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Transplanting Seagrasses in the Lagoon of Venice: Results and Perspectives

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Abstract

As part of a more comprehensive restoration and mitigation plan, a two-year pilot project of seagrass transplanting was initiated in April 1994 in the lagoon of Venice. Two different techniques (non-anchoring method and anchoring method) were tested in five stations with *Cymodocea nodosa* and five stations with *Zostera marina*. Survival rate, coverage, shoot density and biomass were measured at the ten sites for both methods. After two growing seasons, both transplanting methods showed good success. Nineteen of the 20 cells still had seagrass coverage and the coverage ranged, for *C. nodosa*, for both methods from 76 to 86% and for Z. marina from 70 to 74.4%. Compared to the initial densities the increase of the transplanting was, for *C. nodosa*, 15.1 times greater for sod method (681 ± 391 shoots m^{-2}) and 42 times greater for rhizome method (563 ± 463 shoots m^{-2}); for *Z. marina* it was 6.6 times greater for sod method (107.5 ± 50 shoots m^{-2}) and 16.7 times greater for rhizome method (130.6 ± 60 shoots m^{-2}). In comparison with the control site, for both methods after 17 months the density of *C. nodosa* reached 50% and the biomass was 16-36%, while for *Z. marina* the density reached about 50% and biomass was 34-54% that of control site. Statistical differences between the two transplant methods were observed only for *C. nodosa* biomass, which was higher in the sods technique than with rhizome technique. The only treatment that reached a level not significantly different from that of the control was the sod technique for *Z. marina*, for biomass.

Introduction

Over the past several decades, seagrass transplanting has been widely carried out in many different coastal areas in order to re-establish beds which have disappeared due either to natural causes or human activities (den Hartog 1970, Phillips 1976, Ranwell et al. 1974, Fonseca et al. 1998).

Seagrass meadows play an important role in the ecology of coastal areas; these areas provide habitats for many faunal species (den Hartog 1977, Thorhaug 1985, Fonseca et al. 1998, Mazzella et al. 1993). Seagrasses also help stabilize coastal sediments (Ward et al. 1984) and baffle wave energy (Fonseca and Fisher 1986), thereby reducing erosional forces and protecting adjacent shorelines (Christiansen et al. 1981). This latter factor is of great importance in Venice Lagoon, where recent estimates indicate that sediment losses, from a variety of causes such as saltmarsh and shallow bottom erosion caused by boat traffic and amplified wave energy.

In Venice Lagoon, three species of seagrasses occurr: *Cymodocea nodosa* (Ucria) Ascherson, *Z. marina* Linnaeus and *Z. noltii* Hornemann. A detailed mapping performed in 1990 (Caniglia et al. 1992) indicated seagrass coverage had greatly declined since the beginning of the 20th century (Béguinot 1913, Benacchio 1938, Simonetti 1967) but precise information on the past distribution are not available. More recently, a high degree of spatial variability has been reported, with areas showing new occurrence of one or more species and other prairies showing continuing decrease in size (Scarton et al. 1995, Tagliapietra 1999, Rismondo et al. in press). The gradual reduction of the seagrasses in the lagoon coincided with an increase of *Ulvaceae* during the eighties (Curiel et al. 1995, Sfriso 1996).

Transplanting tests in the Venice lagoon (Curiel et al. 1994, Rismondo et al. 1995) were very important in gathering field data useful for designing larger transplanting projects. Worldwide, many transplants have been performed using species of the *Zostera* genus, whereas very few were have used *Cymodocea* genus. In Europe, seagrass restoration has centred either on eelgrass beds in temperate areas (France, U.K., Denmark) or *Posidonia oceanica* (L.) Delile, *C. nodosa* and *Z. noltii* in the warmer areas of the Mediterranean Sea (Piazzi et al. 1998, Molenar and Meinesz 1995).

As part of a broader program of environmental restoration and mitigation in Venice Lagoon, we carried out a two-year seagrass transplanting pilot project (1994-1995). The objectives of the study were: 1) to test sod and rhizome transplanting methods, with *C. nodosa* and *Z. marina*; 2) to monitor growth parameters in transplanted areas; 3) to evaluate possibility and costs of transplanting seagrasses to a larger area in the Venice lagoon.

