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PILOT TRANSPLANTING PROJECT OF *CYMODOCEA NODOSA* AND *ZOSTERA MARINA* IN THE LAGOON OF VENICE: RESULTS AND PERSPECTIVES

Riassunto. *Trapianto sperimentale di* Cymodocea nodosa *e* Zostera marina *nella Laguna di Venezia: risultati e prospettive.*
All'interno di un progetto di ripristino e di mitigazione ambientale, è stato avviato nella Laguna di Venezia un trapianto sperimentale con le fanerogame marine *Cymodocea nodosa* e *Zostera marina,* impiegando la tecnica del trapianto con zolle (cella A) e con rizomi (cella B). Per ambedue i metodi sono stati seguiti nel tempo il tasso di sopravvivenza, il grado di copertura raggiunto, la densità dei ciuffi, la produzione dei rizomi e delle foglie e la biomassa. Rispetto alla densità iniziale l'incremento di copertura al termine del trapianto è stato per *C. nodosa* di 15.1 volte con il metodo delle zolle (681 ± 391 ciuffi m^2) e di 42 volte con il metodo dei rizomi (563 ± 463 ciuffi m^2); per *Z. marina* l'incremento di copertura è stato invece di 6.6 volte con il metodo delle zolle (107.5 ± 50 ciuffi/m^2) e 16.7 volte con il metodo dei rizomi (130.6 ± 60 ciuffi m^2). Per ambedue le tecniche utilizzate, dopo 17 mesi la densità per *C. nodosa* è risultata pari al 50% e la biomassa al 16-36% rispetto al sito di controllo, mentre per *Z. marina* la densità è stata pari al 50% e la biomassa al 34-54% rispetto al controllo. Una differenza statistica tra i due trapianti è stata rilevata solamente per la biomassa di *C. nodosa*, che è risultata più elevata con il metodo delle zolle.

Abstract. As part of a more comprehensive restoration and mitigation plan, a two-year pilot project of seagrass transplanting was started in April 1994 in the lagoon of Venice. Two different techniques were tested in five stations with *Cymodocea nodosa* and five stations with *Zostera marina*. In each station, in cell A a non-anchoring method (30 cm diameter sods with plants and substrate intact) was used while in cell B an anchoring method (rhizomes with shoots fixed with plastic clips) was used. Survival rate, coverage, shoot density, leaf and rhizome growth rate, and biomass were measured at the ten sites for both methods. After 7 months, the survival of Plant Units (sods or bundles of rhizomes) for both methods was 73-74% for *C. nodosa* and 48-60% for *Z. marina*. 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*, with respect to biomass values attained at the end of the study.

Key Words – Seagrasses, transplanting, restoration, *Zostera marina*, *Cymodocea nodosa*

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 (such as increased sedimentation due to hurricanes, foraging activities of benthic feeding fishes, and wasting diseases) or human activities (domestic and industrial pollution,

fishing techniques such as trawling, and dredging; DEN HARTOG 1970, PHILLIPS 1974, 1976a, RANWELL *et al.* 1974, ROBILLIARD & PORTER 1976, FONSECA *et al.* 1979, 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 1990, MAZZELLA *et al.* 1993, FONSECA *et al.* 1998). 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, have been estimated to be about 700,000 $m^3 year^{-1}$ (BETTINETTI *et al.* 1996). Worldwide, eelgrass abundance has declined significatly since the turn of century due to pollution associated with increased human population (SHORT & WYLLIE-ECHEVERRIA 1996).

In Venice Lagoon, three species of seagrasses occurr: *Cymodocea nodosa* (Ucria) Ascherson, *Z. marina* L. and *Z. noltii* Hornemann. A detailed mapping performed in 1990 (CANIGLIA *et al.* 1992) indicated that seagrass coverage had greatly declined since the beginning of the 20th century (BÉGUINOT 1913, BENACCHIO 1938, SIMONETTI 1967, 1973), but precise information on the past distribution is 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 2003). The gradual reduction of the seagrasses in the lagoon coincided with an increase of *Ulvaceae* during the eighties (CURIEL *et al.* 1995, SFRISO 1996).

