



Carbon Sequestration Potential of Shellfish

J. P. Hickey

School of Natural and Built Environs, LMES, University of South Australia, SA, 5000, Australia

ABSTRACT: As the global average temperature increases and CO₂ within the ocean begins to reach saturation the ability of the ocean to absorb carbon will alter significantly. At some point in the future removing carbon from the ocean may need to be considered. One method for achieving the removal of carbon from the ocean would be through the ancient practice of shellfish farming. Using 'plate' oyster stocking density, shellfish sequestration was competitive with some plant species such as *Eucalyptus porosa*, but was eclipsed by other species such as *Eucalyptus socialis*. Taking the 'spat' stocking density as the starting point it can be seen that an oyster farm as a whole does sequester a large amount of carbon per year but this does not necessarily equate to a per hectare figure. An independent assessment of the shellfish industry would be required to determine the extent of carbon sequestration and the overall costs of generating carbon offsets through this method.

Keywords: Carbon sequestration, shellfish, oysters, biosequestration

1. Introduction

Climate change induced by global warming has become a heavily discussed topic over the last two decades, which is understandable when the likely disruption to ecosystems throughout the Earth and therefore human existence is considered. CSIRO predicts that Australia, for example, will become generally hotter and drier in the future. (www.clw.csiro.au/staff/hairsinep/ffp-lw19052004.pdf). The fears and deliberations surrounding climate change have given birth to the quest to reduce the cause of global warming, which is attributed to the amount of greenhouse gas (GHG) in the atmosphere. One method for achieving such ends has become known as 'carbon off-setting', the notion of balancing GHG producing and GHG reducing actions to create an overall zero growth in GHGs. A purchaser of a plane ticket will be asked whether they wish to offset the carbon that will be released during the flight. A new car may include the option to offset its fuel and large events like WOMAD are looking to soften their carbon footprint by contracting an offset provider. On an international scale, the Kyoto Protocol includes binding targets for countries that have ratified the agreement.

There are four categories of offsets including Renewable Energy, Energy Efficiency, Gas Capture, and Sequestration. This paper will compare a recognised form of sequestration known as Biosequestration with the carbon uptake or sequestration potential of shellfish. Carbon is absorbed naturally from the ocean as the shell of the shellfish forms and grows. The practice of generating offsets through forestry activities in Australia will be used as a baseline against which to compare Pacific Oyster farming in South Australia (SA). The amount of land required to sequester a given volume of carbon as well as the time required will be used as a means of comparison. Market value and costs per tonne of Carbon are beyond the scope of this paper, as are the inputs such as operational energy consumption and transport of the oysters. However, it is important to consider the above factors in a comprehensive research project on this topic.

2. Kyoto Protocol

The Kyoto Protocol is the one international response to rising levels of GHG emissions originating from anthropogenic activities.

Developed countries, which are 'Parties' to the Kyoto Protocol are listed in Annex I of the Protocol (UNFCCC, 2007). Hamwey & Baranzini (1999) state that under the Kyoto Protocol, Annex I countries have binding GHG emission targets. These targets are stipulated in Annex B of the Protocol. Within the Kyoto Protocol, however, there is flexibility that allows Annex I countries to achieve their Annex B goals without simply reducing domestic GHG generation. The three flexibility mechanisms defined in the Kyoto Protocol include Emissions Trading, Joint Implementation (JI) and Clean Development Mechanism. Australia is listed in Annex I as a developed country and therefore has access to all three flexibility mechanisms (Hamwey & Baranzini, 1999). However this paper is concerned with the second flexibility mechanism, JI, which allows excess carbon, or emission reduction units to be traded between developed countries (Dury, Polglase, & Vercoe, 2002). JI activities are stated in Article 3.3 of the Kyoto Protocol and include afforestation, reforestation and deforestation (UNFCCC, 2007). There is no limit on the extent to which the flexibility mechanisms can be applied to achieve overall emission reductions (Hamwey & Baranzini, 1999).

