CARBON SEQUESTRATION IN BENTHIC MATS OF SOLAR SALT PONDS

Mark U. Coleman

Actis Environmental Services, Darlington, Western Australia 6070, Australia
E-mail: mark@actis.com.au

Abstract

A technique has been devised to determine the metabolic production and reduction of oxygen by the benthic community in solar salt ponds. The nett oxygen production can be readily converted to an approximation of the carbon sequestration.

Three solar salt fields have been surveyed biannually over four years. The ponds with a significant benthic mat were surveyed and typically were in the salinity range of 100 g l^{-1} to 250 g l^{-1}.

The average carbon sequestration was 0.30 tonne of carbon per hectare but this varied between a minimum of -0.3 tonne of carbon per hectare per year to a maximum of 2.2 tonnes of carbon per hectare per year. Seven of the eight ponds tested always recorded a positive carbon sequestration. Various parameters that may influence the amount of carbon bound into the benthic mat were investigated.

Introduction

A solar salt field in Australia is typically made up of a series of large ponded areas of up to 5,000 ha in size, totalling between nine and twelve thousand hectares. Seawater is pumped into the initial pond and the brine evaporates as it flows or is pumped into successive ponds. The process is carefully controlled and the salinity is kept constant as much as the climatic conditions will allow. Salinity at a particular point in a pond is normally controlled to ± 5g l^{-1}. As a result, the series of ponds is a constant flow system with ponds maintaining a stable hypersaline environment. At roughly five times seawater concentration gypsum starts to precipitate. At about ten times seawater concentration sodium chloride begins to precipitate and the brine is then passed to specialized ponds that have been levelled and engineered to facilitate mechanical harvesting of the salt. The former ponds are normally called concentrators or condensers and the latter crystallizers. At times this stable system is impacted by episodic events such as cyclones and monsoon rainfall which may reduce the salinity by 100 g l^{-1}.

As water is evaporated from the brine in the series of ponds, the biology in the ponds changes as different plants and animals predominate according to salinity, temperature and nutritional variation. The biology of these ponds can be grouped into several general systems as shown in Figure 1.

The benthic algae are very important in the stabilization of the sediment and in reducing seepage; on the negative they provide the greatest biomass of the detrimental cyanobacteria Synechococcus which is normally found in large numbers in the immediate pre and post gypsum ponds. The interaction between the benthic algal mat and the overlying brine is difficult to study in situ and more particularly to monitor on a regular repeatable basis. For this reason it was decided to study the mat's use and production of oxygen as a measure of its productivity. During sunlight hours the cyanobacteria use sunlight as an energy source to produce carbohydrates by which CO_2 is consumed and O_2 is produced. These same organisms use O_2 in their metabolism but the production in the daytime far exceeds their use of O_2. A simplistic hypothetical graph showing the production/use of oxygen is shown in Figure 2. A matrix of possible changes has been compiled and presented in Figure 2. These are not meant to be definitive and all dissolved oxygen (DO_2) production and use scenarios must be interpreted within the context of the local events. It does give an understanding of what might be interpreted if all other factors were constant.

