13 Can transplanting accelerate the recovery of seagrasses?

Numerous attempts have been made to meet the tremendous seagrass losses the marine environment has faced worldwide. Artificial transplanting of shoots and spreading of seeds from intact meadows to non-vegetated coastal sediment are the most applied techniques. Planted seagrass beds can function and grow exactly as natural beds. However, favourable environmental conditions must be obtained before artificial restorations are considered. Furthermore, new approaches involving less labour and improved survival success rates must be developed before transplantation techniques can become an effective and widespread tool for seagrass recolonisation in European coastal waters. Education of the public as to the relevance of seagrasses can be one of several important goals in a restoration project.

By Peter Bondo Christensen (NERI), Elena Díaz Almela (IMEDEA) and Onno Diekmann (CCMAR)

As natural colonisation of many seagrass species are very slow (see chapter 3 and 12), it is tempting to speed up the recovery process by actively introducing vegetative plants or seeds into areas previously colonised by seagrasses and thus restore the environmental benefits that marine meadows provide to coastal ecosystems (see chapter 2). Restoration programs have indeed been introduced worldwide, most pronouncedly in the USA and Australia – but some large-scale programs have also been implemented in Europe. Detailed guidelines have been developed and may be of great help for managers considering seagrass transplantation. Such guidelines provide detailed considerations regarding costs and strategies before, during and after transplanting activities, i.e. donor and recipient site selection, transplanting procedure and monitoring of success rates.

Several interests may find expression in restoration programs:

- Introduction of seagrasses into areas that have been denuded of seagrasses and are far away from donor populations
- Speeding up of seagrass recolonisation in areas where it is proceeding already, but at a slow rate.
- Increase of species diversity in sites that have historically supported a diverse array of dense plant populations.
- Improvement of the genetic material in seagrass populations.
- Education of the general public as to the relevance of seagrasses.

Transplanting to sites in which environmental conditions approach those of the donor site as much as possible is the most obvious way to improve the survival chances of the transplants. Furthermore, recipient sites should preferably have supported seagrass in the past. Before any transplantation is performed, it is therefore essential to examine if the environmental conditions can meet the requirements for plant growth and survival (see chapter 4). Among factors to be considered are requirements such as light availability, water turbidity, nutrient levels, sedimentation rate and nature, sediment type and quality (contents of sand and organic matter, sulphide and oxygen conditions), sediment stability (erosion or siltation), current intensity, wave exposure, water depth, temperature and salinity and potential herbivore pressure. If the required environmental conditions can be met, sites considered for restoration should always be tested by experimental plantings to ensure that both environmental conditions and plants are adequate before any major restoration projects are implemented.

Lack of genetic diversity is thought to make populations more uniformly susceptible to diseases and other disturbances. It has indeed been shown that transplanting a genetically diverse population of i.e. Posidonia oceanica increase the chances of survival and genetic data can thus be useful to avoid transplanting shoots that actually belong to the same genetic individual, i.e. shoots from one clone.

Although information on the local adaptation of seagrasses is still limited, recent information is now available on the genetic similarities across geographically widely distributed populations of all European seagrass species. This information can be useful when selecting populations from which to transplant or restore seagrass beds. Adaptation of seagrasses to their specific environment is reflected in their genetics. The information on genetic structure of European seagrasses obtained in the M&M's project and other works can therefore be a useful tool also for determining recommended maximum distances between donors and recipients.

Transplantation of eelgrass (*Zostera marina*)

Eelgrass is the plant species that has been transplanted most widely in coastal areas. Back in the early 1940s, the first attempts were made to mitigate the massive losses resulting from the eelgrass wasting disease in the Northern Hemisphere. Since then, much effort has been invested in developing different techniques for eelgrass transplantation in particular in USA.

Transplantation of plant material

By the "Plug Methods", plugs consisting of seagrass and attached sediment are harvested using core tubes of various sizes. Plugs are extracted from the donor bed and transported within the tube to the planting site. At the planting site, another hole must be made to accommodate the planting plug.

By the "Staple Method", plants are dug up using shovels. The sediment is shaken from the roots and rhizomes. Groups of plants are then attached to staples by inserting the root-rhizome portion of the group under the bridge of the staple and securing the plants with a paper-coated metal twist-tie. The staples are inserted into the sediment so that the roots and rhizomes are buried almost parallel to the sediment surface, as they occur in nature.

In the "Peat Pot Method", sediment blocks are removed as when using the plug methods. A 3x3-inch sod plugger is used as a standard to cut plugs from existing beds. The sediment-plant plugs are then extruded into peat pots, which are subsequently installed in the donor sediment. Once in the sediment, the sides of the peat pot should be ripped down to allow rhizomes to spread.