Additionality

JI is designed to stimulate new GHG reduction activities, meaning such activities must be additional to that which would be undertaken in the absence of emission targets (Dury, Polglase, & Vercoe, 2002). Activities that are 'business as usual' or that are not contingent upon carbon offsets would not qualify as additional (AGO, 2007). However, the Kyoto Protocol states in Article 3.4 that

Parties to this Protocol shall, at its first session or as soon as practicable thereafter, decide upon modalities, rules and guidelines as to how, and which, additional human-induced activities...shall be added to, or subtracted from, the assigned amounts for Parties included in

Annex I (UNFCCC, 2007).

Australia as a Party to the Kyoto Protocol could submit activities which it felt should be included as additional at a Conference of the Parties (UNFCCC, 2007). This means that although only afforestation, reforestation and deforestation are additional activities at this point in time it is possible for other activities to be included if research and sound arguments are presented at a future Conference of the Parties.

3. Biosequestration

Defined

Afforestation, reforestation and (avoided) deforestation come under the broad heading of Biosequestration. Biosequestration is the general term used to describe activities where plants such as trees are used to 'sequester' or absorb carbon from the atmosphere. Plants achieve this via photosynthesis, which converts Carbon Dioxide into Oxygen and plant material (Dury, Polglase, & Vercoe, 2002). The amount of carbon sequestered can vary considerably depending on the site, species and other external conditions. The CSIRO states that the 'net amount of atmospheric carbon that is sequestered by a [biosequestration project] is the balance between changes in above-ground vegetation, roots, the litter layer, and the soil' (www.clw.csiro.au/staff/hairsinsep/ffp-lw19052004.pdf). The amount of carbon sequestered by a stand of vegetation is given by tonnes of carbon per hectare per year ($\text{tC ha}^{-1} \text{ yr}^{-1}$). Paul et al. (2002) have calculated a figure of 6 to 13 $\text{tC ha}^{-1} \text{ yr}^{-1}$ for commercial operations involving Tasmanian blue-gum and radiata pine. Other more modest figures have been derived by Hobbs & Bennell (2005) for a number of species more representative of the South Australian flora (Figure 1). *Eucalyptus socialis*, for example, is a mallee plant, which can absorb between 2.5 and 4.2 $\text{tC ha}^{-1} \text{ yr}^{-1}$.

Advantages and Disadvantages

Biosequestration in the form of afforestation, reforestation and (avoided) deforestation is a direct counter-action to the large-scale deforestation occurring globally. Deforestation accounts for upwards of 1.6 billion tonnes of carbon per year (Brown & Adger, 1994). In Australia, it is estimated that 50 million hectares of woody vegetation has been cleared since European settlement in the late 1700s (www.clw.csiro.au/staff/hairsinep/ffp-lw19052004.pdf). Biosequestration in the forms of afforestation or reforestation has an important role to play in improving the health of the Australian landscape. The deep roots of trees can control groundwater recharge and therefore reduce the risk of dryland salinity, as well as stabilise soil and provide a biodiversity catchment (Zhang et al, 2007). However tree plantations are more common in regions with rainfall above 800mm, which means they compete with agricultural land (www.clw.csiro.au/staff/hairsinep/ffp-lw19052004.pdf). In some cases the decreased water yield caused by a plantation

could produce an overall increase in river salinity in the long-term (www.clw.csiro.au/staff/hairsinep/ffp-lw19052004.pdf). Ideally plantations should be established in low to medium rainfall zones (500-800 mm) in Australia, but this will result in a less profitable forest industry and therefore may not be viable.

Table 11 – Predicted above-ground carbon sequestration rates for selected species in short rotation crops (~10 year cycle) on dryland sites in the River Murray Corridor region.
Shading represents zones where climatic conditions may not be suitable for selected species.