Study area

The lagoon of Venice (45° 14' N, 12° 17' E, Fig. 1A) has an area of 55,000 hectares. The lagoon is subdivided into three basins, Chioggia, Malamocco and Lido, and exchanges water with the Adriatic through three large inlets. Most of the lagoon is occupied by a large central waterbody (about 370 km^2) with extensive intertidal salt marsh islets (40 km^2), covered with halophytic vegetation. The last mapping showed three species of seagrasses covered an area of about 94,30 km^2 (Caniglia et al. 1992). They form mixed and pure meadows at depths ranging between -0.2 and -3.0 m, mostly in the southern lagoon, near the inlets. The mean depth of the lagoon is 1 m and the tidal range is from 0.6 to 1.0 m; there are also 50 km^2 of tidal flats and 6 km2 of islands. Mean monthly water temperature ranges from 4 ºC in winter to 28 ºC at summer peak, while salinity ranges between 16 and 38 ‰ (Rismondo et al., 1997). Silty and sandy fractions dominate in the sediments.

The transplant sites were located in the southern lagoon (Fig. 1B) and salinity ranged between 30 and 38‰ (on an annual basis). Two donor sites and two control sites were located in the southern lagoon between 0.5 and 5 km from the transplant sites (Fig.1B). The transplant sites were free from algal coverage and remained so throughout the study period (apart from cell no. 9), so the success of the plantings could be measured without interference due to algal growth.

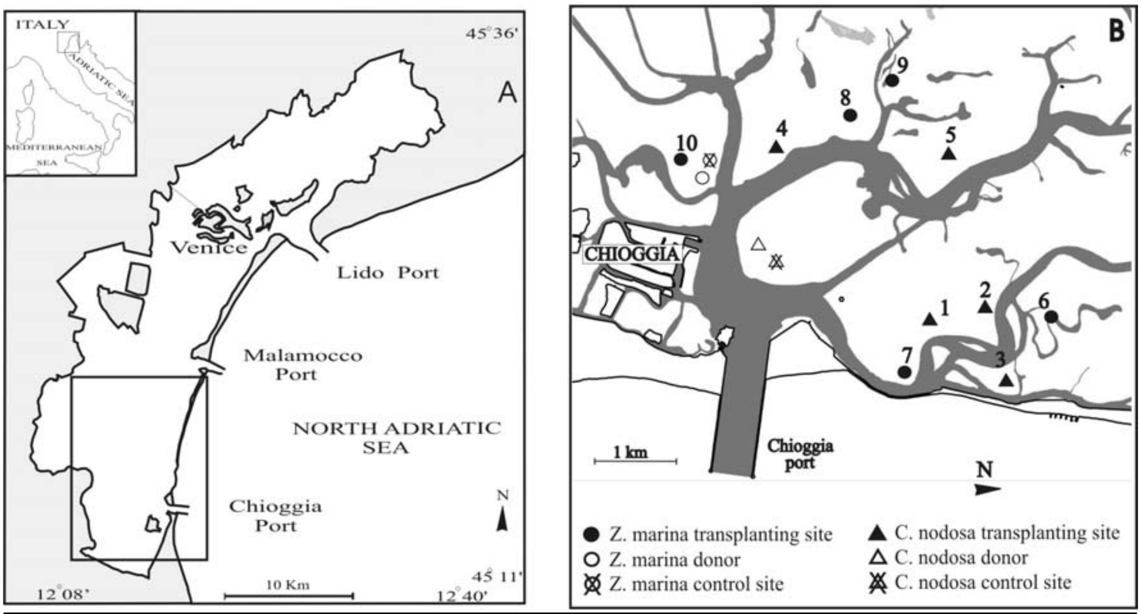

Fig. 1: Map of the Venice lagoon (1A) with location of the ten stations (1B). In gray channels, in white shallow bottoms.