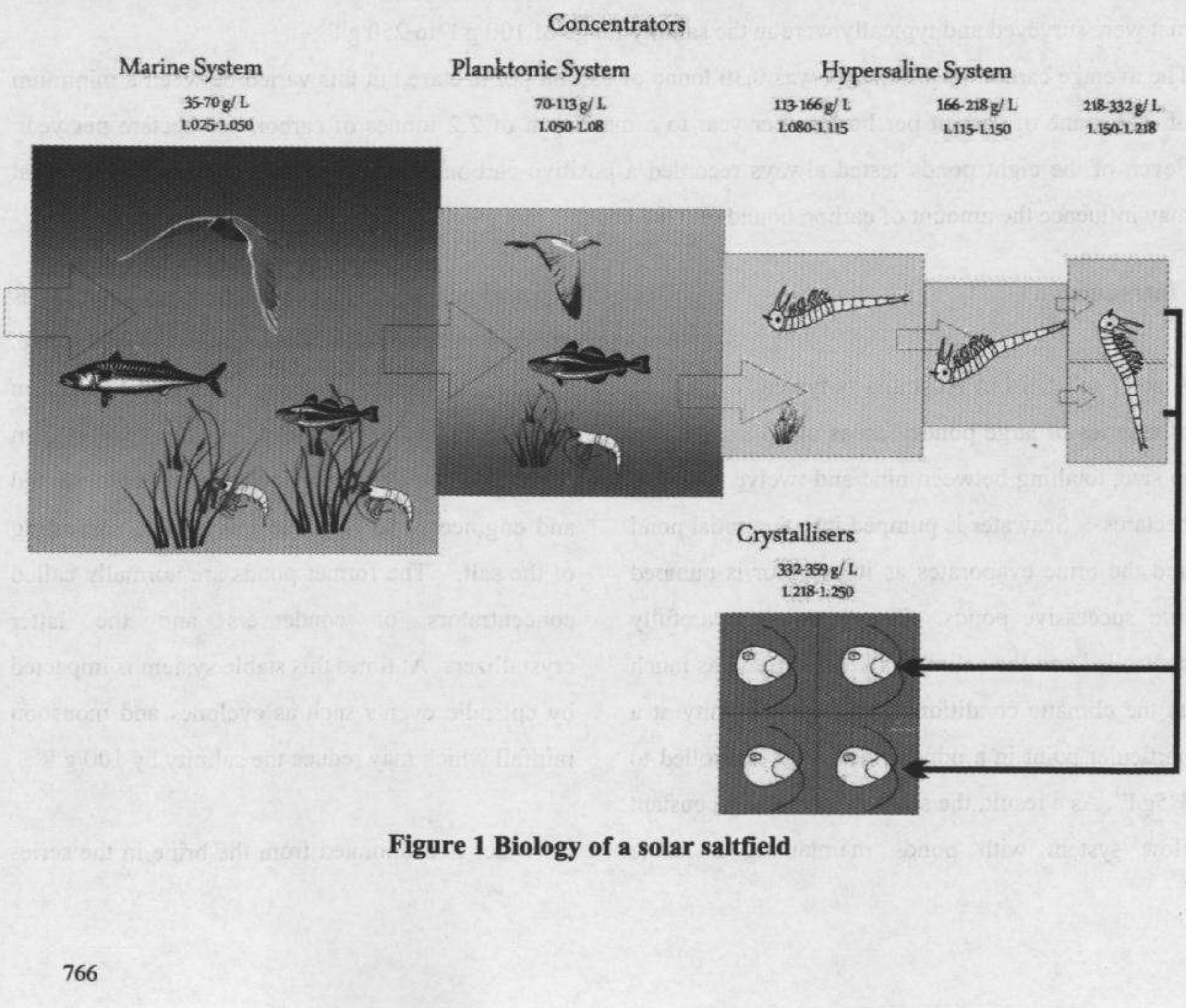

Figure 1 Biology of a solar saltfield

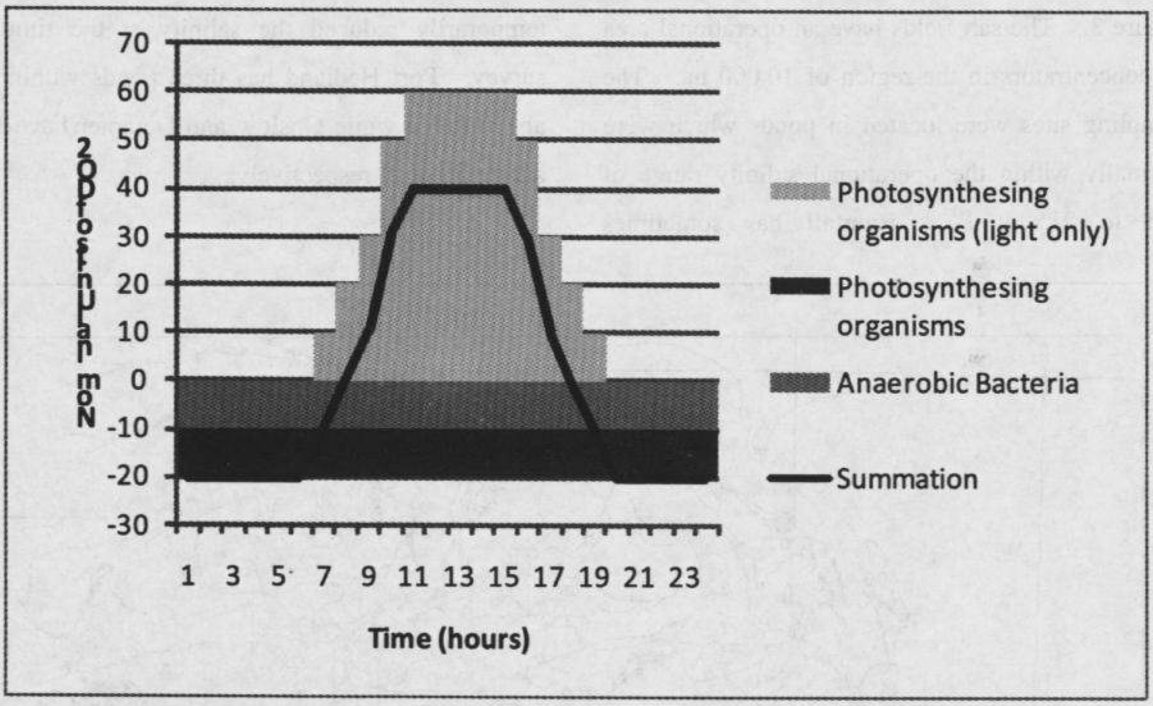

Figure 2 Hypothetical production and use of oxygen in the mat structure

A technique was devised to study the changes of dissolved oxygen in situ. In situ studies provide more accurate estimates of changes in the field for management of a commercial field. For this purpose a technique was devised of isolating algal mats in the ponds of commercial saltfields. This technique is similar to that used by (Segal, Waite et al. 2006)and others. The equipment used was a Perspex dome pressed into the benthic mat with automatic physical chemistry probes measuring conductivity DO_2, temperature, pH and light intensity in the brine above the benthic mat enclosed by the Perspex dome. This technique allows for the isolation of a mat and its composite biology under the mat's 'normal' conditions of light temperature and salinity.

The dome technique (as with most sampling) is limited as follows:

1. Small areas used to extrapolate to the entire pond.
2. Assumes the mat to be homogenous over the entire pond and sampling locations.
3. Isolation of an area is critical to monitoring changes but that in itself introduces changes.

The changes in dissolved oxygen were converted to carbon sequestration based on the nett oxygen change over a day converted to equivalent molar sequestration to organic carbon. The results are expressed as carbon sequestered per unit area not carbon dioxide per unit area.

Methods

Location

The surveys were completed at three tropical solar salt fields in north-west Australia as shown in Figure 3. The salt fields have an operational area of concentrators in the region of 10,000 ha. The sampling sites were located in ponds which were normally within the operational salinity range of 115 to 215 g l^{-1}. Rainfall has sometimes temporarily reduced the salinity at the time of survey. Port Hedland has three ponds within the above range while Onslow and Dampier have two and four ponds respectively.