Plantation Type / Species	Annual Carbon Sequestration Rates [tonnes carbon ha ⁻¹ year ⁻¹]			
	Zone 1	Zone 2	Zone 3	Zone 4
Mallees at 1000 plants ha⁻¹				
<i>Eucalyptus socialis</i>	2.528	2.416	3.271	4.221
<i>Eucalyptus oleosa</i>	1.246	1.191	1.612	2.080
<i>Eucalyptus cyanophylla</i>	1.221	1.167	1.579	2.038
<i>Eucalyptus porosa</i>	0.942	0.901	1.219	1.573
Shrubs at 2000 plants ha⁻¹				
<i>Atriplex nummularia</i>	2.218	2.119	2.869	3.702
<i>Acacia ligulata</i>	2.050	1.959	2.652	3.422
Trees at 1000 plants ha⁻¹				
<i>Eucalyptus leucoxylon</i>			2.713	3.501
<i>Eucalyptus nortonii</i>				4.105
<i>Eucalyptus viminalis</i> ssp. <i>cygnetensis</i>				3.317

Figure 1. Hobbs & Bennell, 2005, p30

4. Alternatives to Biosequestration

So what are the other options for sequestering carbon directly from the atmosphere in Australia and particularly in SA? There are a number of technologies, which attempt to capture carbon or GHGs before they reach the atmosphere such as Carbon, Capture and Storage or Land Fill Gas (Gurney et al, 2007; DEH, 2005). However, these techniques do not address GHGs entering the atmosphere from non-point sources. The ocean has the greatest potential as a carbon sink for Australia and should be given more, or at least equal consideration to Biosequestration. Exchanges between the terrestrial biosphere and the ocean absorb almost 50 per cent of anthropogenic emissions and Australia is fortunate to be surrounded by ocean (Rehdanz et al, 2006). Methods to increase the amount of carbon uptake or sequestration by the ocean include the injection of carbon dioxide into the deep ocean, and increasing nutrient levels through iron fertilisation to encourage more plant production (Rehdanz et al, 2006). Deep ocean injection is difficult although the formation of a CO₂ hydrate may prove more viable (Brewer et al, 2000). Iron fertilisation would have an intrinsic cost that could also prove a barrier to its adoption (Rehdanz et al, 2006). In either case the Kyoto Protocol does not currently cover ocean sequestration but research into this offset technique is encouraged (Rehdanz et al, 2006). However, as global average temperature increases and CO₂ within the ocean begins to reach saturation the ability of the ocean to absorb carbon will alter significantly (Rehdanz et al, 2006). At some point in the future the removal of carbon from the ocean may need some consideration.

5. Shellfish & Pacific Oyster

One method for achieving the removal of carbon from the ocean would be through the ancient practice of shellfish farming. As

previously mentioned the shell of a shellfish absorbs Carbon as it grows. The shellfish secretes Calcium Carbonate (CaCO₃) to form its shell (oceanacidification.wordpress.com/2008/04/24/can-seashells-save-the-world/), which means a percentage of its shell contains Carbon. Oyster farming in particular dates back to ancient times with evidence this practice existed during the Roman civilisation (en.wikipedia.org/wiki/Oyster). Shellfish farming in South Australia dates back to 1910 when Chief Inspector Randall attempted to cultivate the native oyster, *Ostrea angasi*. Randall's relatively unsuccessful venture was spurred by low numbers of *Ostrea angasi* occurring naturally due to unsustainable commercial activity. Other endeavours into native oyster farming in the 1960s achieved similarly poor results. This led to the adoption of hardier species such as the Pacific oyster, *Crassostrea gigas*, which was already being farmed in Tasmania. SA received its first shipment of Pacific oysters from Tasmania in 1969. In 2001/02 the oyster industry was the second largest aquaculture sector in the state with a value of over \$14.1 million (www.pir.sa.gov.au/aquaculture/aquaculture_industry/oysters). SA has proven to be an ideal location for oyster farming for a number of reasons including low human population density, high quality marine environments and low rainfall, which decreases pollution impacts from storm water runoff. (PIRSA, 2000)