Beginning in the early 1990s, several aspects of the ecology of the three species in the lagoon of Venice have been studied, including growth and primary production (RISMONDO *et al.* 1995a, 1997, SFRISO & GHETTI 1998), flowering (BELLATO *et al.* 1995, CURIEL *et al.* 1996a, 1997, 1999), and relationships with phytobenthos (CURIEL *et al.* 1996b, 1998) and zoobenthos (PRANOVI *et al.* 2000, SFRISO *et al.* 2001). These studies, and the first transplanting tests (CURIEL *et al.* 1994, RISMONDO *et al.* 1995b) were very important in gathering field data useful for designing larger transplanting projects. Seagrass restoration in Europe has centered 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 (MOLENAR & MEINESZ 1995, PIAZZI *et al.* 1998, LORD *et al.* 1999). As far as we know, no restoration works with *Z. marina* and or *C. nodosa* has been attempted in Italy so far. Information specific to Venice Lagoon was particularly important because the northern Adriatic lagoons have environmental and climatic conditions different from all the other Mediterranean coastal habitats and more similar to those of the European north Atlantic Sea such as higher tidal range, lower mean water temperature, higher nutrient load (SACCHI *et al.* 1989).

Seagrass transplanting methods can be grouped into three broad categories: (1) shoots with sediment intact, known as cores, plugs or sods; (2) shoots with bare roots and rhizomes attached to staples and inserted into the sediment, known as staple, rhizome or cutting method; (3) seeds. Extracting cores of shoots with the sediment intact has been recommended as the preferred trasplanting method (PHILLIPS, 1990, FONSECA *et al.* 1996). Nevertheless, in recent years good results have been obtained using roots and rhizomes with or without anchoring,

thus reducing the damage to the donor sites (DAVIS & SHORT 1997, ORTH *et al.* 1999). Worldwide, many transplants have been performed using species of the *Zostera* genus, whereas very few were have used *Cymodocea* genus (BUTLER & JERNAKOFF 1999).

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 seagrass to a larger area in the Venice lagoon.

STUDY SITES

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 (mainly *Puccinellia palustris* (Seen.) Hayek, *Sarcocornia fruticosa* (L.) A.J.Scott, and *Limonium narbonense* Miller. 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 km^2 of islands. Mean monthly water temperature ranges from 4 °C in winter to 28 °C at summer peak, while salinity ranges between 16 and 38‰ (RISMONDO *et al.*, 1997). Silty and sandy fractions dominate in the sediments (BARILLARI 1981).

The transplant sites were located in the southern lagoon (Fig. 1b) and salinity ranged between 30 and 38‰ (on an annual basis). Based on previous data about the characteristics of sediments in seagrass beds in the lagoon of Venice (CANIGLIA *et al.* 1992) we selected sandier (70-100% sand content) transplant areas for *C. nodosa* than for *Z. marina* (50-80%). 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 donor sites were chosen following our field data and the suggestions of FONSECA *et al.* (1979, 1998), i.e. a high wave energy environment with plants with high productivity, high root standing crop, and high vegetative propagation. 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.

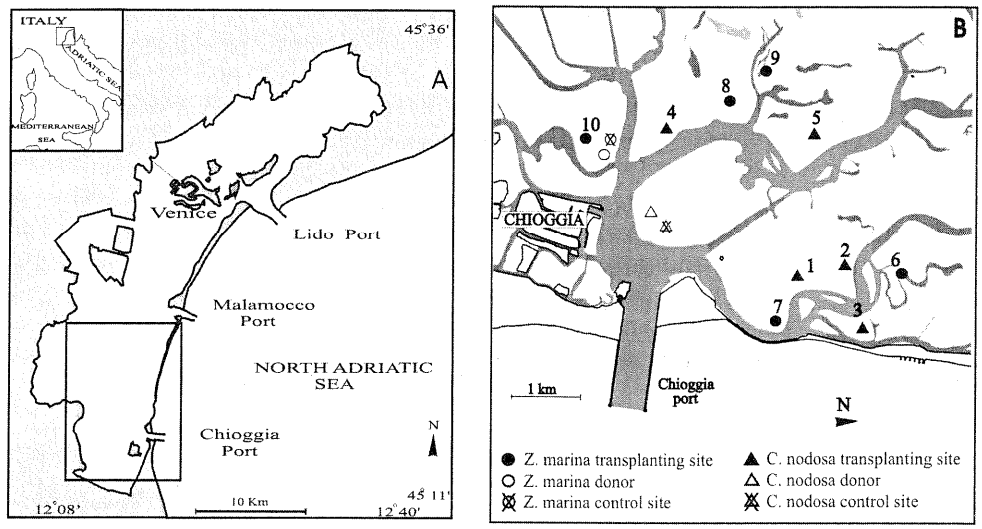

Figure 1. Map of the Venice lagoon (1a) with location of the ten stations (1b). In gray channels, in white shallow bottoms.

