Estuarine, Coastal and Shelf Science 79 (2008) 289–299

Contents lists available at ScienceDirect

Estuarine, Coastal and Shelf Science

journal homepage: www.elsevier.com/locate/ecss

Transplantation as a method for restoring the seagrass *Posidonia australis*

G.R. Bastyan, M.L. Cambridge*

School of Plant Biology M090, The University of Western Australia, 35 Stirling Highway, Crawley, WA 6009, Australia

ARTICLE INFO

Article history:
Received 24 August 2007
Accepted 9 April 2008
Available online 26 April 2008

Keywords:
seagrass
transplantation
restoration
rhizomes
Posidonia australis

Regional index terms:
Southwestern Australia
Albany
Oyster Harbour
Princess Royal Harbour
35°04′S, 117°55′E

ABSTRACT

Transplant trials of the seagrass *Posidonia australis* were carried out after loss of seagrasses following eutrophication and increased turbidity in two marine inlets on the south coast of Western Australia. A pilot study in Oyster Harbour measured survival and growth *in situ* for 4 years. Long-term survival rates were high (96–98%), providing plants were anchored into the sediment. All unanchored plants were lost in the first winter. Following the success of the pilot study, a more comprehensive program began 3 years later with over 500 transplant units collected from either actively growing edges of nearby patches (plagiotropic growth form) or within established meadows (orthotropic growth form). Transplant units from edges expanded at a faster rate compared to units from mid-meadow but increases in shoot numbers were similar. Growth rates in the first 2.5 years averaged 10–20 cm yr^{-1} horizontal rhizome extension, depending on the source of the transplant units, and 4–12 shoots per initial shoot yr^{-1}, depending on the initial shoot number of the transplant unit. After 5 years, shoot numbers of individual transplants were similar to shoot densities recorded for natural meadows, >500 shoots m^{-2}. Approximately, 10% of transplants from mid-meadow flowered in the first year, whereas transplants from edges flowered only after 5 years.

Transplant trials were also established in nearby Princess Royal Harbour at a site selected to test the effect of disturbance by bioturbation from large sand-burrowing worms or by sediment erosion. Survival was lower than in Oyster Harbour, 75–89% in areas with bioturbation but only 14% in areas where sediments were eroded. Growth was poor, <1–2 shoots per shoot yr^{-1} with high shoot mortality, and low rates of increase in rhizome length, <5 cm yr^{-1}. In areas affected by worm bioturbation, there was almost no horizontal expansion of plants because rhizomes grew vertically to keep pace with sediment deposition.

This study showed that *Posidonia australis* could be transplanted with a high degree of success into a protected embayment previously vegetated with seagrass meadows. After 4 years, flower and seed production had occurred, and transplants spaced 1 m apart began merging. By the fifth year, individual transplant units could no longer be distinguished and planted areas resembled a natural meadow. These findings have important implications for restoration of impaired *Posidonia* habitats in Australia, using conventional low-cost techniques for transplantation once the sources of injury have abated.

1. Introduction

Seagrass communities play a major role world wide in the marine ecology of coastal and estuarine areas, supporting fish, shellfish and invertebrate communities (Orth et al., 1984; Bell and Pollard, 1989; Howard et al., 1989; Heck et al., 1995; Lemmens et al., 1996). Major losses have occurred, usually due to eutrophication or turbidity from industry, dredging or catchment run-off, as well as natural disturbances (Cambridge and McComb, 1984; Cambridge et al., 1986; Walker and McComb, 1992; Short and Wyllie-Echeverria, 1996; Seddon et al., 2000; Kendrick et al., 2002). Once seagrass cover is lost, recovery may take decades, particularly for slow-growing species with no seed bank (Hastings et al., 1995; Kendrick et al., 2000; Meehan and West, 2000, 2004; Cambridge et al., 2002) in contrast to faster growing species with a seed bank (Olesen and Sand-Jensen, 1994). Loss of seagrass habitat and evidence of slow regeneration times have provided the impetus for investigating restoration of seagrass habitat. Here we report on a long-term study, which examined the feasibility of transplanting the seagrass *Posidonia australis* Hook. *f.* to restore degraded seagrass meadows on the south-west Australian coast. *Posidonia australis* forms extensive meadows on sheltered coasts and in estuaries, and is the most widespread of the Australian species of *Posidonia*, occurring around the southern temperate half of Australia to the edge of the tropics (Cambridge and Kuo, 1979; Short et al., 2001).

