ARTIFICIAL TIDAL SYSTEM FOR GROWING MANGROVES

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INTRODUCTION

Mangroves of several species can easily be grown in hydroponics or as pot-plants: at present we have *Aegiceras corniculatum*, *Avicennia marina*, *Bruguiera exaristata*, *B. gymnorrhiza* and *Rhizophora stylosa* in our glasshouses. However the morphology of the root-system in these conditions differs from field-grown plants, and the physiology of aeration of the roots will be different too. During our investigations of root gas-exchange in *Avicennia marina* it became clear that for any real understanding of gas movements in the roots it was necessary to grow the plants under controlled tidal conditions. The main practical reason for this was the need to be able to obtain complete isolated root systems of known age and provenance for physiological studies. To this end we designed a very simple tidal system consisting of a series of pumps and time switches which pumped water between two domestic bath tubs in a cycle which approximated to a tidal cycle, although the fluctuations of water level possible were much less than those naturally occurring even in Sydney. The results obtained with plants from this system, which are reported in detail elsewhere (Curran, 1985; Curran, Cole and Allaway, 1986), were as follows.

Firstly, the pneumatophores and air-spaces had ample capacity to supply oxygen to the roots when they were exposed at 'low tide'. Secondly, the amount of air stored within the root system was adequate to cope with the respiratory demand of the roots during a normal 'high tide' of about 6 hours, keeping the oxygen level high enough for aerobic respiration. Encouraged by these results from the prototype, we then built the large artificial tidal system described in this paper; in this system the movement of water levels can approximate that experienced in estuaries in the Sydney area.

DESCRIPTION OF THE APPARATUS

The system developed consists of two 'fibreglass' tanks approximately two metres square and 900mm deep. These tanks are located side by side with a sunny northerly aspect (Figure 1) and are covered by a framework supporting a 30% shadescreen cover to exclude leaves and other debris falling from nearby trees. Each tank is fitted with a small magnetic drive centrifugal pump so that the contents of one tank can be pumped into the other as required.

The central control of the system consists of a series of time-switches and pressure switches which enable the change of tides to follow a 25 hour cycle so that the time of 'high'