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 (Fig. 2). 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}), leaf growth (mm day^{-1}) and rhizome growth (mm day^{-1}) were 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. In addition, during the monitoring surveys we evaluated the occurrence of fertile shoots in the donor and transplant sites. 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 °C. Leaf growth was measured using 15 shoots for each cell (A and B) according to the method reported by ZIEMAN (1974). Rhizome growth was measured using 15 rhizomes by placing plastic cable strips just ahead of the last node (TERRADOS & ROS, 1992).

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). ANOVA analysis was used to detect differences among areas (SOKAL & ROHLF 1995).

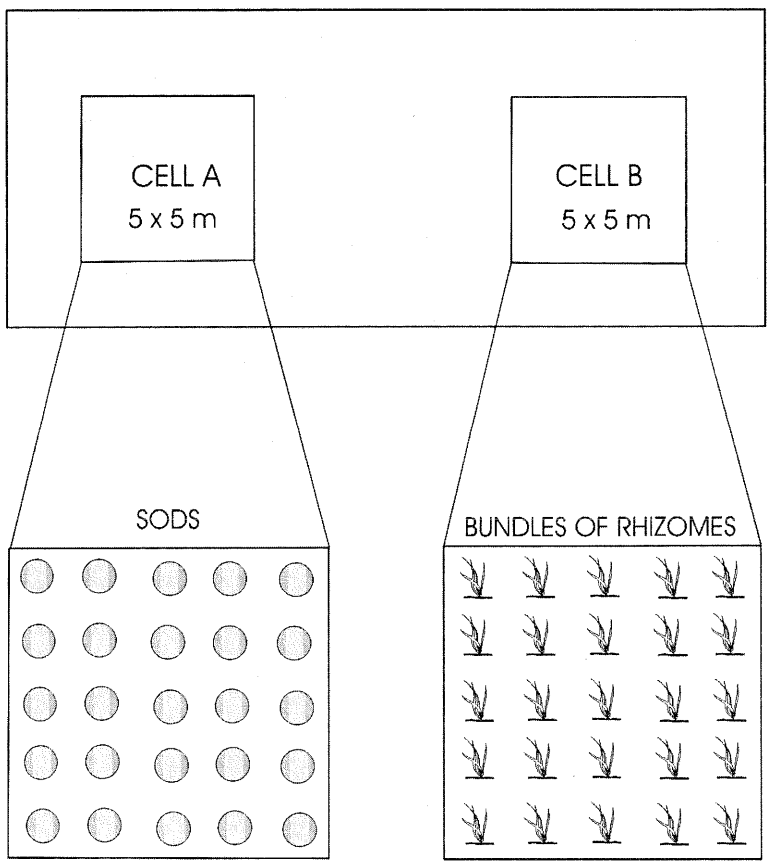

Figure 2. Schematic view of an experimental station with the two cells.

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% (Tab. 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, Tab. 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 (Tab. 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, Tab. 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).

Leaf and rhizome production were similar for the two methods (Fig. 3) but there were some differences when compared to the control station. Leaf growth in the experimental stations was lower in most months, whereas rhizomes growth was higher in the transplant cells in summer and autumn.

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.

We did not observe fertile shoots or seeds in the transplant area.

Z. marina

Due to an overgrowth of seaweeds *Ulva rigida* C. Agardh and *Chaetomorpha linum* (O.F. Mueller) Kützing 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% (Tab. 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 (Tab. 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 (Tab. 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.) (Tab. 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.).

There were no clear differences for leaf and rhizome production between the two transplant methods (Fig. 4). In comparison with the control site, both leaf production and rhizome production were substantially lower early in the study and quite similar toward the end.

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.

Fertile shoots were recorded in the transplant sites during the flowering period beginning in March 1995. The mean number of fertile shoots ranged between 4 and 6 in sod transplanted cells and 5-8 for rhizome transplanted cells. In the control site between 25 and 35 fertile shoots m^{-2} were observed from March to July 1995.

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	
	m² (%) sod	m² (%) rhizome	m² (%) sod	m² (%) 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 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-below-ground) from month 8 to month 17.