Materials and methods

In April 1994 (month 0), we established ten transplant stations, five for *C. nodosa* and five for *Z. marina*. At each station two 5 m x 5 m cells (A and B) were established. At cell A, we used a non-anchoring method (sods, i.e. plants with substrate intact), whereas at cell B we used a rhizome method (bundles of rhizomes with shoots held in the superficial sediments with plastic clips). At each station we transplanted 25 Planting Units (PU) sods in cell A and bundles of 7-9 rhizomes each in cell B. Sods were harvested using a 30 cm high by 23 cm diameter metallic corer. Rhizomes with an average length of 30-50 cm were collected using a water jet to minimize damage to the plants. Between harvesting and transplanting (about three hours) the PUs were carried by boat and sods stored in PVC buckets, covered with a wet cloth, whereas rhizomes were stored in containers filled with sea water. In the A cells, holes were dug using the corer and sods were placed in the holes. In the B cells, PUs were buried in the bottom with plastic clips. PUs were installed at a regular distance of 1 m by using 5 m x 5 m aluminium frame with uniform grid of PVC piping. The planting frame was removed after each grid was transplanted. Transplanting was done by SCUBA or SNORKEL divers. Divers were required in the transplanting areas not accessible at low tide due to the soft-grained and easily resuspended mud.

From May 1994 (month 1) to November 1994 (month 7) we monitored survival rate (in %) of PUs monthly. From December 1994 onwards, survival rate of PUs was replaced by the % of colonized bottom area, since coalescence was observed. Shoot density (shoot m^{-2}), was monitored monthly from May 1994 (month 1) to September 1995 (month 17) taking random samples. Biomass (leaves, roots and rhizomes, in g d.w. m^{-2}) was recorded only from December 1994 (month 8) onward, in order to avoid destruction of recently transplanted material. Shoot density was measured using four 40 x 40 cm quadrats. Seagrass biomass was determined from five random samples per cell with the corer used to extract transplant sods, and dried at 80 ºC. Leaf growth was measured using 15 shoots for each cell (A and B) according to the method reported by Zieman (1974).

Data are expressed as mean ± 1 standard deviation. Statistical analyses were performed with parametric (Student t-test, Analysis of variance) and non parametric methods (Mann-Whitney U-test). Tukey HSD and ANOVA analysis was used to detect differences among areas (Sokal and Rohlf 1995).

Results

C. nodosa

The survival rate of PUs for *C. nodosa* transplants decreased steadily, and at month 7 it was about 73% for each method, ranging from 60% - 80% (Table 1A). There were no significant differences between the two techniques (Mann-Whitney U-test).

At the end of the study after 17 months, coverage was not different between the sod method (21.5 m^2, 86% of the total cell area) and the rhizome technique (19 m^2, 76%; Mann-Whitney U-test, Table 1B). Coverage values ranged widely across stations, between 40% and 100%; the lowest value resulting from natural causes of disturbance (such as macroalgae overgrowth), which led to mortality of most of the seagrass plants.

Shoot density increased greatly during the study, with final values of 681 ± 391 shoots m^{-2} for the sod method and 563 ± 463 shoots m^{-2} for the rhizome method (Table 1C); no differences were detected between the two methods (ANOVA, $F_{1,53}=1.34$, n.s.). Both values are lower than those observed in the control area

(ANOVA, $F_{1,32}$=8.53, p<0.0001 for sod methods and $F_{1,35}$=30.2, p<0.0001 for rhizome method).

Biomass decreased from month 8 (December 1994), until month 14 (June 1995, Table 1D). At the end of the study, biomass in the transplant cells was higher for the sod method (402.9 ± 369.9 g d.w. m^{-2}) compared with the rhizome method (177 ± 164.1 g d.w. m^{-2} (ANOVA, $F_{1,40}$=17.29, p<0.001). Compared with control site (1252.3 ± 170.5 g d.w. m^{-2}, N=9), biomass values at month 17 in the transplant sites were always lower for both sod and rhizome methods (ANOVA; $F_{1,27}$=65.3, p<0.0001 and $F_{1,27}$=327.6, p<0.0001, respectively).