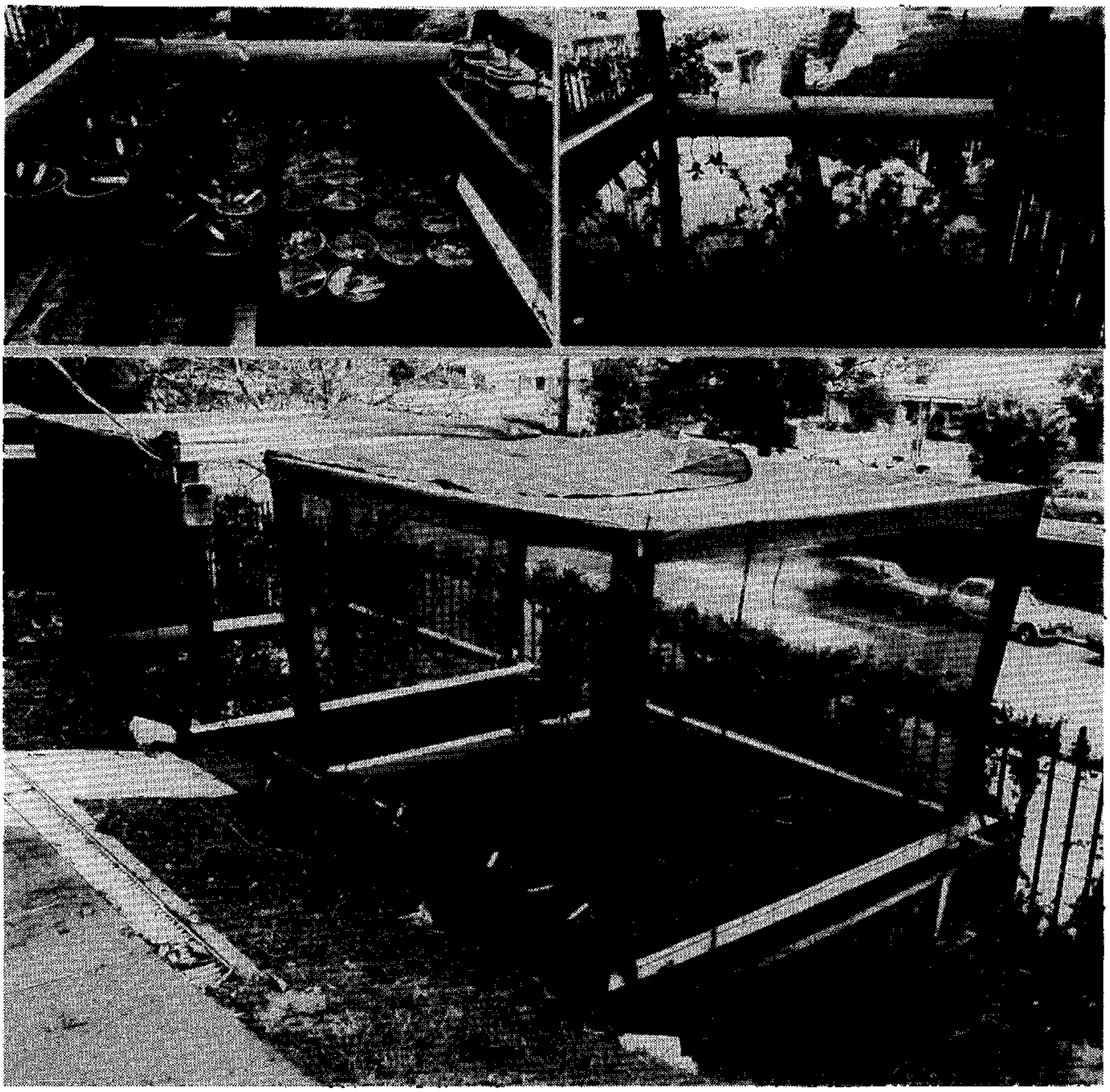

Figure 1.

The upper photographs show one of the tanks at low and high 'tides', and the position of the plants on the shelves. The lower picture shows a view of the whole apparatus; the control box with the clocks and switches is in a building just out of the picture.

and 'low' tides occur at successively later times each day, as with the natural tide. The circuit diagram of the control is shown in Figure 2. Time-switch (1) is an electronic controller (Kambrook KD36) which is set to switch off the power supply to the drive motor of time-switch (2) for 15 minutes every six hours. Time-switch (2) (Paragon Electric Co 4006 21B) is a mechanical drive clock without a spring reserve, in which it is possible to separate the clock drive from the switching circuit. When the two clocks are arranged in this way the second clock will make one complete revolution in 25 hours (sometimes 25¼ hours). This second time-switch is set to switch the electrical supply to either of the two outlets to which the pumps are attached, thus supplying power to each pump alternately. The size of the pumps (Iwaki MD 20R) is such that the transfer of water from one tank to the other occupies about three hours. The completion of the transfer is sensed by a pressure sensitive switch (Hoover part No 026535) which is adjusted so as to interrupt the current to the pump when 15cm of water remains in the tank being emptied. This switch controls the minimum level of water