Lifecycle

According to Primary Industries and Resources SA (PIRSA), the Pacific Oyster begins life as a free-floating embryo or larvae and remains in this phase for approximately 3 weeks. In order to morph into a juvenile oyster or "spat" the larvae must attach themselves to a suitable substrate. When the spat have grown to between 3 and 15 mm in length they can be sold to farmers. There are four 'grow-out' techniques used in SA including intertidal racks and baskets, intertidal racks and trays, intertidal long-lines, and subtidal long-lines.

The technique used will depend on the individual farmer, location of lease and the size of oyster. The oysters must be continually graded into similar sizes so that larger oysters do not out-compete smaller oysters. Grow-out time depends on conditions within its habitat such as water quality, strength of current, and food concentrations. (PIRSA, 2000)

Harvest

Pacific Oysters are harvested in the warmer months in SA when they are in peak condition. The oysters are transported in refrigerated trucks directly to wholesalers within 24 hours of harvest and have a maximum shelf life of 10 days. Oysters are sold in various sizes including bistro (50-60mm), plate (60-70mm), standard (70-85mm), large (85-100mm) and jumbo (100+mm). (PIRSA, 2000)

Carrying capacity

The density of aquatic plants and animals, or carrying capacity in a given waterbody is dependant on the amount of phytoplankton in the water. Pacific oysters obtain most of their diet by filtering this phytoplankton from the water. If oysters are stocked beyond the carrying capacity of the area it can seriously affect other marine species and the economic return of a particular farm. Even one over-stocked farm can cause damage to an entire bay and disrupt the industry in that area. (EPA, 2005)

Disease

There are a number of diseases that can infect oyster populations. The main two problems in SA include the Mud Worm and the Flat Worm. The treatment for Mud Worm is a fresh water bath at regular intervals. The Flat Worm only becomes a problem when sediment is allowed to build up in the baskets or cylinders. Therefore it is not an issue when the stock is graded regularly. Other diseases exist in oyster populations throughout the world but Australian oyster populations have not been exposed to these as yet

(en.wikipedia.org/wiki/Oyster). Although the risk of coming into contact is low due to spat being produced domestically, stronger treatments may be required if other diseases did manifest (www.pubmedcentral.nih.gov/articlerender.fcgi?artid=91374).

6. Method

The aim of this study was to investigate the carbon uptake potential of shellfish, and compare this result to afforestation or reforestation. In order to make this comparison it was necessary to express findings using the same unit. As already stated in this report the accepted unit for Biosequestration is tonnes of carbon per hectare per year ($tC\ ha^{-1}\ yr^{-1}$). Oyster farms are leased and monitored on a hectare basis so there is a spatial aspect to oyster farming, which can be related to Biosequestration. It was also necessary to simplify or limit the study using a number of assumptions and scoping decisions. The first decision was to limit the area of the study to oyster farming in SA. Secondly the Pacific Oyster was chosen as the subject of the study as it is the predominant oyster farmed in SA. The third restraint was to limit the harvest size of the oyster to the 'plate' size, which was defined above, because it is the most common size produced. Other assumptions such as the consistency of oyster shell and growth rate of individuals were made which are explained below.

Calculating the Carbon Uptake

Four main factors were considered in order to calculate the amount of carbon sequestered per year. These included the shell carbon content, spat weight, grow-out time and stocking density. Table 1 shows the parameters used in calculating the carbon sequestration values of Table 2 and Table 3. Five oyster farmers were interviewed concerning aspects of their operation from different regions of SA. Two variables emerged from the interviews including grow-out time and stocking density. A

representative of the SA Oyster Growers Association also gave advice on recommended stocking density.