* Corresponding author.
E-mail address: mcambr@cyllene.uwa.edu.au (M.L. Cambridge).

0272-7714/$ – see front matter © 2008 Elsevier Ltd. All rights reserved.
doi:10.1016/j.ecss.2008.04.012

Between the mid-1960s and 1988, some 80% of the seagrass cover was lost from Oyster Harbour and Princess Royal Harbour, two marine inlets on the south coast of Western Australia (Hillman et al., 1991). Early records of Oyster Harbour in 1960 describe luxuriant stands of *Posidonia australis* to a depth of 8 m (McKenzie, 1962). Clearing for agriculture occurred over much of the Oyster Harbour catchment in the mid-1960s, and phosphatic fertilizers were applied routinely to broad-acre pastures to supplement the extremely P-deficient soils (Weaver and Prout, 1993). Phosphorus loading was particularly high in 1981 and 1988 with high river flows after a prolonged dry period carrying sediments and nutrients into Oyster Harbour. Phosphorus, not nitrogen, is considered as the critical limiting element to plant growth in south-west Australian estuaries. Proliferation of epiphytic algae and the macroalga, *Cladophora prolifera* (L.) Kutz. occurred after the increase in phosphorus loading, followed by extensive dieback of seagrasses in Oyster Habour (Hillman et al., 1991). By the mid-1990s, following improved catchment management and a series of drier years with reduced run-off, minor recovery was reported on shallow sand banks (Bastyan et al., 1996). Seagrass loss in Princess Royal Harbour occurred over a similar time but was due primarily to point-source release of nutrients from industrial and urban sources, followed by turbidity from harbour dredging (Hillman et al., 1991; Gordon et al., 1994). Subsequent reduction of nutrient inputs improved conditions sufficiently to allow some recovery of seagrasses (Bastyan et al., 1996).

The first serious efforts to use transplanting for restoration date back to work in Florida in 1960, and there have been many attempts since to establish seagrasses with varying degrees of success (Fonseca et al., 1998; Hemminga and Duarte, 2000). Most projects resulted in the creation of relatively small areas at the scale of 1–10 ha rather than hundreds of hectares. Poor site selection has been identified as the major limitation on survival of transplanted seagrass (Harrison, 1990; Fonseca et al., 1998; Short et al., 2002). This encompasses a number of physical and biological factors which have been reviewed in detail by Short et al. (2002), including excess water movement, bioturbation by burrowing organisms (Harrison, 1987; Fonseca et al., 1994, 1996; Philippart, 1994; Molenaar and Meinesz, 1995), reduced light (Zimmerman et al., 1995), and poor water quality promoting excess epiphytic algae, drifting macroalgae or phytoplankton blooms (Cambridge et al., 1986; Short et al., 1995; Valiela et al., 1997; Hauxwell et al., 2001).

Fast or slow growth rates and associated morphological traits influence both success and methods of transplanting. Methods for vegetative propagation have been developed for only a few seagrass species, and usually for few of the habitats in which seagrasses occur. Most methods involve manual planting of vegetative shoots with attached rhizome sections, either free of sediment (sprigs or bare root cuttings) or with sediment intact (plugs, turfs or sods), usually with some form of anchoring (Kirkman, 1989, 1998; Davis and Short, 1997). Mechanical transplantation is still rare with the most notable involving a large harvesting and planting machine designed to improve transplant success in areas exposed to strong wave movement (Paling et al., 2001a,b).