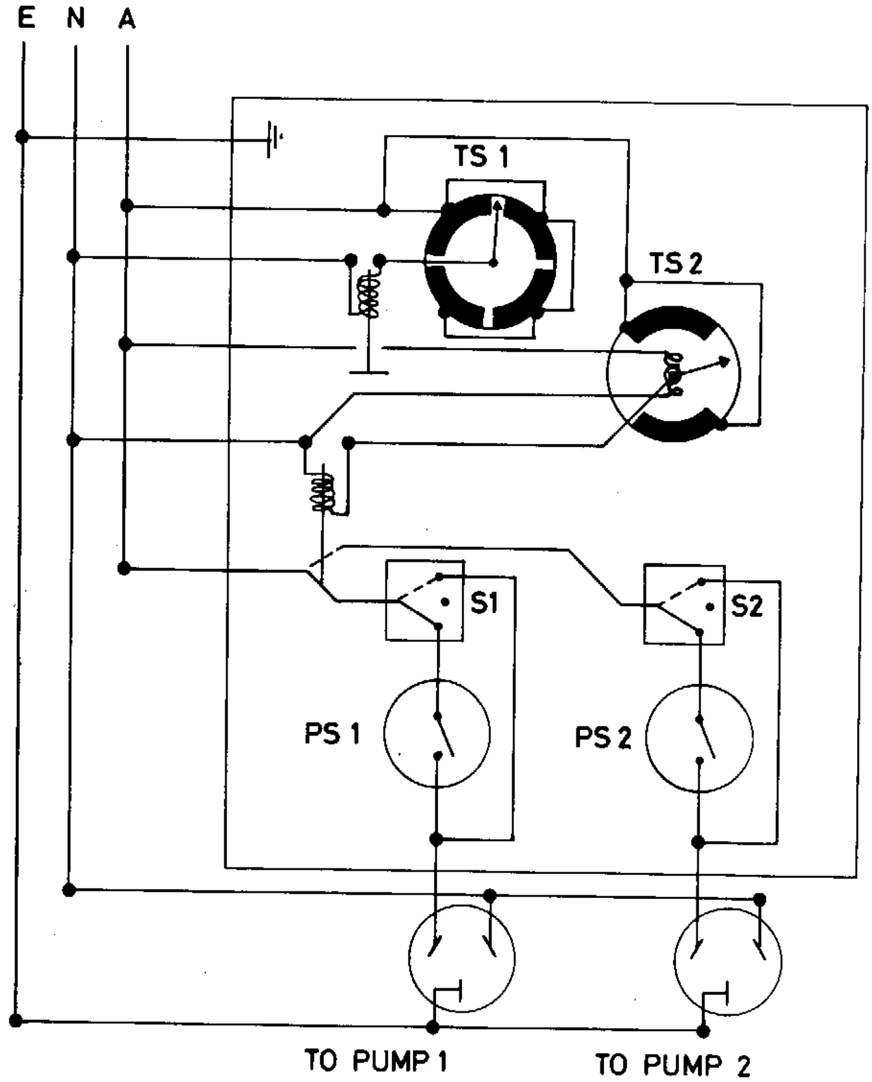

Figure 2. Circuit diagram of the controls. TS1 is the time-switch which switches off (via a relay) the visitor of the second clock (TS2) for 15 minutes every 6 hours, giving an overall cycle of 25 hours. TS2 controls the pumps, switching them on and off alternately through a second relay. S1 and S2 are double-throw switches which allow manual control of the pumps. PS1 and PS2 are washing-machine pressure-switches, one in each tank, which turn the pumps on and off. Pumps 1 and 2, also one for each tank, are connected via the 3-pin sockets shown.

in the tank and prevents the pump from running dry. A degree of flexibility in the use of the system is possible as the duration of the tides in each tank can be varied. If the two ON and OFF pointers on the second time-switch are set symmetrically with a nominal 6 hour interval between them, the length of the 'tide' in each tank will be equal. If the pointers are set, for example, in a pattern so as to give a nominal 5hr-7hr-5hr-7hr cycle then the duration of the tide will be different in each tank: one tank will have long 'high tides' and short 'low tides' (such as occurs at locations between mean sea level and high-water mark). The system is filled with a mixture of seawater and tap water adjusted to a conductivity of 20000 u Siemens cm^{-1} and this conductivity is maintained by the addition of the appropriate component.

The plants within the tanks stand on a series of shelves of different height so that they can be flooded by different depths of water. Using pots 25cm high it is possible in these tanks to position plants so that soil level is covered by depths of water between zero and seventy centimetres. Using pots with bottom drainage it is also possible to arrange for plants to experience periods of tidal wetting of the roots without the surface being covered by water. The pots are tied down to their shelves with stainless steel wire clips: this is necessary to avoid the larger plants being blown over by the wind at 'high tide' because the weight of the pot is so much reduced when submerged (see Archimedes c. 250 BC).