The Amount of Carbon Contained in the Shell

The Carbon content of an oyster shell can be derived from the overall mass of the oyster. Oysters are generally sold to wholesalers unopened by the dozen. One dozen oysters weighs on average 1 kilogram (kg). This works out to 83.33grams (g) per oyster. However, as the oysters are unopened this 83.33g includes the meat. The meat of a healthy oyster ranges from 12 – 15g, which equates to an average mass of 13.5g. Subtracting meat weight from the total oyster weight gives an approximate shell weight of 69.83g. The shell consists of the chemical compound Calcium Carbonate (CaCO₃) as stated above. Using the atomic weight of the elements within this compound the amount of carbon within the shell can be calculated. Calcium (Ca) has an atomic weight of 40g; Carbon (C), 12g; and Oxygen (O), 16g (Serway, 1996). Therefore the overall molecular weight of CaCO₃ is:

$$40+12+(3\times 16)=40+12+48=100\text{g}$$

Therefore Carbon contributes 12g for every 100g of shell, or 12% of overall shell mass. It must be noted that this equation does not take into account impurities in the shell such as trapped sediment and water.

The Spat Weight

This paper is dealing with the carbon sequestration resulting from oyster farming so the initial weight of the spat has to be discounted in order to achieve a more accurate result. The weight of the spat can vary greatly depending on the size desired by the farmer. According to Richard Pugh of the Tasmanian company Shell Fish Culture, the average size of spat is considered to be 5mm with an average weight of 0.1g (www.shellfishculture.com.au). This correlated with Craig Lowe of Ceduna and Mark Jarvis of Coffin Bay who had records of orders of 5220 spat per kilo and 14286 per kilo respectively, which produced an

average spat weight of 0.131g. The figure of 0.131g was used in calculations (Table 1). Subtracting spat weight from shell weight gives a ‘farmed mass’ of 69.699g.

Grow-out Time

The Pacific Oyster can take anywhere from 11 months to 4 years to reach plate oyster size due to varying conditions and growth rates. Judd Evans of SA Oyster Growers Association (SAOGA) suggested that 2 years is the average grow-out time for a plate oyster. This was also the consensus among the others interviewed, with Colleen Holmes of Smokey Bay suggesting 4 years was the maximum amount of time any one oyster would spend on the farm.

Stocking Density

Plate Oysters Per Hectare

Calculating the plate stocking density per hectare was difficult due to the variation encountered on a farm by farm, and even a region by region basis (see Table 2). For example, Coffin Bay generally has a greater level of nutrients in the water, which allows a higher stocking density. There are also several different farming techniques, requiring a different method of calculating density. Rack and rail, according to Judd Evans, is allowed one kilometre of rail per hectare. The kilometre is made up of 18m sections, which calculates to 55.55 sections per kilometre, or 56 ha⁻¹. Each section contains approximately 3000 oysters giving a density of:

$$3000 \text{ oyster/section} \times 56 \text{ sections/hectare} = 168,000 \text{ oysters ha}^{-1}$$

Craig Lowe, also using rack and rail used another approach to calculate density. His farm contained 3000 cylinders per hectare, and would stock 65 plate oysters per cylinder. So this equated to:

$$65 \text{ oysters/cylinder} \times 3000 \text{ cylinders/hectare} = 195,000 \text{ oysters ha}^{-1}$$

Mark Jarvis used the same approach as Craig Lowe but stocked 72 oysters per

cylinder. The results of Table 2 reflect this approach to stocking density.

Spat per Hectare

The second approach to stocking density was to take the spat stocking density for one hectare and project it forward over a time frame of 2 years to determine the potential number of plate oysters produced by the ‘planting’ of one hectare. Unlike trees, which are not moved (they may be ‘thinned’), oysters are continually graded and allowed more space as they grow. For example, one hectare of spat with a stocking density of 2 million could result in approximately seven hectares of plate oysters after taking into account a 30 per cent mortality rate. This survival rate varies from farm to farm as shown in Table 3. Regardless of increased spatial requirements it could be argued that one hectare of spat stocked at 2 million per hectare will result in the sequestration of 5.85 tC ha⁻¹ yr⁻¹. The figures shown in Table 3 assumed a linear mortality rate.