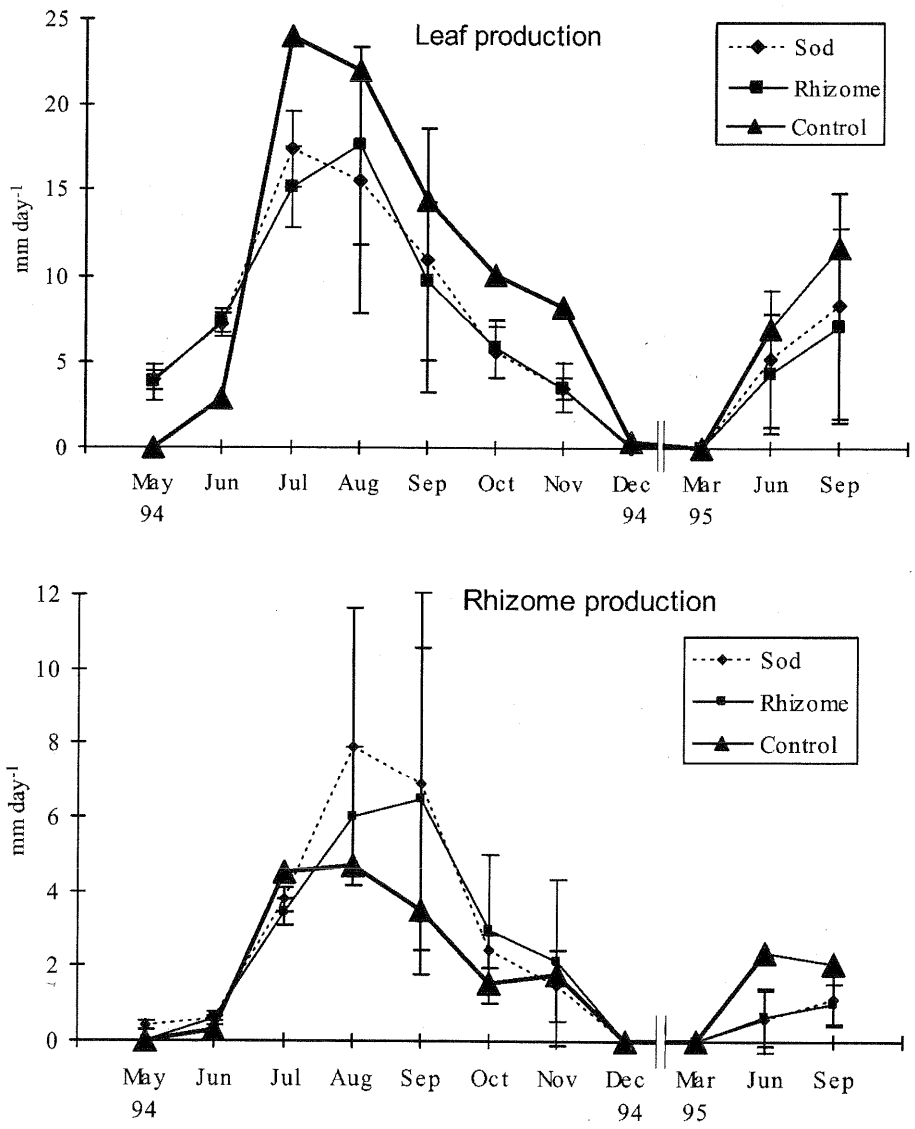

Figure 3. Leaf production (mm day^{-1}), above, and rhizome production (mm day^{-1}), below, for *C. nodosa*.

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

Sod

Cell	8th month	11th month	14th month	17th month
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

Cell	8th month	11th month	14th month	17th month
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

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-below-ground) from month 8 to month 17.

