *Water* **2019**, *11*, 2135. [\[CrossRef\]](#)
58. Bonometto, A.; Sfriso, A.; Oselladore, F.; Ponis, E.; Cornello, M.; Facca, C.; Boscolo, R. Il trapianto di fanerogame acquatiche come misura per il ripristino delle lagune costiere. *Quad. Ric. Mar.* **2018**, *12*, 52.
59. Sfriso, A.; Facca, C.; Bonometto, A.; Boscolo, R. Compliance of the Macrophyte Quality index (MaQI) with the WFD (2000/60/EC) and ecological status assessment in transitional areas: The Venice lagoon as study case. *Ecol. Indic.* **2014**, *46*, 536–547. [\[CrossRef\]](#)
60. ISPRA. *Manuale per la Classificazione dell’Elemento di Qualità Biologica “Fauna Ittica” nelle Lagune Costiere Italiane—Applicazione Dell’indice Nazionale HFBI (Habitat Fish Bio-Indicator) ai Sensi del D.Lgs 152/2006. Manuali e Linee Guida*; ISPRA: Rome, Italy, 2017; Volume 168, ISBN1 9788844808716. Available online: https://www.isprambiente.gov.it/files2018/pubblicazioni/manuali-linee-guida/MLG_168_17_Classificazione_fauna_ittica.pdf (accessed on 5 July 2021).
61. Uhrin, A.V.; Hall, M.O.; Merello, M.F.; Fonseca, M.S. Survival and Expansion of Mechanically Transplanted Seagrass Sods. *Restor. Ecol.* **2009**, *17*, 359–368. [\[CrossRef\]](#)
62. Scarton, F.; Curiel, D.; Baldin, M.; Miotti, C. *Avifauna, Benthos e Trapianti di Fanerogame Marine su Velme Artificiali della Laguna di Venezia*. 3° Seminario di Ecologia Costiera; MAV—Museo Ambientale di Valle Vecchia di Caorle (VE): Caorle, Italy, 2017.
63. Interregional Superintendency for Public Works for Veneto, Trentino Alto Adige, Friuli Venezia Giulia; CORILA; SELC Soc. Coop. B.6.72-B/13 Study. *Survey activity for the monitoring of the effects produced by the construction of the inlet barriers; macroactivity: Monitoring of marine seagrass transplantation*; Final Report; Concessionaire: Consorzio Venezia Nuova: Venice, Italy, 2018; p. 40.
64. MAGISTRATO ALLE ACQUE DI VENEZIA (Venice Water Authority) (now Interregional Superintendency for Public Works for Veneto, Trentino Alto Adige, Friuli Venezia Giulia); SELC Soc. Coop. *Additional Specialized Activities and Surveys for the Assessment of the Environmental Improvement Processes of the Coastal Areas (Submerged and Emerged Sites of Pellestrina)*; Final Report; Concessionaire: Consorzio Venezia Nuova: Venice, Italy, 2005; p. 135.
65. Da Ros, Z.; Corinaldesi, C.; Dell’Anno, A.; Gambi, C.; Torsani, F.; Danovaro, R. Restoration of *Cymodocea nodosa* seagrass meadows: Efficiency and ecological implications. *Restor. Ecol.* **2020**, *29*, e13313. [\[CrossRef\]](#)
66. SASPAS. WP4 Activity 4.2. Marine seagrasses pilot transplantations and surrounding seabed cleaning. In *Technical Report on Additional Transplantation Actions in Panzano Bay (Monfalcone)*; 2014–2020 Interreg V-A Italy-Croatia CBC Programme; SASPAS: Venice, Italy, 2021; p. 6.

67. SASPAS. WP4 Activity 4.2. Marine seagrasses pilot transplantations and surrounding seabed cleaning. In *Technical Report on Transplantation Actions in Kornati National Park*; 2014–2020 Interreg V-A Italy-Croatia CBC Programme; SASPAS: Venice, Italy, 2020; p. 6.
68. SASPAS. WP4 Activity 4.2. Marine seagrasses pilot transplantations and surrounding seabed cleaning. In *Technical Report on Transplantation Actions in Regional Park of Coastal Dunes from Torre Canne to Torre San Leonardo (Ostuni-Fasano)*; 2014–2020 Interreg V-A Italy-Croatia CBC Programme; SASPAS: Venice, Italy, 2021; p. 6.