Total Carbon Sequestration

The total carbon uptake was calculated separately using the two stocking densities. In both cases the amount of carbon per plate oyster and the number of plate oysters was used to determine the overall carbon sequestration. This figure was then divided by the grow-out time to determine sequestration per year.

$$(\text{Carbon per plate oyster} \times \text{number of plate oysters}) / \text{Grow out time} = \text{tC ha}^{-1} \text{ yr}^{-1}$$

The total carbon sequestration of each stocking density is shown in the last column of Table 2 and Table 3.

7. Results

Table 1 shows the figures used in calculating the values in Table 2 and Table 3. Table 2 shows the amount of carbon sequestered per hectare per year based on the first approach, considering plate stocking density. The average sequestration figure for the five locations was 0.83 tC ha⁻¹ yr⁻¹, with a median of 0.82 tC ha⁻¹ yr⁻¹. The results of the second approach, beginning with spat stocking density is shown in Table 3. This approach produce an average of 9.03 tC ha⁻¹ yr⁻¹, with a median of 5.85 tC ha⁻¹ yr⁻¹.

Table of figures	
Plate oyster (g)	83.33
Meat weight (g)	13.5
Shell weight (g)	69.83
Spat weight (g)	0.131
Farmed mass (g)	69.699
Carbon per oyster (g)	8.36388
Grow-out time (years)	2

Table 1. Values used in calculations

Oyster Farmers	Plate oyster stocking density (ha ⁻¹)	Carbon sequestered 2yrs (kilograms)	Carbon Sequestration (tC ha ⁻¹ yr ⁻¹)
Mark Jarvis (Coffin Bay)	216,000	1806.60	0.90
Colleen Holmes (Smokey Bay)	302,400	2529.24	1.26
Craig Low (Ceduna)	195,000	1630.96	0.82
Mike Willis (Coffin Bay)	180,000	1505.50	0.75
Oyster Bay (Stansbury)	260,000	2174.61	1.09
Judd Evans (SAOGA)	168,000	1405.13	0.70

Table 2. Carbon uptake of Pacific Oyster using dimensions and stocking density of plate size oyster

Oyster Farmers	Spat Stocking density (ha ⁻¹)	Spat survival rate(%)	Potential surviving plates (ha)	Carbon sequestered 2yrs (kg)	Carbon Sequestration (tC ha ⁻¹ yr ⁻¹)
Mark Jarvis (Coffin Bay)	1,500,000	70	1,050,000	8782.07	4.39
Colleen Holmes (Smokey Bay)	1,400,000	65	910,000	7611.13	3.81
Craig Low (Ceduna)	2,000,000	70	1,400,000	11709.43	5.85
Mike Willis (Coffin Bay)	5,250,000	60	3,150,000	26346.22	13.17
Oyster Bay (Stansbury)	6,600,000	65	4,290,000	35881.05	17.94

Table 3. Investigating the potential carbon uptake of one hectare of spat

8. Discussion

There was a significant difference in the final results depending on the approach used. The first approach (Table 2) using the stocking density of plate oysters was perhaps the more realistic figure as it was only looking at one hectare. The point to note regarding this approach is that one

hectare could not sustain such large densities of plate oysters. In reality the hectare or farm would constitute a mix of sizes, from spat to harvest-ready oysters, all growing at varying rates. As mentioned the second approach (Table 3) starts with one hectare of spat but results in several hectares of plate oysters. This means the tonnes of carbon per hectare per year unit measurement is not

entirely accurate, and perhaps simply tonnes of carbon per year would be more representative of Table 3 figures. However, if carbon offsets were to be sold per oyster then perhaps the spat would be the appropriate starting point.