Coalescence among PUs started from month 4 (September 1994) in sod transplanted cells and from month 5 (October 1994) in rhizome transplanted cells. For both methods, about 60-70% of PUs reached coalescence by month 17**.**

Z. marina

Due to an overgrowth of seaweeds *Ulva rigida* C. Agardh and *Chaetomorpha linum* (O.F. Mueller) Kuetzing which completely covered the seagrassess at station 9 after month 14, results refer only to the remaining four stations after that date.

The mean survival rate of PUs at the end of month 7 was 48% for the sod method and 60% for the rhizome method, ranging between 30% and 70% (Table 2A). The differences between the two methods were not significant (Mann Whitney U-test).

At the end of the study, mean surface coverage was 17.5 m^2 (70% of the total cell area) for the sod method and 18.6 m^2 (74.4%) for the rhizome method (n.s, Mann-Whitney U-test), with minimum values of 50% and maximum of 100%, as compared 4.1% for the sod method and 1.2% for the rhizome method at the beginning of the study (Table 2B).

Z. marina shoot density increased from 16.2 ±1.3 shoots m^{-2} to 107.5 ± 50 shoots m^{-2} by the end of the study for the sod method and from 7.8 ± 0.8 shoots m^{-2} to 130.6 ± 60 shoots m^{-2} for rhizome method (Table 2C). Variability among stations was as high as 50%, leading to a lack of difference between the two methods. Both mean values were lower than those found at the control site at the end of the research (ANOVA: $F_{1,37}$= 10,93, p<0.01 for sod method and $F_{1,38}$=6.75, p<0.01 for rhizome method).

Mean biomass at the end of month 17 did not vary between the two techniques (209.0 ± 223.4. 3 g d.w. m^{-2} for sods and 134.8 ± 106.6 g d.w. m^{-2} for rhizomes, ANOVA, n.s.) (Table 2D). For both techniques, mean monthly biomass values increased regularly from month 8 to month 17. At the end of the study, biomass in transplant sites was significantly lower than in the control site for the rhizome method (ANOVA, $F_{1,23}$=24.9, p<0.0001), whereas for sod method the difference was not statistically significant (ANOVA, n.s.).

Coalescence among PUs was observed starting from month 8 (December 1994) in sod cells and from the month 11 (March 1995) for rhizome cells. For both methods, about 30% of PUs reached coalescence by month 17**.**

Table 1: Parameters monitored for *C. nodosa*: A) % survival of transplanted sods and rhizomes from the beginning to month 7; B) area covered (in m^2 and % of the total cell area, 25 m^2) at the beginning and at the end of transplanting; C) density of shoots (per m^2) at the beginning and at the end of transplanting; D) biomass (g d.w. m^{-2} above-belowground) from month 8 to month 17.

A

Cell	Beginning		3rd month		7th month	
	sod	rhizome	sod	rhizome	sod	rhizome
1	100	100	90	65	80	65
2	100	100	90	70	80	70
3	100	100	80	80	70	80
4	100	100	90	90	80	80
5	100	100	80	70	60	70
Average	100	100	86	75	74	73

B

Cell	Beginning		17th month	
	m^2 (%) sod	m^2 (%) rhizome	m^2 (%) sod	m^2 (%) rhizome
1	1.038 (4.1)	0.3 (1.2)	22.5 (90)	22.5 (90)
2	1.038 (4.1)	0.3 (1.2)	25 (100)	25 (100)
3	1.038 (4.1)	0.3 (1.2)	25 (100)	25 (100)
4	1.038 (4.1)	0.3 (1.2)	25 (100)	10 (40)
5	1.038 (4.1)	0.3 (1.2)	10 (40)	12.5 (50)
Average	1.038 (4.1%)	0.3 (1.2%)	21.5 (86)	19 (76)

C

Cell	Beginning shoot m^{-2}		17th month shoot m^{-2}	
	sod	rhizome	sod	rhizome
1	47	15	815	1288
2	45	13	885	757
3	46	12	462	208
4	45	13	1120	212
5	42	14	123	350
Average	45	13.4	681	563
Control			1250	