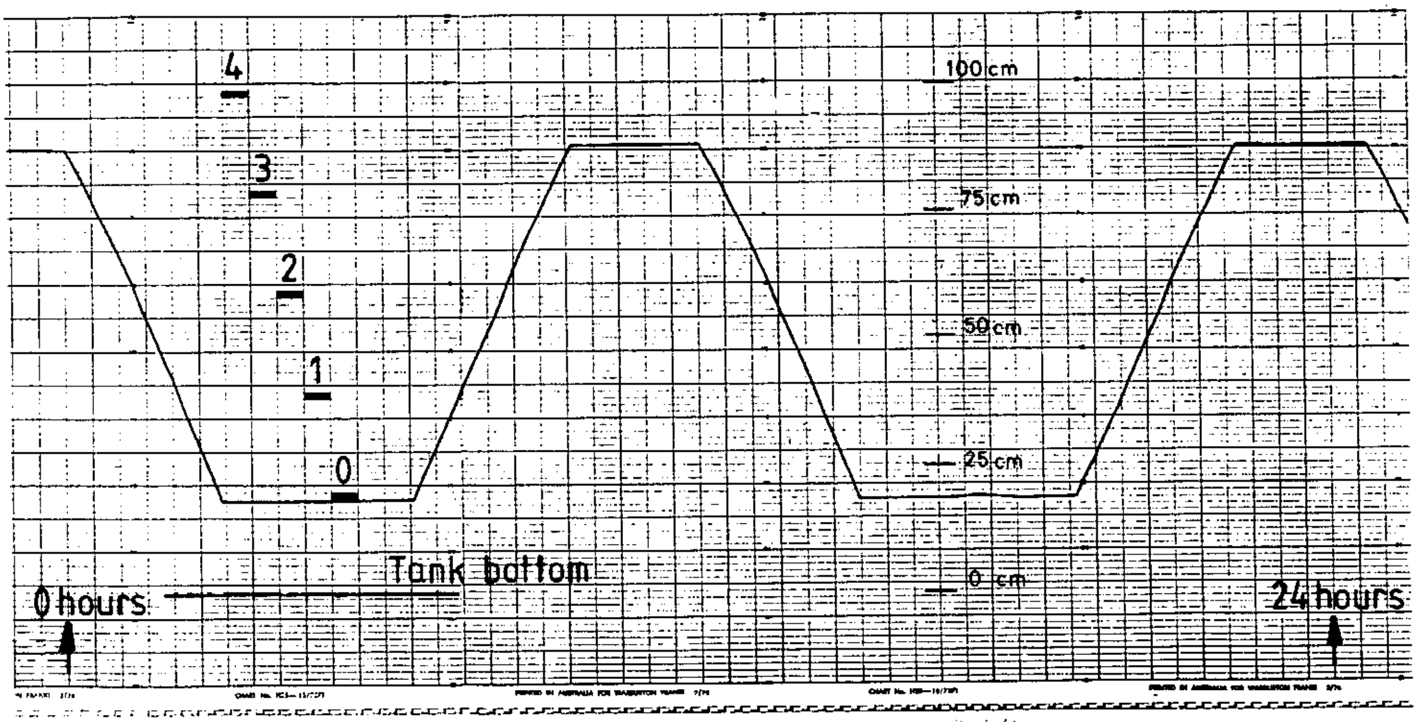

Figure 3. Chart record of a pressure transducer showing the changes in depth in the Eastern tank during a nominal 25-hour cycle of the experiment described in Table 1. Note the different duration of 'high' and 'low tide' which can be altered by changing time-switch (2) as described in the text. Levels 0, 1, 2, 3, and 4 show positions at which maximum flooding depths of 70, 50, 30, 10 and -10cm respectively occur in this tank (see description in the text and Table 1). The vertical scale shows centimetres above the bottom of the tank. The changes in level in the Western tank are the converse of those shown here.

RESULTS AND DISCUSSION

Changes in water depth, measured with a pressure transducer installed at the bottom of one of the tanks, are shown in Figure 3. On this occasion the time-switches were set unevenly as in the second example above so that this tank had short 'low tides' and long 'high tides'. The change in water level was almost linear in both directions and a steady water level lasted for about 4 hours at 'high' and 2 hours at 'low' tides. Variations on this shape are possible by incorporating restrictions into the pump piping or adjusting the speed or capacity of the pump. In the other tank the 'tide' movement is almost exactly the converse, except for small differences caused by the slight taper of the sides which was necessary so that they could be removed from the mould during manufacture.

The form of the curve does not exactly resemble that of the real tide in two ways. It is the same nearly every time, while there are often large differences between the two real tides of each day and flooding depths vary in the longer term between springs and neaps. Secondly, the real tide resembles a sine curve (see Schwartz, 1982) rather than the zig-zag provided by the artificial system. However, these differences from the real situation are not drawbacks for our experimental purposes. Because of the constancy and precise form of the artificial tidal changes, an exact specification of the growing conditions can be made while there is still a general resemblance to a real tidal situation.

We have set up a number of preliminary experiments with both of the local species of mangroves. Seedlings of *Avicennia marina* and *Aegiceras corniculatum* were placed on all of the available levels, in order to study the survival of the seedlings under different conditions of depth and time of inundation. Time-switch (2) was set to give the form shown in Figure 3. Complete plant nutrient was added occasionally, and the water changed every two months. After 6 months all seedlings were alive and growing. This was unexpected, at least for *Aegiceras corniculatum*, which tends in the Sydney area to occur most frequently at the landward edge of mangrove swamps or at upstream sites. Table 1 shows measurements of these seedlings. With the onset of the growing season all have increased in both stem length and leaf number; to this stage there is little difference in performance at any of the depths.