Posidonia australis grows from underground stems, termed rhizomes, with leaf-bearing shoots at the rhizome apices. New shoots are produced by branching at the rhizome apex, and growth over several years usually results in a large, clonal plant with each of the leaf-bearing shoots connected by the branched rhizome. Rhizomes growing at expanding edges have a horizontal growth form with longer internodes, more rapid lateral expansion and widely spaced shoots, whereas rhizomes in the center of dense beds typically have short internodes, compact habit and crowded shoots, leading to vertical growth. The differing growth forms have been termed "plagiotropic" for the horizontal form and "orthotropic" for the vertical form by Molenaar et al. (2000) in their studies of *Posidonia oceanica*, and later by Meehan and West (2000, 2002) for *P. australis*. In this paper, we use these terms interchangeably with the position transplants were collected from, either edges or centers [mid-meadow] of donor beds.

Studies on transplanting *Posidonia* were first made in the French Mediterranean with *Posidonia oceanica* (L.) Delile, including pioneering work by Cooper and others (Meinesz et al., 1992). Later work tested the effects of plagiotropic or orthotropic shoot morphology, plant spacing and orientation of planting units (Molenaar et al., 1993; Molenaar and Meinesz, 1995), and effects of transfer to different depths (Molenaar and Meinesz, 1992; Genot et al., 1994), planting season, length of rhizome and differences in the initial number of shoots (Meinesz et al., 1992) and substrate type (Molenaar and Meinesz, 1995). Survival rates after 3 years ranged from 40 to 85% for plagiotropic shoots and from 25 to 73% for orthotropic cuttings at depths from 3 to 11 m (Molenaar and Meinesz, 1992, 1995; Meinesz et al., 1993; Piazzi et al., 1998). On the Italian coast, trials with *P. oceanica* were carried out at a site where industrial and sewage pollution had been reduced, with survival and growth investigated for transplants taken from different geographical locations and planted at 3 depths (Piazzi et al., 1998). These trials were also notable for flowering, which occurred on 5.5% of all transplants but only orthotropic rhizomes developed mature fruits. From these small-scale but comprehensive trials in the Mediterranean, which concentrated on investigating conditions and procedures for larger scale transplanting, it was evident that transplanting did not replace lost meadows but could usefully enrich zones where seagrass had been destroyed, such as pipeline scars and shoreline developments. Transplantation was most successful on areas of dead *Posidonia* "matte" (Molenaar and Meinesz, 1995). In general, transplantation is most likely to succeed where the original cause of decline has abated (Fonseca et al., 1998).

In Australia, despite regional losses of temperate seagrass related to nutrient enrichment and coastal development, restoration of seagrass habitats has not been widely explored. Reports of slow natural recovery, even in healthy meadows as a result of very low rates of rhizome growth and seedling establishment for *Posidonia* spp., led to pessimistic forecasts of transplant success (Kuo and Kirkman, 1996; Kirkman, 1998) borne out by the fact that no restoration program has yet succeeded in increasing the amount of seagrass habitat. Meehan and West (2000, 2004) estimated that *Posidonia australis* meadows would take about 100 years to grow over a series of circular gaps in the course of natural recovery. Small-scale transplanting experiments on the east coast of Australia have had limited success, leading to the conclusion that *P. australis* was difficult to transplant (Larkum and West, 1983; West et al., 1990). More recent testing of larger planting units of *P. australis* rhizome sections, attached to wire grids at a range of estuarine habitats near Sydney, resulted in good growth at one site over 18 months but high mortality at other sites (Meehan and West, 2002).

The main objective of this study was to assess the feasibility of transplanting *Posidonia australis* in areas once vegetated by seagrasses in Oyster Harbour, following improvement in conditions which caused the original loss of seagrass. Field trials were carried out over more than 8 years, beginning with a pilot study in Oyster Harbour to test the need for anchoring planting units. The success of the pilot study prompted a second, more comprehensive series of trials at the same site 2 years later to assess whether results for survival and growth were repeatable and to compare growth of planting units taken from the edges versus centers of seagrass stands (plagiotropic versus orthotropic growth forms). Another study site at nearby Princess Royal Harbour was established to assess two factors that have been identified as major causes of transplant failure, worm bioturbation and erosion of sediment by water currents. Observations of *P. australis* suggested that most growth occurred during spring and