TERFS (Transplanting Eelgrass Remotely with Frame Systems) is a modification of the staple method. Several eelgrass shoots are attached with biodegradable paper ties to a metal frame, which is lowered into the water until it rests on the bottom. Once the eelgrass has rooted and the paper ties have dissolved, the metal frames are retrieved.

Transplantation of seeds

Several experiments have tested the use of eelgrass seeds for restoration purposes. This technique has the advantage that the impact on the donor population is minimised, and working with seeds may also be less laborious and time-consuming.

Normally, seeds are harvested by manual collection of mature reproductive shoots from established beds when seeds are being released from the flowing shoots. Shoots are then maintained in large flow-through tanks until the seeds are released from the shoots, after which seeds can be kept in tanks under ambient conditions until use. It has been reported that several divers jointly collected up to 30,000 seeds per hour, thus obtaining a large amount of seeds through relatively low effort.

Several seed planting techniques have been tried out. The seeds must be broadcasted before the onset of natural seed germination, the time of which may vary from latitude to latitude. Seeds have been broadcasted by hand, either from a boat or while wading in shallow water. The seeds are relative heavy and therefore sink to the sediment surface and are rapidly incorporated into the sediment very close to where they were broadcasted. However, the number of seedlings resulting from such broadcasting experiments have been very low, because seeds are either washed out, fail to germinate or are consumed by predators.

Attempts to protect the seeds by planting 15-20 seeds in 5x5x5-cm peat pots did not improve the results. The peat pots were held in greenhouse tanks until after seed germination and then planted in the field. The peat pots were, however, susceptible to being washed out during periods of high wave activity.

The most successful of the experimental seed planting methods is a technique by which seeds are placed in 1-mm burlap bags (5x5 cm) before planting. The burlap bags protect the seeds from potential predation and minimise burial and/or lateral transport.

Success of Zostera marina transplantation activities

A compilation of data on planting unit survival from 53 reports published in the USA showed a mean percentage planting unit survival of 42% after app. one year. The survival rates may vary considerably with the planting methods applied, but in general many of the planting units are lost, a fact that must be taken into account in the planning of transplantation projects concerning *Zostera marina*.

Transplantation using *Zostera marina* seeds has not been very successful. In several experiments carried out in the USA, less than 10% of the broadcasted seeds germinated and formed seedlings and the density of the seeds did not influence those results. Seeds from eelgrass are very exposed to predation, and measures must be taken to prevent the seeds from disappearing when broadcasted on bare sediment. Furthermore, survival of eelgrass seedlings may be very low, and the low percentage germination and limited initial seedling success are the major challenges facing future research directed at making transplantation of *Zostera marina* economically feasible and environmentally successful.

Transplantation of *Zostera noltii*

Experience in transplanting *Zostera noltii* is very sparse compared to *Zostera marina*. Vegetative transplantation of *Zostera noltii* can be achieved relatively easily at low tide, and *Zostera noltii* has been transplanted successfully i.e. on the mud flats of Southeast England and in the German and Dutch Wadden Sea. The experiments demonstrated that bioturbating infauna like lugworms may prevent growth of transplanted *Zostera noltii* and that the strong hydrodynamics may reduce the density of meadows.

Laboratory experiments have demonstrated that the seeds of *Zostera noltii* potentially have a high germination rate. At a low salinity of 1 ppt and a temperature of 10^{o}C up to 70% of the seeds germinated under laboratory conditions. However, less than 3% of the plants survived seven days at ambient laboratory temperatures. Thus, much research is needed before the use of *Zostera noltii* seedlings in transplanting experiments is considered.

Transplantation of *Posidonia oceanica*

Posidonia oceanica, the endemic and most widespread seagrass along the Mediterranean coasts forms extensive meadows, thousands of years old, at between 0.5 and 40 m depth. Due to the extremely slow rhizome growth rate of this species (1-6 cm/year) natural meadow recovery takes place on a time scale of centuries. This fact alone motivates artificial acceleration of recovery through transplantation. However, for a major transplanting programme to be implemented, thousands of plants are needed, and the slow growth rates of the plants therefore introduce the added problem of source material. If plants are to be supplied in the form of vegetative cuttings, collection of donor plants should be distributed in as many meadows as possible to avoid serious impacts on donor beds.

It is recommended that plant material be obtained on an intra-basin scale. The consequences of mixing Eastern and Western Mediterranean plants, which differ with respect to genetic as well as anatomic characteristics, are still unknown. When choosing donor meadows, the main factors to take into account seem to be environmental health (high rhizome reserves), genetic diversity (heterozygosity and number of alleles) of donors and depth of collection with respect to the trnaplnat site. Plants transferred from lower to higher water depths have a very low survival success while plants from relatively deep water may survive in shallow waters.