69. ISPRA. Conservazione e gestione della naturalità negli ecosistemi marino-costieri. In *Il Trapianto Delle Praterie Di Posidonia Oceanica, Manuali E Linee Guida*; ISPRA: Rome, Italy, 2014; Volume 106, p. 97, ISBN 9788844806422. Available online: https://www.isprambiente.gov.it/files/pubblicazioni/manuali-lineeguida/MLG_106_2014.pdf (accessed on 5 July 2021).
70. Molenaar, H.; Meinesz, A. Vegetative reproduction in *Posidonia oceanica*: Survival and development of transplanted cuttings according to different spacings; arrangements and substrates. *Bot. Mar.* **1995**, *38*, 313–322. [[CrossRef](#)]
71. Gobert, S.; Cambridge, M.L.; Velimirov, B.; Pergent, G.; Lepoint, G.; Bouqueneau, J.M.; Dauby, P.; Pergent-Martini, C.; Walker, D.I. Biology of *Posidonia*. In *Biology, Ecology and Conservation*; Larkum, W.D., Orth, R.J., Duarte, C.M., Eds.; Springer: Cham, Switzerland, 2006; pp. 387–408.
72. Sanchez-Lizaso, J.L.; Fernandez-Torquemada, Y.; Gonzalez-Correa, J.M. Evaluation of the viability of *Posidonia oceanica* transplants associated with a marina expansion. *Bot. Mar.* **2009**, *52*, 471–476. [[CrossRef](#)]
73. Carannante, F. Monitoraggio a lungo termine di trapianti di *Posidonia oceanica* su vasta scala. In Proceedings of the Tesi di dottorato in Ecologia e Gestione delle Risorse Biologiche–XXII Ciclo, Rome, Italy, 27–30 September 2010.
74. Calvo, S.; Scannavino, A.; Luzzu, F.; Di Maida, G.; Pirrotta, M.; Orestano, C.; Paredes, F.; Montagnino, F.M.; Tomasello, A. Tecnica di Reimpianto Mediante Supporto Biodegradabile. In *Conservazione E Gestione Della Naturalità Negli Eco-Sistemi Marino-Costieri. Il Trapianto Delle Praterie Di Posidonia oceanica. Manuali E Linee Guida*; ISPRA: Rome, Italy, 2014; Volume 106, pp. 47–51. Available online: https://www.isprambiente.gov.it/files/pubblicazioni/manuali-lineeguida/MLG_106_2014.pdf (accessed on 5 July 2021).
75. Alagna, A.; D’Anna, G.; Musco, L.; Vega Fernández, T.; Gresta, M.; Pierozzi, N.; Badalamenti, F. Taking advantage of seagrass recovery potential to develop novel and effective meadow rehabilitation methods. *Mar. Pollut. Bull.* **2019**, *149*, 1–12. [[CrossRef](#)]
76. Scannavino, A.; Pirrotta, M.; Tomasello, A.; Di Maida, G.; Luzzu, F.; Bellavia, C.; Bellissimo, G.; Costantini, C.; Orestano, C.; Sclafani, G.; et al. Biodegradable anchor modular system for transplanting *Posidonia oceanica* cuttings. In Proceedings of the 5ème Symposium Méditerranéen sur la Végétation Marine, Portorož, Slovenia, 27–28 October 2014; pp. 236–237.
77. Sfriso, A.; Ghetti, P.F. Seasonal variation in the biomass, morphometric parameters and production of rhizophytes in the lagoon of Venice. *Aquat. Bot.* **1998**, *61*, 207–223. [[CrossRef](#)]
78. Rismondo, A.; Curiel, D.; Marzocchi, M.; Scattolin, M. Seasonal pattern of *Cymodocea nodosa* biomass and production in the lagoon of Venice. *Aquat. Bot.* **1997**, *58*, 55–64. [[CrossRef](#)]
79. Bellato, A.; Rismondo, A.; Curiel, D.; Marzocchi, M. Ritrovamento di frutti e semi in germinazione di *Cymodocea nodosa* (Ucria) Ascherson in Laguna di Venezia. *Lav. Soc. Ven. Sc. Nat.* **1994**, *20*, 163–164.
80. Curiel, D.; Scarton, F.; Rismondo, A.; Marzocchi, M. Pilot transplanting project of *Cymodocea nodosa* and *Zostera marina* in the Lagoon of Venice: Results and perspectives. *Boll. Mus. Civ. St. Nat. Venezia* **2005**, *56*, 25–40.