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Photosynthetic recovery of transplanted *Posidonia sinuosa*, Western Australia

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ABSTRACT

Changes in photosynthetic activity during transplantation of *Posidonia sinuosa* Cambridge et Kuo, from Cockburn Sound, Western Australia, were assessed using a Diving-PAM fluorometer. Two transplantation methods, sprigs and plugs (5, 10 and 15 cm diameter) were examined and photosynthetic activity was compared before, during and after transplantation. Maximum electron transport rate (ETR_{max}) of transplanted sprigs took 1–2 months to increase to the same level recorded at a control meadow, primarily due to desiccation stress suffered during transport. Effective quantum yield ($\Delta F/F'_m$) of sprigs decreased below 0.2 after transplantation, but fully recovered after 3 months and the ETR_{max} of transplanted plugs took up to 1 week to recover to control meadow values. Once transplanted, the survival of sprigs was reduced due to strong currents and heavy epiphytic fouling, while that of plugs declined due to winter storms and swells. Since the leading human-controlled cause of transplant stress was desiccation, future rehabilitation efforts may be improved by keeping seagrasses submerged at all times during the transplanting process.

1. Introduction

A variety of methods have been used to transplant and restore seagrasses (Phillips, 1990; Fonseca et al., 1996; Orth et al., 1999; Paling et al., 2001). All methods result in their handling but little is known about the physiological effects of this manipulation or the recovery process when plants are placed in new environments. Similarly, the use of chlorophyll fluorometry to assess the photosynthetic responses of transplanted seagrasses has been limited. Durako et al. (2003) used reciprocal transplants to evaluate photosynthetic patterns, using PAM fluorometry, in two *Halophila* species in Florida. They noted that *H. johnsonii* possessed UV-absorbing pigments (UVPs) which, together with a tolerance to higher irradiances, allowed this species to exploit shallow habitats without competition from *H. decipiens*, which lacks UVPs and experiences a high mortality. Figueroa et al. (2002) also used fluorometry on transplanted *Posidonia oceanica* in southern Spain to examine the effects of solar radiation on photosynthesis. They concluded that this species seemed acclimated to high solar irradiance and that UV radiation triggered the induction of photoprotective mechanisms.

This study investigated the variation in photosynthetic performance of *Posidonia sinuosa* occurring during two methods of transplantation. The specific aims were (a) to examine changes in photosynthetic rates (maximum electron transport rate (ETR_{max}), effective quantum yield ($\Delta F/F'_m$) and potential quantum yield (F_v/F_m)) of sprigs and plugs during the process of removal, transport and planting; (b) to determine if sprigs and plugs recovered to the same photosynthetic rate as naturally occurring seagrasses at the same sites; (c) to estimate the time required for full photosynthetic recovery; and (d) finally, to assess the long term survival of the sprigs and plugs.

2. Methods

2.1. Sprig transplantation at Southern Flats

This study was part of a large restoration exercise in Western Australia involving the transplantation of 1.5 ha of *P. sinuosa* sprigs between November 2004 and February 2005 (Paling and van Keulen, 2004). Donor material was collected from 5 to 7 m depth at Parmelia Bank (S 32°08.097′, E 115°42.387′) and transplanted 20 km to the south at a depth of 2–4 m at Southern Flats (S 32°15′, E 115°43′).

Sprigs (rhizomes with attached leaves and roots) were excavated from the edge of the donor meadow, brought onto a boat and stored in seawater-filled containers. During transport to

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the recipient site (taking up to 2 h), the sprigs were removed from the containers and the rhizomes tied to wire staples with biodegradable twine. Sprigs were emersed for up to 15 min during the tying process and then returned to seawater until ready to plant. Upon arrival at the recipient site, sprigs were transferred to free-draining crates to enable underwater transport. As not all crates could be used underwater at once, some remained on the boat for up an hour, covered with wet calico bags while awaiting deployment. Transplantation took place on three occasions in spring and summer, each consisting of four consecutive days (November 8–11, December 6–9 and February 14–17). *In situ* fluorescence measurements were made between 08:50 and 16:40 h each day on *P. sinuosa* plants before removal from Parmelia Bank, on sprigs tied onto wire staples and stored during transport, on sprigs after deployment at Southern Flats and on control *P. sinuosa* plants naturally occurring near the recipient site. Sprigs transplanted on previous days were remeasured. During March and May 2005, fluorescence measurements were made on the transplanted sprigs and control *P. sinuosa*.

Measurements were collected with a Diving-PAM fluorometer (Heinz Walz GmbH, 1998) using SCUBA. One leaf per sprig was dark-acclimated for 6 min (Horn, 2006), followed by a saturating pulse, giving an F_v/F_m measurement. Light-acclimated $\Delta F/F'_m$ and rapid light curves (RLCs) were measured using a pre-installed software routine, where the actinic illumination was incremented in nine steps, each with a duration of 10 s (Heinz Walz GmbH, 1998). An absorptance factor of 0.64 for *P. sinuosa* was used in this study (Horn, 2006), instead of the Diving-PAM's default value of 0.84. RLCs were measured at the base of rank two (second youngest) *P. sinuosa* leaves 40–60 mm from the leaf sheath and leaves were shaded from ambient light during the measurement of RLCs (Horn, 2006). Visible epiphytic growth at the measurement sites was easily removed by rubbing the leaf with a finger. Ten replicate measurements of F_v/F_m, and seven replicate measurements of $\Delta F/F'_m$ and ETR (RLCs) were made at each stage of the transplant process. Ambient underwater irradiance was measured using the Diving-PAM's quantum sensor and was taken as close to the sampling site as possible.