In comparing the above results to afforestation and reforestation it must first be noted that extensive research has been applied to Biosequestration while little work has been done towards the topic of this paper. Despite thorough research concerning Biosequestration there is still no true understanding of the carbon value of vegetation and numerous interpretations of research exist (Van Kooten, 2004). In Australia the first approach (Table 2) using the plate oyster stocking density was competitive with some plant species such as *Eucalyptus porosa*. Other species such as *Eucalyptus socialis*, clearly eclipsed the potential of the first approach, sequestering four or five times the amount of carbon per year. Taking the spat hectare as the starting point (Table 3) it can be seen that an oyster farm as a whole does sequester a large amount of carbon per year but this does not necessarily equate to a per hectare figure. The figures shown in Table 3 may be more suited to an analysis of the oyster industry independent of the methods used in Biosequestration calculations. Furthermore, the inclusion of other parameters such as opportunity costs of land and the fact that oysters are producing a valuable food source may demonstrate that oyster sequestration is quite competitive with Biosequestration. There are also many uses for shell waste that have not been discussed. Beyond this, vegetation stands have a carbon uptake lifespan, after which it is considered they are no longer sequestering carbon whereas oyster farming is perpetual. However, oysters could still positively impact on the amount of carbon present in a given water body. Unlike trees, which primarily draw in carbon dioxide and release oxygen, oysters are respiratory animals, which means they inhale oxygen and exhale carbon dioxide. A clearer understanding of the potential sequestration of oysters would be gained by

subtracting all of the inputs from the total output. This would have to be done on a single farm or lease basis and require very accurate records to be kept.

9. Conclusion

The oyster industry is well established in SA and the establishment of shellfish as a carbon sink could be of great benefit to SA, particularly to regional areas. Also, with its reputation as the driest state in the driest continent, SA is not necessarily the ideal location for thirsty Biosequestration projects. This should give impetus for a greater utilisation of alternatives to Biosequestration in the state. Qualifying as an 'additional' activity under the Kyoto Protocol may prove difficult for the oyster industry, especially as it is self-sufficient and not reliant on funding from carbon offsets. The industry will remain sustainable as long as stocks are kept below the carrying capacity of the water body and diseases are not introduced. The main advantage of oyster farming is that unlike other ocean sequestration techniques, the oyster shell permanently removes carbon from the ocean as well as the atmosphere. This aspect will become more important as global warming and ocean carbon capacity affect the amount of carbon absorbed by oceans. A direct comparison between Biosequestration activities and shellfish farming may be unrealistic as the former is underpinned by photosynthesis and the latter by respiration. An independent assessment of the shellfish industry would be required to determine the extent of carbon sequestration and the overall costs of generating carbon offsets through this method. After additionality, the carbon price tag will ascertain whether shellfish sequestration is a viable option in the struggle against global warming. Regardless of anthropogenic policy making, however, shellfish will continue to play their role in mitigating the greenhouse effect.