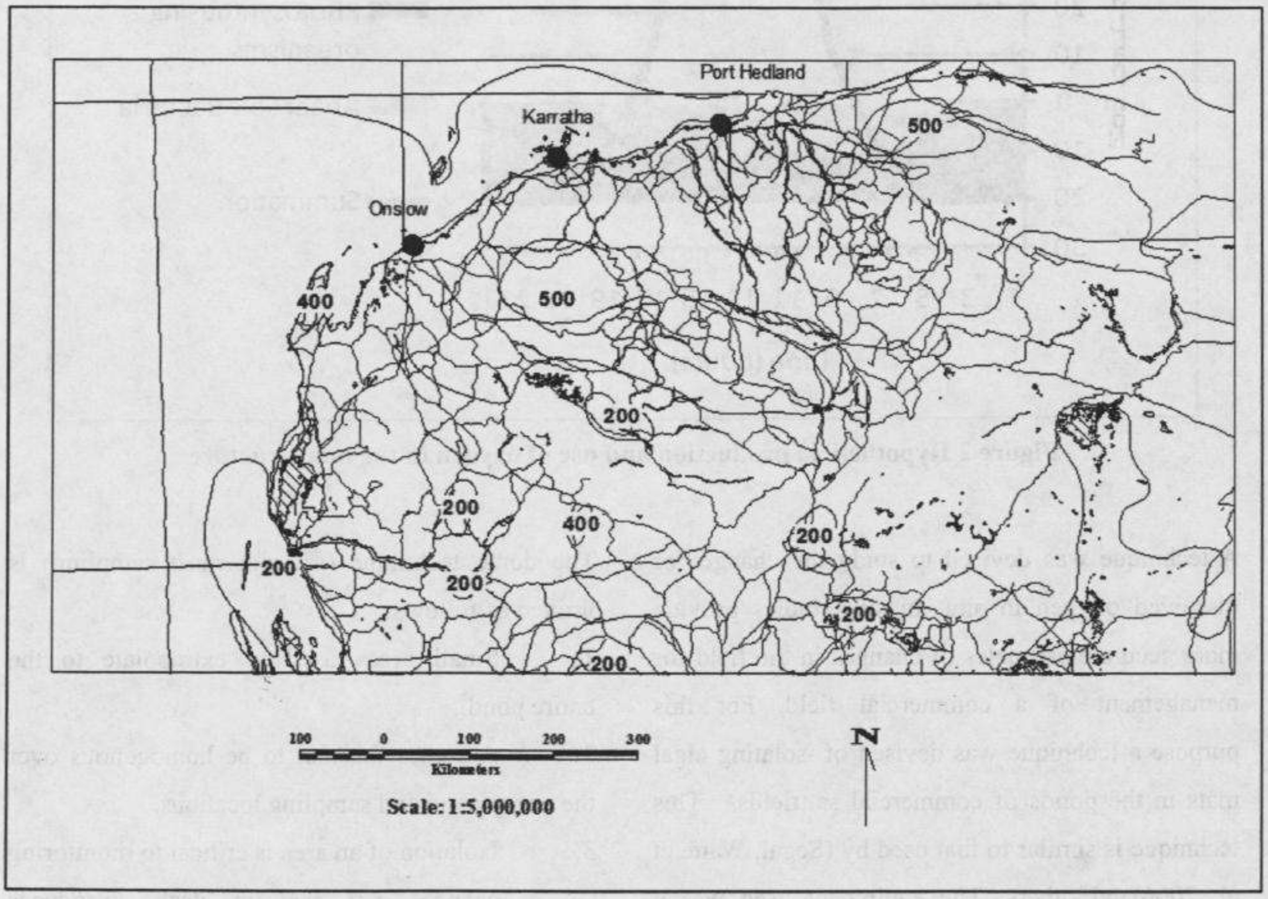

Figure 3 North-west Australia showing field locations (contours of annual rainfall mm isohyets)

Dome Construction

The Perspex domes are 700 mm in diameter and have an approximate rise of 200 mm to the top of the dome. Each dome has a 100 mm PVC skirt that drops from the rim of the dome. The dome also has several ports: a large port at the apex of the dome to allow air to be removed, a large port at roughly 45° to insert the probe and two small ports lower on the dome profile for recirculating brine within the dome by a small pump. All ports can be sealed for water tightness. The Perspex dome is then placed in a stainless steel base that protects it and enables the dome to be fixed to the substrate with steel posts through the four channels welded to the base. The area of the dome is 0.385 m^2, and its volume is 0.0725 m^3.

The loggers for the domes were Tyco CS304 loggers with multiple probes temperature, pH, DO_2 and conductivity. An Odyssey PAR light meter was attached to the dome for all four domes. The light meters and loggers were calibrated by Murdoch University MFWRL. Care was taken when assembling and placing the domes that the light meters and the domes were not shaded by the infrastructure or sediment disturbed on installation of the domes. A 12v pump was used to circulate the brine within the dome to maintain accurate and average oxygen saturation at the probe.

Analysis of data collected

Step one: The data from the logger was downloaded and analysed at the close of the experiment. The data are expressed as percent saturation which has been found to accurate under laboratory circumstances with varying salinity and temperature.

Step two: the values were converted to ppm DO_2 at ambient temperature and salinity using the algorithm:

DO_2 at saturation (ppm) = 10.790 - 0.113*Temperature (°C) - 0.032*Salinity (gl^{-1})[1]

Step three: The light meter information was calibrated and expressed as both instantaneous light intensity and accumulative incident light (PAR).

Step four: The daytime in situ DO_2 was graphed against accumulative incident light and the regression curve calculated. (The DO_2 and instantaneous incident light is shown in Figure 4.) The slope of the curve is the rate of DO_2 change per unit of light, giving the activity of the photosynthesising algae.

[1] This relationship was derived by the author in previous work unpublished.