D

Sod

Cell	8th month	11th month	14th month	17th month
1	272.8	228.9	106.6	138.7
2	372.0	352.0	141.9	402.6
3	259.0	216.6	235.7	502.5
4	365.1	351.4	402.3	887.0
5	183.6	165.9	98.7	83.6
Average	290.5	263.0	197.0	402.9

Rhizome

Cell	8th month	11th month	14th month	17th month
1	205.4	169.3	176.0	409.4
2	193.8	190.3	102.7	179.4
3	155.8	121.8	125.8	115.9
4	303.1	214.3	54.8	57.5
5	192.2	119.9	111.5	122.9
Average	210.1	163.1	114.2	177.0
Control	951.6	773.8	970.0	1116.9

Table 2: Parameters monitored for *Z. marina*: A) % survival of transplanted sods and rhizomes from the beginning to month 7; B) area covered (in m^2 and % of the total cell area, 25 m^2) at the beginning and at the end of transplanting; C) density of shoots (per m^2) at the beginning and at the end of transplanting; D) biomass (g d.w. m^{-2} above-belowground) from month 8 to month 17.

A

Cell	Beginning		3rd month		7th month	
	sod	rhizome	sod	rhizome	sod	rhizome
6	100	100	80	70	50	40
7	100	100	80	90	70	70
8	100	100	70	80	50	70
9	100	100	70	80	30	60
10	100	100	50	80	40	60
Average	100	100	70	80	48	60

B

Cell	Beginning		17th month	
	m² (%) sod	m² (%) rhizome	m² (%) sod	m² (%) rhizome
6	1.038 (4.1)	0.3 (1.2)	22.5 (90)	25 (100)
7	1.038 (4.1)	0.3 (1.2)	15 (60)	12.5 (50)
8	1.038 (4.1)	0.3 (1.2)	20 (80)	17.5 (70)
9	1.038 (4.1)	0.3 (1.2)	------	------
10	1.038 (4.1)	0.3 (1.2)	12.5 (50)	20 (80)
Average	1.038 (4.1%)	0.3 (1.2%)	17.5 (70)	18.6 (74.4)

C

Cell	Beginning shoot m^{-2}		17th month shoot m^{-2}	
	sod	rhizome	sod	rhizome
6	18	8	160	186
7	17	7	140	160
8	16	9	68	129
9	15	8	0	0
10	15	7	62	48
Average	16.2	7.8	107.5	130.6
Control			236	

D

Cell	8th month	11th month	14th month	17th month
Sod				
6	65.5	94.5	111.1	113.0
7	92.1	117.6	166.4	434.9
8	80.8	104.2	118.3	162.6
9	49.4	65.1	76.0	0.0
10	90.6	108.8	121.1	125.6
Average	75.7	98.0	118.6	167.2
Rhizome				
6	43.3	62.3	121.5	188.3
7	145.1	73.6	113.6	106.4
8	63.5	83,0	101.9	179.9
9	45.0	63.7	86.1	0.0
10	87.3	97.0	113.4	64.6
Average	76.8	75.9	107.3	107.8
Control	148.5	195.0	492.6	308.3

Discussion

The results, after two growing seasons, showed a good success for both transplanting methods. Indeed, 19 out of 20 cells still had seagrass coverage after two years. At one cell *Z. marina* did not survive due to an overgrowth of seaweeds *Ulva rigida* and *Chaetomorpha linum* which completely covered the seagrasses.

The percent survival of PUs for both methods after 7 months (73-74% for *C. nodosa* and 48-60% for *Z. marina*) is similar to that reported in other studies (Davis and Short 1997, Orth et al. 1999, Fonseca et al. 1996, Molenar and Meinesz 1995). We did not observe statistical differences between the two methods in survival rate in either species.