References

- AGO, 2007, Greenhouse Friendly Additionality Factsheet, Australian Greenhouse Office www.greenhouse.gov.au/greenhousefriendly/publications/pubs/additionality-fs.pdf 9/6/2008
- Brewer, P., Peltzer, E., Friederich, G., Aya, I., Yamane, K., 2000, Experiments On The Ocean Sequestration Of Fossil Fuel CO₂: Ph 2 Measurements And Hydrate Formation, *Marine Chemistry* vol. 72 pp. 83–93
- Brown, K. & Adger, W. N., 1994, Economic and political feasibility of international carbon offsets, *Forest Ecology and Management* vol. 68 pp. 217–229
- CSIRO, *Maximising the benefits of new tree plantations in the Murray-Darling Basin*, CSIRO, www.clw.csiro.au/staff/hairsinep/ffp-lw19052004.pdf 30/5/2008
www.csiro.au/files/files/pirs.pdf 6/5/2008
- DEH, 2005, *Methane to Markets Partnership Landfill Gas Technical Subcommittee, Country Specific Profile*, Australia, Department of the Environment and Heritage, Australian Greenhouse Office, Australian Government, Canberra
- Dury, S.J., Polglase, P.J., Vercoe, T. 2002, *Greenhouse Resource Kit for Private Forest Growers*. Agriculture, Fisheries and Forestry – Australia (AFFA), Canberra.
- EPA, 2005, *Code of Practice for the Environmental Management of the South Australian Oyster Farming Industry*, Environment Protection Authority of South Australia
- Gurney, A., Ford, M., Low, K., Tulloh, C., Jakeman, G. and Gunasekera, D. 2007, *Technology: Toward a Low Emissions Future*, ABARE Research Report 07.16 prepared for the Australian Government Department of Industry, Tourism and Resources, Canberra, September.
- Hamwey, R., & Baranzini, A. 1999, Sizing the global GHG offset market *Energy Policy* vol. 27 pp 123–127
- Hobbs, T. & Bennell, M., 2005, *Plant Biometrics and Biomass Productivity in the River Murray Dryland Corridor*, FloraSearch, SA Department of Water, Land and Biodiversity Conservation.
- Osborne, T., & Kiker, C., 2005, Carbon Offsets as an Economic Alternative to Large-Scale Logging: A Case Study in Guyana, *Ecological Economics* vol. 52, pp. 481– 496
- oceanacidification.wordpress.com/2008/04/24/can-seashells-save-the-world/
- Paul, K.I., P. Polglase, N.C. Coops, C. Baillie, J. C. Carlyle, T. Grove, P.K. Khanna, A. M. O’Connell, B. May, D. Mendham, P. Smethurst (2002). *Modelling change in soil carbon following afforestation or reforestation: Preliminary simulations using GRC3, and sensitivity analyses*. Australian Greenhouse Office, Canberra, Australia, NCAS Technical Report No. 29.
- PIRSA, 2000, *Pacific Oyster Aquaculture in South Australia fact sheet*, Primary Industries and Resources South Australia.
- PIRSA, 2000b, *Shellfish Aquaculture – Factors which can affect Site Suitability*, Primary Industries and Resources South Australia www.pir.sa.gov.au/aquaculture/aquaculture_industry/oysters 26/5/2008
www.pubmedcentral.nih.gov/articlerender.fcgi?artid=91374 10/6/2008
- Rehdanz, K., Tol, R.S.J., Wetzel, P., 2006, Ocean carbon sinks and international climate policy *Energy Policy* vol. 34, pp. 3516–3526
- Serway, R., 1996, *Physics for Scientists & Engineers with Modern Physics 4th Edition*, Saunders College Publishing, Sydney.
www.shellfishculture.com.au Richard Pugh 2/6/2008
- UNFCCC, 2007, Kyoto Protocol To The United Nations Framework Convention On Climate Change, unfccc.int/resource/docs/convkp/kpeng.html
- Van Kooten, G. C., Eagle, A. J., Manley, J., Smolak, T., 2004, How Costly Are Carbon Offsets? A Meta-Analysis Of Carbon Forest Sinks *Environmental Science & Policy* vol. 7, pp. 239–251
en.wikipedia.org/wiki/Oyster 6/6/2008
- Zhang, L., Vertessy, R., Walker, G., Gilfedder, M., & Hairsine, P. 2007, Afforestation in a catchment context, CSIRO Land and Water Science Report Number 01/07

Special Thanks to:

John Cann of “UniSA”, Ian and Cheryl Bishop of “Oyster Bay Shellfish”, Bruce Tilbrook of “ITEK”, Mark Jarvis, Colleen Holmes, Craig Lowe, Mike Willis, Judd Evans of “SA Oyster Growers Association”, Bob Simmonds of “Oyster Bob”, Richard Pugh of “Shellfish Culture”, Simon Kalucy of “Trees for Life”