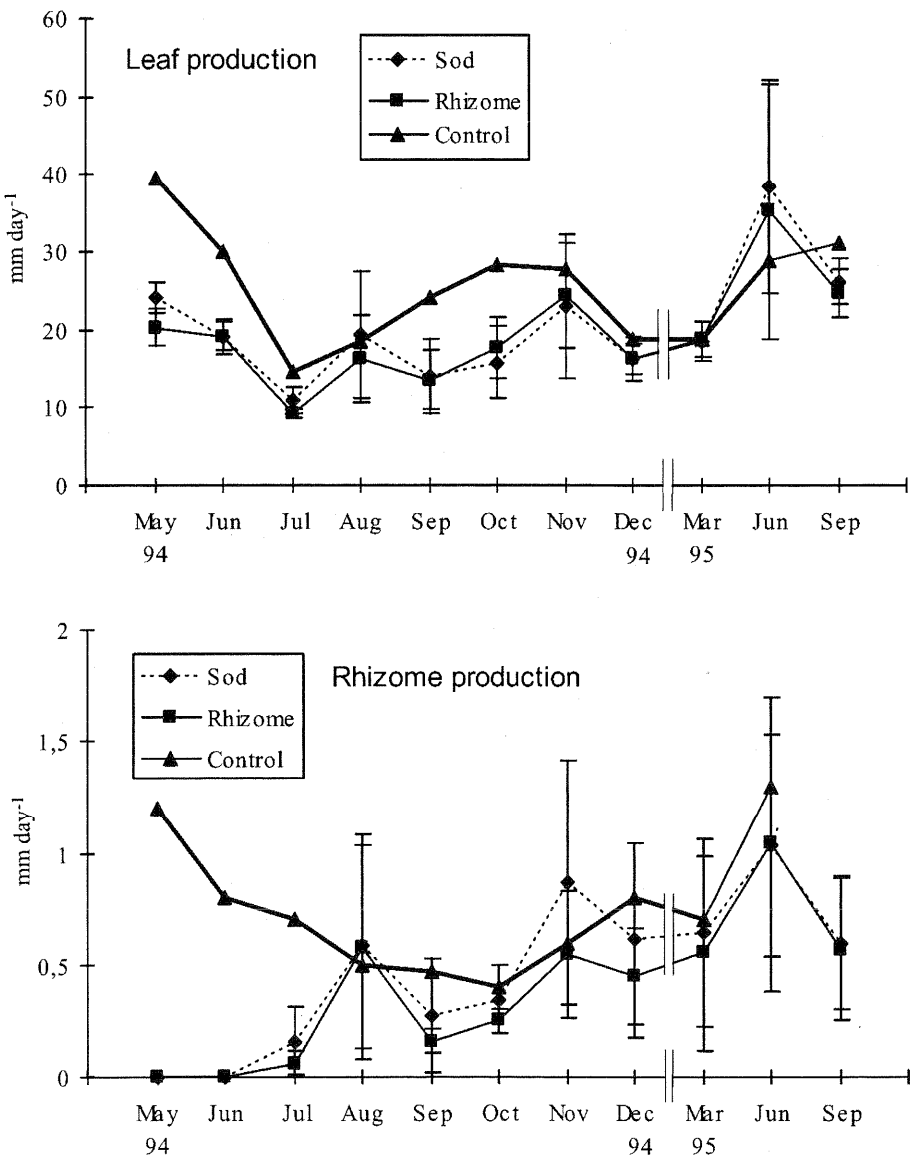

Figure 4. Leaf production (mm day^{-1}), above, and rhizome production (mm day^{-1}), below, for *Z. marina*.

Discussion

Feasibility and transplanting success depend heavily on the characteristics of host sites. It is clearly unwise to carry out transplanting where seagrasses have never been present or where factors which caused seagrasses decline are still present. To maximize success in our transplanting, we selected only sites where seagrasses were known to have previously existed and that exhibited physical characteristics (i.e. grain size, bathymetry, wave energy) which could support meadows.

If the site and environmental conditions are suitable, success of transplanting depends heavily on the plant's capability for new shoot production and shoot branching. This happens, depending on species strategy, through sexual reproduction (seed propagation) and asexual reproduction (rhizome growth or vegetative propagules). In our transplant sites and in the control sites, we observed that *C. nodosa* used chiefly asexual growth, whereas *Z. marina* used sexual and asexual growth, in agreement with previous data gathered by Curiel *et al.* (1997, 1999). For *Z. marina*, in the transplanting site the fertile shoots occurred in the second year after a period of acclimation and stress.

The rhizome propagation of *Z. marina* was less efficient than that of *C. nodosa* (Fig. 3 and 4), as already found by Rismondo *et al.* (1997) in the same area. The summer rhizome production of *C. nodosa* (4.7 mm day^{-1}) was three times as much as that of *Z. marina* (1.3 mm day^{-1}); in just a single growing season rhizomes of *C. nodosa* could reach 0.6 m in length. Moreover, the higher growth of rhizomes in the transplanting cells compared to the control bed was higher in summer and autumn; this could be due to 1) lack of competition with other rhizomes and 2) to an increased storage capacity in the belowground compartment.

The higher coalescence and rhizome production confirm a higher capability, for *C. nodosa*, to colonise substrata because of the faster growth rate of rhizomes, compared to *Z. marina*. In transplanting, these factors are very important, whereas the sexual reproductive mode, which is involved in the expansion of populations over large areas, is more important for the maintenance of genetic diversity (Alberte *et al.* 1994, Ruckelshaus 1996, Williams & Orth 1998).

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 & Short 1997, Orth *et al.* 1999, Phillips 1974, Fonseca *et al.* 1996, Molenar & 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 17-18 times (for *Z. marina*) and 18-21 times (for *C. nodosa*) the area covered at month 0. These increases are much more than 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.

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 diferences 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 (PHILLIPS 1990, 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 & 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 current and wave activity.

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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