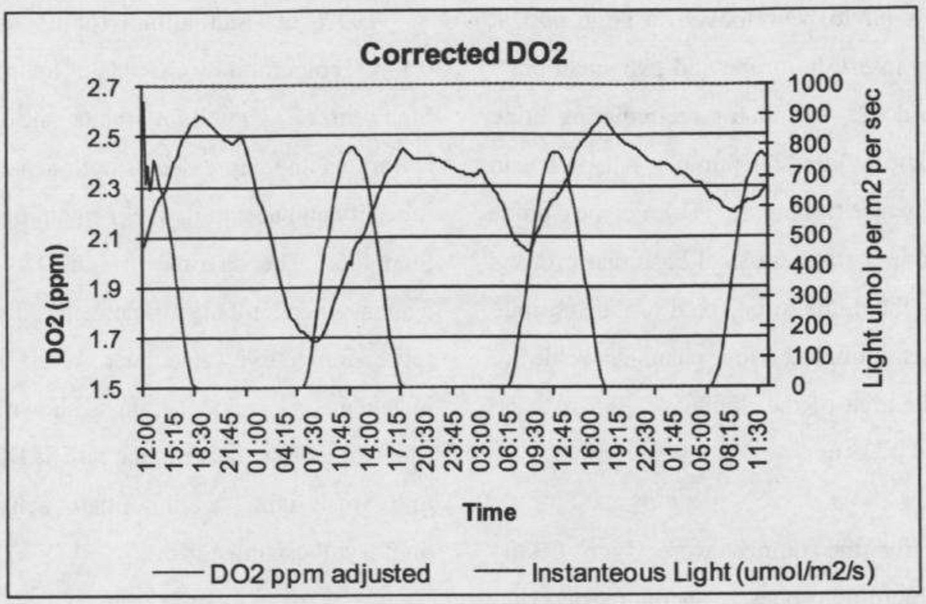

Figure 4 Typical variation of DO_2 with incident light

The DO_2 demand of the benthos at night or dark cycle data was expressed as change of DO_2 per unit time. There is a slight discrepancy due to the activity of the plankton in the entrapped brine within the dome, but as the majority of the biomass is within the mat in these ponds it has been ignored as trivial. Excess oxygen during the day time is collected in an air trap at the top of the dome. This is measured and compared with the calculated production/respiration rates, but is not used other than as a check.

Results

The results are an accumulation of surveys over four years at a frequency of twice a year for each site.

Table 1 Carbon Sequestration Dampier (tonne per hectare per year)

Pond	N	Mean	SE Mean	StDev	Median	Salinity (ppt)
1A	9	0.305	0.171	0.513	0.107	108
1B	14	0.1844	0.0517	0.1935	0.1283	137
2	8	0.0742	0.0595	0.1684	0.0225	192

Table 2 Carbon Sequestration Onslow (tonne per hectare per year)

Pond	N	Mean	SE Mean	StDev	Median	Salinity (ppt)
2	12	0.421	0.171	0.593	0.259	142
3	14	0.3042	0.0814	0.3044	0.204	198

Table 3 Carbon Sequestration Port Hedland (tonne per hectare per year)

Pond	N	Mean	SE Mean	StDev	Median	Salinity (ppt)
4	6	0.3973	0.0847	0.2074	0.3651	136
5	10	0.379	0.264	0.834	0.144	159
6	6	-0.0349	0.0307	0.0752	-0.0319	179