This experiment illustrates a limitation of this type of apparatus. Because the pumps take about 3 hours to move the water from one tank to the next, depth of immersion is necessarily confounded with duration of immersion. As remarked above, this resembles the situation with the real tide, but it is not satisfactory for experimental purposes if depth and duration need to be investigated independently. The set-up with different tide-lengths in the two tanks allows - for any depth within a restricted range - an examination of two different durations of flooding. However, plant positions and clock settings must be chosen very carefully if comparative data are required. The example shown in Figure 3 and Table 1 comes from an experiment to compare different flooding durations, each at two different depths. Clearly with this system the range of possibilities in any one experiment is limited. With this simple kind of 'tidal' system such limitations can not be circumvented entirely. Possible alternatives would be to use much larger pumps so that the 'tide' changes much more quickly, although this would not be so good an approximation of the real tide; we can also imagine arrangements of floating shelves of various degrees of complexity. The simplest means of coping with this would, of course, be to have more pairs of tanks, each with different clock settings.

One of the advantages of the system is that it is possible to move plants from one level to another and make rapid changes to the aeration conditions of the roots. In this way it is possible to minimise the changes that occur between neap and spring tides and also to look at the effects of longer-term changes in water depth. We placed some native plants of *Avicennia marina*, which had been grown in flower-pots (with restricted drainage) for more than six years, at various positions in the tanks. Figure 4 compares the appearance of the pneumatophores of two of these plants after about two months at 30cm and 70cm maximum depths for about 7 hours and 10 hours each 'tide', respectively. The plant with deeper and longer immersion shows greater pneumatophore development and hypertrophy of the lenticels producing excrescences up to 5mm long from the pneumatophore surface. The latter of these two occurrences is a well-known effect of increased levels of the plant-hormone ethylene in other species (Jackson, 1985). We speculate that in *Avicennia* roots, as duration of flooding increases restricting diffusion of ethylene gas away into the atmosphere, the average level of ethylene may rise: the hypertrophy of lenticels would follow from this, and it may be that production of pheumatophores is stimulated by ethylene as well. More experiment is required, but clearly these speculations can be examined using the 'tidal' system described here. We feel that this simple system is useful both for the production of material of uniform quality and known previous treatment for physiological studies, and to help bridge the gap between field and glasshouse investigations.

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Table 1. Durations and depths of flooding in the two tanks, and preliminary growth results

Tank	Maximum depth over soil (cm)	Flooding duration each 25h (hours)	Exposed time each 25h (hours)	*Avicennia marina*						*Aegiceras corniculatum*					
				Mean length of axis per plant (cm) at:			Mean no. of leaves per plant at:			Mean length of axis per plant			Mean no. of leaves per plant at:		
				22/7	10/10	9,10/12	22/7	10/10	9,10/12	22/7	10/10	9,10/12	22/7	10/10	9,10/12
East	-10	0	25	-	-	-	-	-	-	56	69	83	4.8	5.2	10.0
	10	6¾	18¼	110	143	220	3.7	8.0	13.7	68	88	130	5.5	7.0	9.0
	30	10½	14½	129	161	226	3.5	7.2	12.0	83	114	117	5.3	7.5	10.8
	50	13¾	11¼	121	155	216	3.7	5.7	7.7	73	99	157	4.5	5.8	9.0
	70	17¼	7¾	127	149	218	4.0	7.0	8.7	-	-	-	-	-	-
West	-10	0	25	-	140	169	-	8.7	11.0	-	-	-	-	-	-
	10	10	15	-	164	238	-	9.0	13.5	-	89	123	-	6.5	10.3
	30	13¾	11¼	-	162	240	-	8.3	11.3	-	98	135	-	6.5	8.3
	50	17	8	-	136	174	-	6.0	8.7	-	72	107	-	5.5	8.3
	70	20	5	-	147	196	-	6.8	9.0	-	-	-	-	-	-

"Flooding duration" refers to the length of time the soil surface is flooded in each 25-hour cycle: this duration is divided equally into the two "high tides". "Exposed time" is the length of time the soil surface is exposed to the air each 25-hour cycle, again divided equally into two "low tides". "Length of axis per plant" is the total length of all the internodes. "Leaf" is defined as any leaf 1 cm long or greater, with any part green. For *Avicennia marina* each value shown is the mean of 6 plants; for *Aegiceras corniculatum* the values are means of 4 plants. Dates are in 1985. Dashes (-) indicate where data are not available. Times of flooding and exposure are given to the nearest quarter hour.

Figure 4.

Pneumatophores of mature plants grown at 30cm (about 7 hours immersion each tide) (left) and 70cm (about 10 hours immersion each tide) (right) maximum flooding depths.