Survival rates of *P. oceanica* transplants and seedlings are highest on “dead-matter” reefs, that is structures formed by *P. oceanica* meadow growth over millennia. Those reefs consist of a framework of dead rhizomes and sediment particles that persist years after the disappearance of the *P. oceanica* meadow. Transplants do not survive for long on pebbles or gravel but may develop on rocks covered with epiphytes if currents and waves are sufficiently weak.

Transplantation of plant material

Horizontal rhizomes with an apex and two lateral branches constitute the most active parts of the plants for spatial colonisation (see chapter 3) and are therefore the best vegetative material for transplants of *P. oceanica*. However, as horizontal apexes are less abundant and more vital to donor meadows, vertical shoots can be chosen as alternative transplants. Furthermore, survival rates of vertical shoots are virtually the same as those of horizontal rhizomes, if the vertical shoots bear

Table 13.1. Suggestion for a monitoring programme to measure the success of *Posidonia oceanica* transplantation in the Mediterranean

	Beginning	After some years
Basic parameters	Survival Shoot formation Rhizome elongation Root production	Cover Shoot density Patch size
Frequency	Year 1: every 4 months Years 2 & 3: every 6 months Years 4 & 5: once a year	Until patch coalescence or targeted cover and density : visits every 2 or 3 years
Ecological parameters	Biotope: water turbidity, sedimentation rate, sediment granulometry, organic content and oxic level Biocenosis: composition and abundance of epiphytes on leaves and of associated fauna and flora	
Frequency	At least three times during the project: (1) before transplanting (2) intermediate stages (species-dependent) (3) end of project (when targeted cover is obtained)	
Monitoring item	**Parameter**	**Frequency**
Individual plants	Survival Shoot formation Rhizome elongation Root production	Year 1: every 4 months Years 2 & 3: every 6 months Years 4 & 5: once a year
Plant population	Cover Shoot density Patch size	Until patch coalescence or desired cover and density: every 2 or 3 years
Biotope	Water clarity Sedimentation rate Sediment granulometry Organic content Oxic level	At least 3 times during the project: (1) Before transplanting (2) Intermediate stages (species-dependent) (3) End of project (when desired cover is reached)
Biocenosis	Leaf epiphyte composition and abundance Associated flora & fauna	

two leaf bundles. One year after transplantation, most double vertical shoots spontaneously switch to horizontal growth and thus become more active in spatial colonisation.

Some vegetative shoots are naturally detached from meadows by storms, and such shoots have been used successfully as transplant material. The use of detached vegetative shoots does not impact donor meadows and the plant material is available throughout the year. To serve as transplant material, detached shoots should have at least one leaf bundle and show good signs of vitality. The rhizome fragments of the shoots should be at least 8-12 cm to provide sufficient nutrient reserves and antibiotic substances, which is present in the rhizomes, to protect the plant.

Shoots attached to plastic or nylon nets (of 25x25cm or 60x17 cm, 1cm^2 mesh), which in turn are attached to the substrate with metal sticks have been used successfully to transplant vegetative fragments or seedlings of *P. oceanica* in the Mediterranean Sea. Seedlings were protected with cheese clothes before being attached to the nets. The spacing between plants has ranged from 3 to 17 cm, respectively, in different transplanting experiments, resulting in similar rates of success.

Rhizomes secured between two pieces of superposed wire netting on rectangular concrete frames (0.07 m^2) have also been transplanted with success. These frames are easy to handle and could reduce the transplanting cost since they can simply be lowered from the boat and do not need any attachment to the sediment. However, they are not recommended on soft, muddy bottoms, because these heavy structures may sink into the sediment, where the transplants would be unable to survive.

Horizontal growth of *P. oceanica* plants is straightforward at first with low branching angles (see chapters 3 and 10). Therefore, it is be best to arrange the plants within a planting unit with apexes and leaf bundles facing away from the centre of the unit, so that growth can take place more efficiently from the centre outwards.

Transplantation of seedlings

P. oceanica does not flower every year and seeds do not enter into dormancy, which means that a seed bank is not established below the plants. However, some meadows reproduce sexually more frequently than others – on average every second year. Further, widespread flowering and fruiting occurs especially in years following exceptionally high summer temperatures. Information on such meadows and on temperatures allows planning of seed collection. Fruits of *P. oceanica* float and seeds or seedlings can easily be collected in great numbers along the coasts in spring and summer. The seeds germinate very well in tanks containing seawater (70-80% germination success), where they can survive and grow under suitable conditions and thus make up a plant nursery for later transplantation.