2.2. Plug and sprig transplantation at Woodman Point

Three plug sizes (5, 10 and 15 cm diameter) and one set of sprigs were transplanted at Woodman Point, Western Australia (S 32°08.180′, E 115°44.745′), during February 2005. They were collected from the edge of a *P. sinuosa* seagrass meadow at 2.0 m depth and transplanted into an adjacent area of bare sand 1.9 m deep.

Ten replicate plugs of each size were extracted and planted using the method described by van Keulen et al. (2003). Ten sprigs were collected by removing sections of rhizome with attached roots and leaves and then tying them onto wire staples underwater. Plugs and sprigs were moved underwater approximately 10 m to the recipient site and planted at spacings between 15 and 35 cm (plugs), and 25 cm (sprigs).

In situ fluorescence measurements were made between 08:00 and 11:35 h each day as described above. Ambient underwater irradiance was measured next to the sampling site using the Diving-PAM's quantum sensor. Ten replicate measurements of F_v/F_m, $\Delta F/F'_m$ and ETR (RLCs) were made at each stage of the transplant process; *in situ P. sinuosa* before removal; plug material contained within cores after insertion of the PVC tube into the sediment; excavated plug material waiting to be planted; planted plugs; and transplanted sprigs. These and adjacent control seagrass were measured once a week for 4 weeks and then periodically until July 2005.

2.3. Data analysis

RLC data were fitted to a double-exponential decay function (Platt et al., 1980) to determine ETR_{max}, as described by Ralph and Gademann (2005). ETR_{max}, F_v/F_m, and $\Delta F/F'_m$ were compared before, during and after transplantation using two-way ANOVAs (factors: transplant × time). All assumptions for the ANOVAs were met and when yielding significant results ($p < 0.05$), a post hoc pair-wise comparison of the means was performed using Tukey's HSD test. Analyses were performed using JMP for Windows (Version 6.0, SAS Institute Inc.).

3. Results

3.1. Sprig transplantation to Southern Flats

ETR_{max} of *P. sinuosa* at Parmelia Bank growing at 5–7 m was significantly lower than that occurring at Southern Flats (2–3 m, $F_{13,498} = 10.19$, $p < 0.05$). Parmelia Bank also had lower ambient light levels (197 μmol quanta m^{-2} s^{-1}) compared to the shallower site (544 μmol quanta m^{-2} s^{-1}), however the lowest light levels occurred during transport (Table 1). Although sprigs did show a consistent reduction in ETR_{max} when being transported on the boat, in comparison to values recorded before their removal at Parmelia Bank, this change was not significant in November, December or February (Fig. 1). Similarly, by the time they were planted at Southern Flats, their ETR_{max} was not significantly different. There were however significant differences between the ETR_{max} of newly transplanted sprigs and the naturally occurring meadow at Southern Flats ($F_{13,498} = 10.19$, $p < 0.05$). Sprig ETR_{max} increased to the same level recorded at the control meadow within 2 months (Fig. 1).

$\Delta F/F'_m$ in natural meadows ranged between 0.58 and 0.67 at Parmelia Bank and 0.45–0.66 at Southern Flats. F_v/F_m was also similar at both sites and varied between 0.76 and 0.80 at Parmelia Bank and 0.71–0.84 at Southern Flats. The $\Delta F/F'_m$ and F_v/F_m of the transplanted sprigs did not immediately change after their extraction from Parmelia Bank (Fig. 2). However, by the time they were planted at Southern Flats, $\Delta F/F'_m$ and F_v/F_m had decreased significantly to around 30% (i.e. 0.15–0.29) of their original values ($F_{13,534} = 10.06$, $p < 0.05$ for $\Delta F/F'_m$ and $F_{13,720} = 6.31$, $p < 0.05$ for F_v/F_m). The transplanted sprigs showed significantly lower $\Delta F/F'_m$ and F_v/F_m compared to the control meadow at Southern Flats ($F_{13,534} = 10.06$, $p < 0.05$ for $\Delta F/F'_m$ and $F_{13,720} = 6.31$, $p < 0.05$ for F_v/F_m). Sprig $\Delta F/F'_m$ had increased to values similar to surrounding meadows at Southern Flats within 3 months, as had F_v/F_m.

Heavy epiphytic fouling on sprigs was observed after transplantation and their mean (±S.D.) survival by May 2005 had decreased to 34 ± 3% for sprigs extracted in November, 37 ± 6% for December and 68 ± 16% for February. Sediment erosion had uncovered some of the wire staples resulting in exposed rhizomes with colonising epiphytes but surviving sprigs were producing new shoots and leaf growth up to 1 cm was observed.

Table 1
The ambient light (μmol quanta m^{-2} s^{-1}, mean ± S.D.) at location of rapid light curve measurement at Parmelia Bank, on the boat during transport and at Southern Flats (n = 96–111)

Location	Ambient light (μmol quanta m^{-2} s^{-1})
Parmelia Bank	197.3 ± 140.8
Boat (during transport)	87.2 ± 160.5
Southern Flats	543.8 ± 291.8