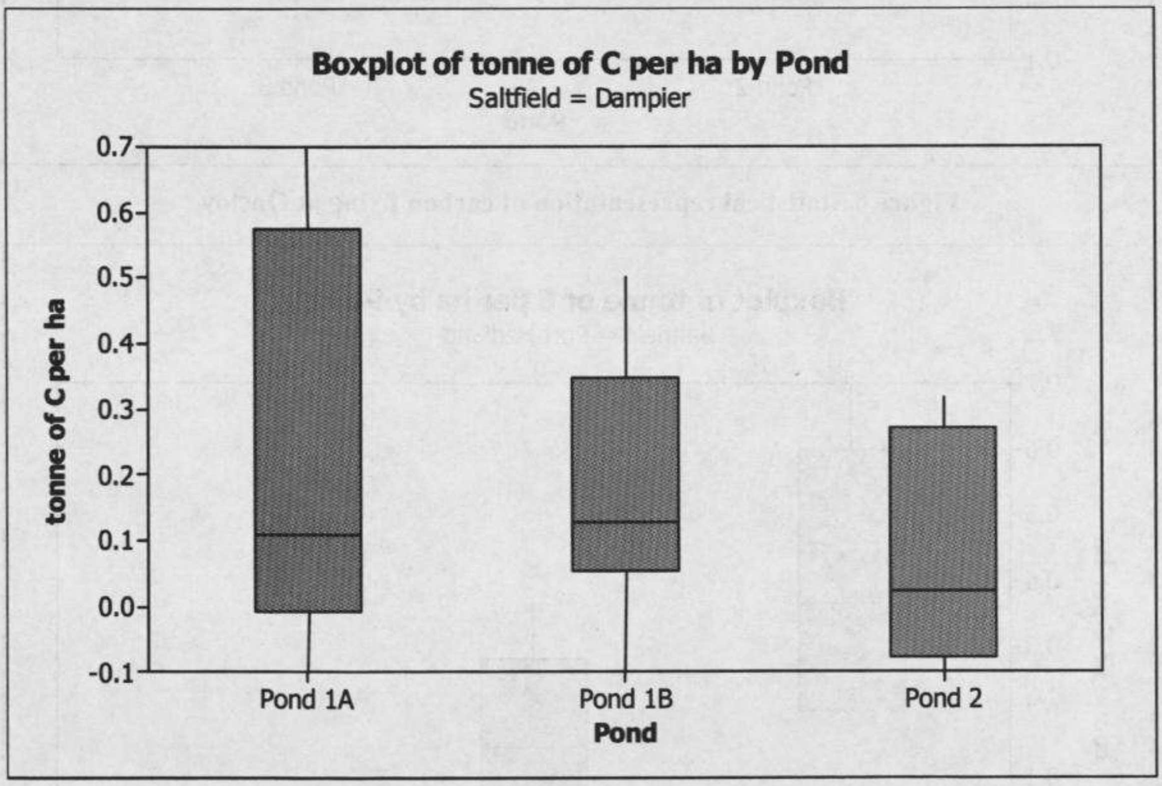

Figure 5 Statistical representation of carbon fixing at Dampier

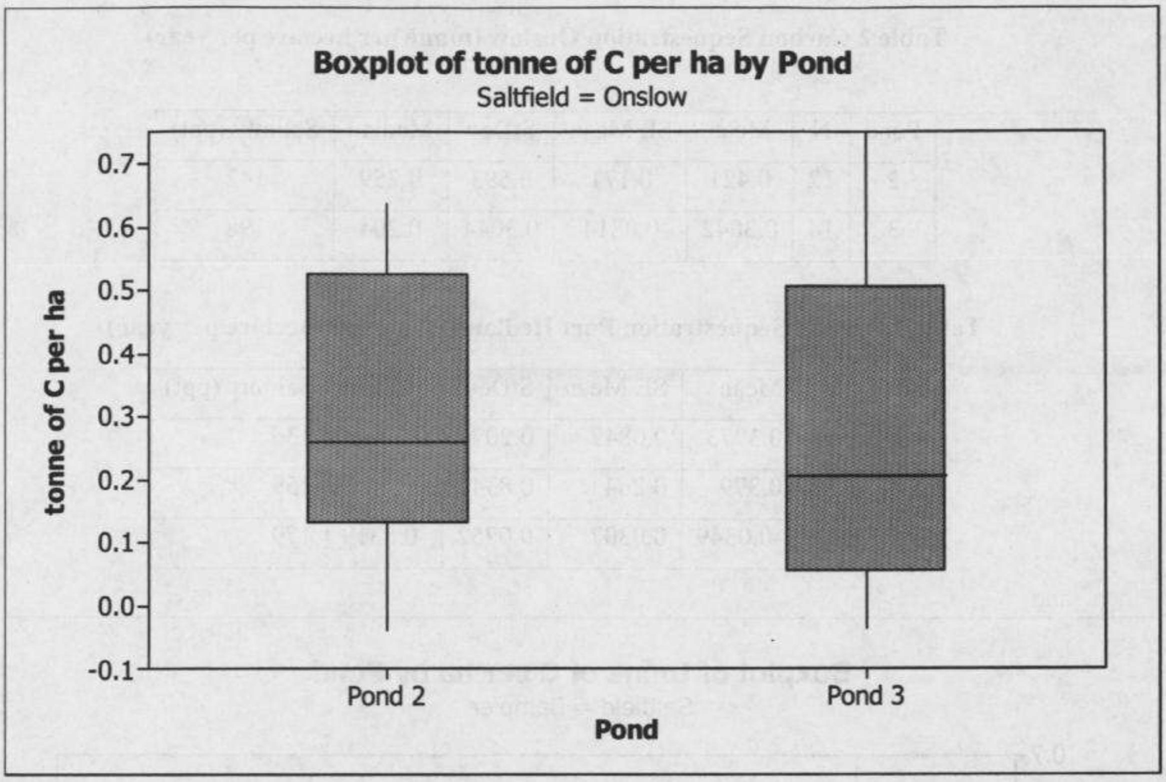

Figure 6 Statistical representation of carbon fixing at Onslow

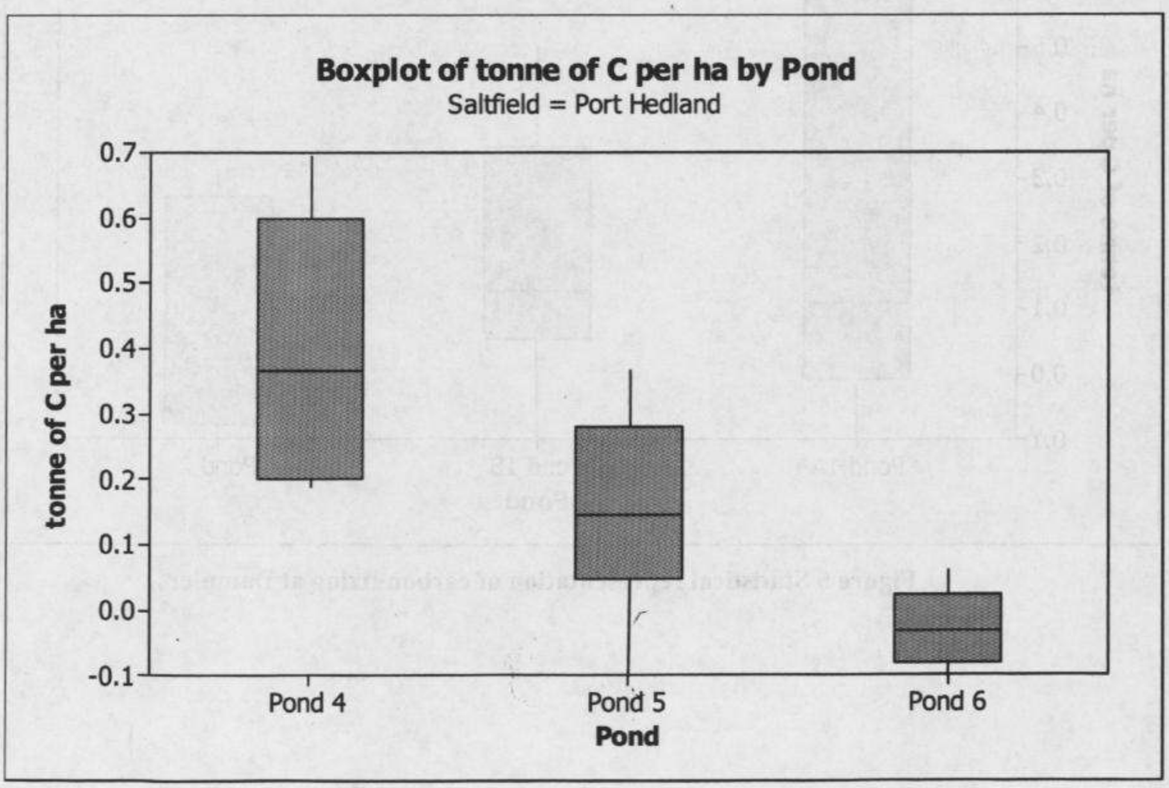

Figure 7 Statistical representation of carbon fixing at Port Hedland

Discussion

There have been a number of papers on the productivity of benthic mats in saltfields in the salinity range between 100-200 g l^{-1} ((Canfield, Sørensen et al. 2004); (Wieland, Zopfi et al. 2004); (Wieland and Kuhl 2005) to name several). The general trends have been to show that with increasing salinity the benthic primary productivity decreases while the respiration remains relatively constant. It has also been suggested that cyanobacteria habituated to a constant salinity within this range will increase productivity if the salinity is decreased. This was reported by (Coleman and White 1993) and by (Canfield, Sørensen et al. 2004). It is thought that most species within this range are halotolerant and not truly halophilic and organisms typically have an optimum salinity less than found in the field.

In the salinity range tested there was a clear trend for the carbon sequestration to decrease with salinity (Figure 8). What is not shown is that the actual oxygen production peaked in the salinity range between 120 and 160 ppt but the oxygen reduction by the benthic mat increased across the salinity range, making the nett change and hence carbon sequestration greater at the lower salinity range. It is thought that the carbon sequestration would be at least as great as in the untested lower salinity ponds as for the range between 100-140 ppt. All ponds had an average positive value except for the higher salinity pond at Port Hedland. The very low nett values have always been a feature of this pond; a consideration may have been the impact of a cyclone mid sampling however it is unlikely as the low carbon sequestration values were recorded before the cyclone as well.

The carbon sequestration rates per pond for all fields against the average salinity show a reduction across the salinity range albeit the relationship is not strong (Figure 9). The reason for the weak relationship is that although the ponds are usually maintained at a steady salinity, cyclonic depressions can cause significant dilution from rainfall. The mats in a diluted pond remain ecologically consistent with the pre-dilution ecology but the rates of oxygen respiration change radically. For this reason there is a very poor relationship between instantaneous salinity and carbon sequestration as the history of the pond influences the current biological activity and ecology.