Success of P. oceanica transplantation activities

The first year after transplantation is crucial for the survival of *P. oceanica* plants, as they must acclimate and establish roots during this time (Balestri *et al.* 1998). The best time of the year to transplant *P. oceanica* plants is in late winter after the severe autumn and winter storms have passed. The most active growth period of *P. oceanica* is from February to May, and the plants are therefore able to produce roots and anchor into the sediment before the next stroin autumn storm. Seedlings, in contrast, must be planted in June-July, after collecting the seed and seedlings from March to July. Collected seeds must germinate and the seedlings are preferably kept to grow at least two months in an aquarium before being transplanted.

Large-scale transplanting (1 ha) of vegetative shoots detached from meadows by storms was performed in the Bay of Cannes in 1984 with concrete frames. Ten years later, the plant-covered area had increased by a factor of seven and the number of shoots had increased nine times. The plants formed oblong islets with numerous running rhizomes indicating active colonisation.

However, epiphyte growth on leaves of transplanted plants was three times higher compared with leaves of adjacent non-transplanted meadows. This phenomenon may be density-dependent and destructive to the plants, since considerable epiphyte growth may lower the photosynthetic efficiency of the plants and attract grazers that might damage the transplants.

Pilot studies have shown that *P. oceanica* seedlings transplanted onto “dead matter” have high survival rates (70%) after three years. However, seedlings seem to be less capable of developing branching shoots compared with transplanted vegetative fragments – at least in the short term. Thus, after three years from transplantation, 87% of the vegetative transplants showed branching growth while this number was only 14% for seedlings.

Transplantation of *Cymodocea nodosa*

Experience in transplanting C. nodosa is very limited. Experiments in the southern basin of the Lagoon of Venice have demonstrated that C. nodosa can be transplanted successfully and that the performance of transplanted meadows after only two vegetative seasons were similar to those recorded in a natural meadow.

New thoughts may be considered

Transplantation of seagrasses is a laborious and expensive activity. The costs of transplanting are, of course, site and method specific and may vary dramatically. The price for a transplantation project in New Hampshire, USA, was approximately 250,000 Euro per hectare in 2002 prices. The costs may, however, be considerably higher depending on several factors, such as the need for SCUBA divers (depending on water depth), cold-water planting, soft sediment, low visibility, high disturbance or actual loss of transplanted material (e.g. due to bioturbation, rough seas etc.), which may necessitate replanting.

In addition, survival rates of both vegetative and seed transplants are still rather low and collection of material from existing meadows may affect the donor meadows negatively. This is especially the case when harvesting of vegetation for transplantation purposes leaves bare patches, which are susceptible to erosion. For slowly spreading species like *Posidonia*, such patches may stay bare for many years. Collection of seeds from a population may also be critical, as natural seedling recruitment may be necessary to ensure meadow vitality in the long term. Furthermore, however carefully donor plants are freed from the sediment, some damage to belowground plant components is inevitable, which may weaken the donor plants and lead to lower transplantation success. Thus, using vegetative shoots that have been naturally detached from existing meadows or collecting floating seeds that have washed up at the coast seems to be the least destructive way of obtaining plant material for restoration purposes. In this light, more research should be applied to the development of laboratory-cultured plants for restoration efforts.

Assessment of transplantation success requires monitoring of the restored site, preferably for several years, and may therefore also be lengthy and costly. The monitoring survey may vary from species to species and from latitude to latitude. In Table 13.1, a monitoring programme for evaluating the success of *Posidonia* transplantation is suggested.

Increased public understanding of the ways in which conditions for seagrasses in coastal waters can be improved is essential. To achieve this goal, closer collaboration between scientists, managers and the general public must be obtained. In the USA, both management and environmental groups have now developed activities directed towards primary and secondary school children. The school groups are provided with necessary materials for raising species of seagrasses in the classroom and are later assisted in transplanting the plants into appropriate habitats.

"Xarxa de Vigilancia de la Posidonia" is the name of a new project with a similar goal that is being established in the Mediterranean. When seeds from *Posidonia* become available around Mallorca and the Balearic Islands, a large number of volunteers can be requested at short notice to collect the seeds. The seeds are then transferred to nursery greenhouses for germination and the seedlings are later transplanted to areas where a new population is needed. The help provided by numerous volunteering divers not only makes the project economically feasible, but also has a very important educational aspect, the objective being to create a much wider public understanding of the importance of protecting existing seagrass covered areas in whichever way possible.

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