Bottom surface covered by both species in the transplanting cells, with both methods, reached 70-86% of the whole area after 17 months, which means an increase for both methods of 16.6-17.9 times (for *Z. marina*) and 18.3-20.7 times (for *C. nodosa*) the area covered at month 0. These increases are much more that those reported by Orth et al. (1999) for *Z. marina* (2-3 times the initial area after 20 months). For both species we did not observe statistical differences between the two methods in survival rate.

Plant density was also similar between the two techniques at month 17 (tabs. 3 and 7) for both species. Compared to the values at the beginning, the increase was 6-16.7 times for *Z. marina* and 15.1-42 times for *C. nodosa*. For both species density values are 50% lower than the donor site, the difference being statistically significant.

In *C. nodosa* cells, mean biomass was 34.8% (sod method) or 15.0% (rhizome method) the control site biomass. Differences between the two techniques were statistically significant ($F_{1,40}$=17,29, P<0.001). For *Z. marina*, mean biomass ranged from 42% (rhizome method, difference statistically significant: ANOVA, $F_{1,23}$=24,9, P<0.001) to 65% (sod method, no difference) those of control site.

Conclusions

According to the criteria that we used for evaluating planting success, the sod method performed better. In particular, the mean values of survival, coverage, shoot density and biomass of *C. nodosa* were higher for sod technique compared to the rhizome technique, but the differences were statistically significant only for biomass. Survival, coverage, shoot density and biomass of *Z. marina* were no different between the two techniques. Compared to the control area, in the transplanting sites only biomass values (sod method) were not lower.

In order to design a project of restoration and mitigation, the choice of the transplant method depends on logistic and economic factors, and impacts to donor site as well. We found that the sod method is more labour intensive during collection, transport and planting (each core has a weight of about 15 kg). However, transplanted sods are more resistant to currents and waves and are more suitable in less firm sediments, such as sands with very low concentrations of organic matter. This method also reduced plant stress during the period just after transplanting. This technique has been recommended by several authors (Fonseca et al. 1996, 1998) but costs can become prohibitive for a large scale transplant.

The sod method has a higher impact on the donor site, since the holes resulting from the explanting could lead to erosion on the bed surface. To avoid this problem, sods were dug at least two meters apart one another. After two-three months the holes were already filled up with sediment and in the following season they were colonized by seagrasses.

The rhizome method has a lower impact on the donor sites and requires less labour and equipment. Plants have to be treated manually, they are exposed to the air during the operation and have to be planted in a substratum which is different from that of the donor site. Recent improvements for this technique were adopted with very good results by Orth et al. (1999) and Davis and Short (1997), reducing the number of rhizomes to be used and so limiting the impact on the donor site.

In an environment of high variability such as the Lagoon of Venice, the choice of the species must also consider the geomorphologic and physical features of the proposed transplanting areas. From our field observations, clear differences in depth and sediment characteristic preferences exist for the two species. *C. nodosa* can colonize shallower depths than *Z. marina*, but it needs a sandier sediment. Along the edge of the channels, where sediments are sandier, transplanting *C. nodosa* is more suitable. In deeper areas, where sediments are less sandy, *Z. marina* transplanting should be preferred. Moreover, in the lagoon of Venice *Z. marina* tolerates a wider salinity range than *C. nodosa* and, is therefore suitable for transplanting in a larger area.

Higher shoot density, underground biomass and rhizome growth make *C. nodosa* much more suitable for stabilizing coastal sediments and reducing turbulence and wave activity (Rismondo et al. 1997).

Finally, costs of the whole project must be carefully evaluated. A three person team, with one boat and SCUBA equipment, was able to carry out the whole transplanting cycle (digging, carrying, transplanting) for 50 PUs (sods or rhizome bundles) in one day. Working difficulty is approximately the same for plant extraction and transplanting in shallow bottom areas. All aspect of transplanting are much more labour intensive at deeper locations.

On the basis of the results of this study we estimate that transplanting a one hectare area with 10,000 vegetated sods or 10,000 rhizome bundles could be accomplished using four teams of three people each over 50 days. The length of field operation could be reduced (as much as 50%) utilizing hydraulic machinery for sod extraction from the donor site and an air lifter for digging the holes and inserting the sods in the host site.

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