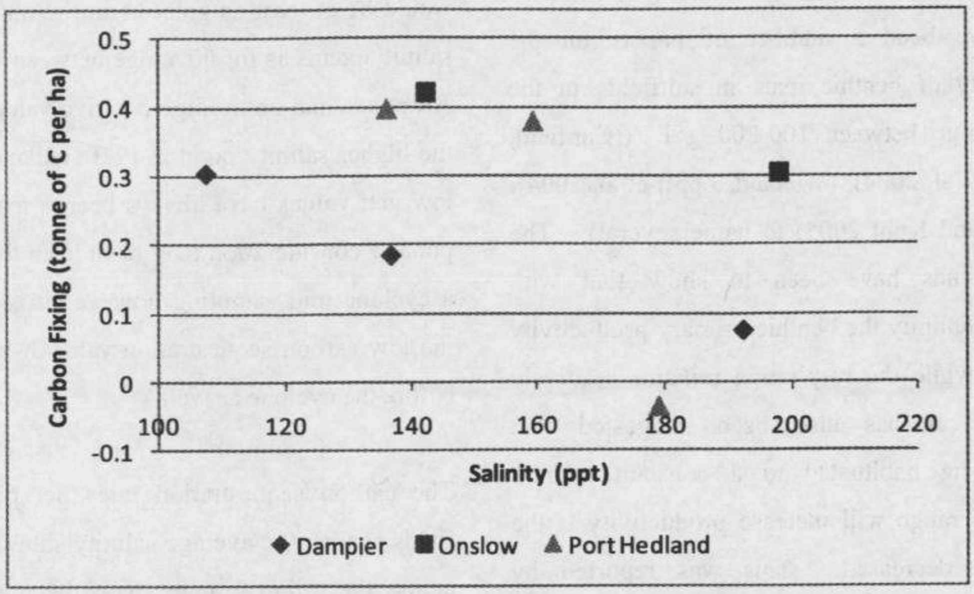

Figure 8 Carbon sequestration over salinity range per field

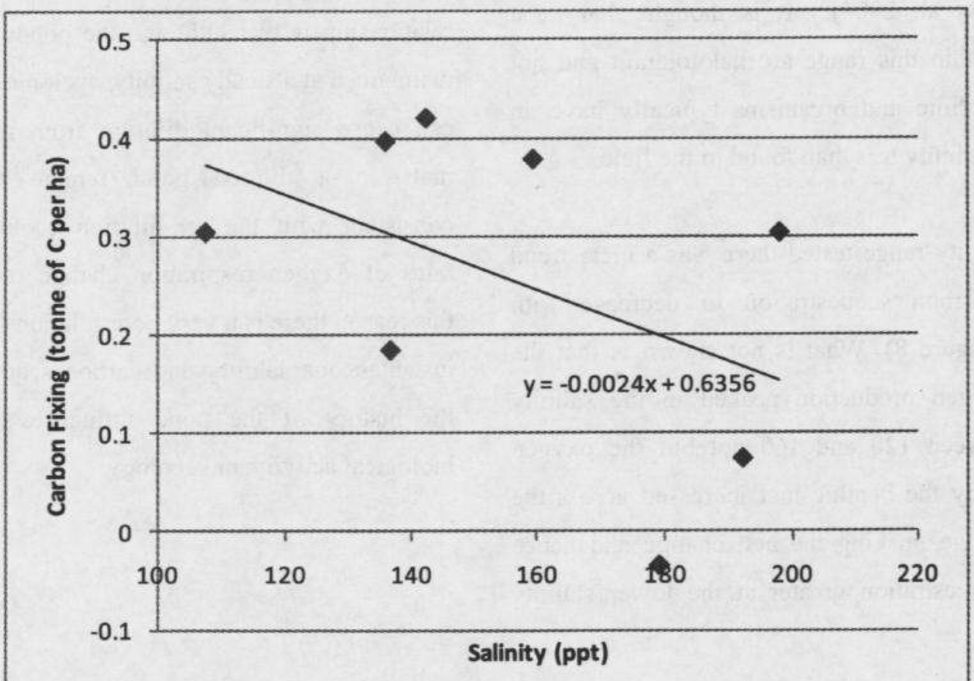

Figure 9 Carbon sequestration over salinity range for all fields

The salinity range shown in Figure 9 is approximately half of a normal solar seawater input salt field. The carbon sequestration in the lower salinity ponds has not been ascertained because or two reasons. The first is that the program's primary function was to determine the dissolved oxygen cycle as part of the management of solar salt fields biology and the initial results have been reported in (Coleman 2009). The second is that the lower salinity ponds are more difficult to monitor because the wave fetch, depth and interference of animals with the monitoring equipment. However it is reasonable to assume that the lower salinity ponds have a similar rate of carbon sequestration as the lower range monitored because of the general trend as shown in Figure 9 and the similarity of the benthos in the lower unmonitored salinity ponds.

Based on the discussion above an estimate of the total carbon sequestration for the three fields has been calculated (Table 4).

Table 4 Carbon Sequestration per salt field

	Area (ha)	Carbon Sequestration (t)	Carbon dioxide Sequestration (t)
Dampier	8,312	2,035	7,461
Onslow	7,726	2,477	9,083
Port Hedland	7,312	1,934	7,091

The above values are considered conservative in the technique and do not include any carbon sequestration in the brine which is considerable.

Acknowledgements

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