National review of *Ostrea angasi* aquaculture: historical culture, current methods and future priorities

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Executive summary

Currently in Australia *Ostrea angasi* oysters (*angasi*) are being cultured on a small scale, with several farmers growing relatively small numbers of angasis on their predominately Sydney rock or Pacific oyster farms. Very few farmers are culturing commercially viable quantities of angasi oysters. There are several reasons for this. Although angasi oysters occur in the intertidal zone, they are naturally most abundant in the subtidal and are less tolerant of fluctuating environmental conditions, especially temperature and salinity, than other oyster species. They also have a much shorter shelf life and start to gape after one to two days. Additionally, angasi oysters are susceptible to Bonamiosis, a parasitic disease which has caused major mortalities in several areas. Stress caused by extremes or a combination of factors such as high stocking densities, rough handling, poor food, high temperatures and low salinities have all been observed to increase the prevalence of Bonamiosis. Growth rates of angasi oysters have also been variable, ranging from two to four years to reach market size.

From discussions with oyster famers, managers and researchers and from a review of the literature I suggest that the survival and growth of cultured angasi oysters could be significantly improved by altering some farm management practices. Firstly, growout techniques need to be specifically developed for angasi oysters which maintain a low stress environment (not modifications from other oysters). These include growing the oysters low in the water column or subtidally, reduced densities and more careful handling. Improved broodstock management, including selective breeding and quality control of spat from the hatcheries should also lead to consistent and higher growth rates. Increased shelf life can be attained using methods already developed although they are very time consuming. Mechanisation and new methods of packaging such as modified atmosphere or quick freezing should be investigated.

R&D priorities identified are:

- Develop growout techniques specifically for angasi oysters and their environment.
- Determine improved farm management methods to reduce the effects of Bonamiosis disease.
- Develop a structured breeding program with selection for Bonamiosis resistance and improved growth and condition characteristics.
- Investigate cost-effective methods to extend the shelf life.
- Develop and expand markets, including into SE Asia and to Europe.

Information obtained in this review that is relevant to restoration of angasi reef habitat include:

- Select sites carefully, with good food supply, low energy waters, and not subject to major flooding
- Need good quality spat, low densities and handle them carefully.
- Raise the oysters off the bottom to avoid predators and sediment build up.
- Experiment with size of spat released into the wild to avoid predation.

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Acknowledgments

Many thanks to all the oyster farmers, Government managers and researchers who have provided information for this review. I hope I have accurately presented their views and information that they provided.

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Introduction

Ostrea angasi (Sowerby 1871) is endemic to southern Australia with a wide distribution from Western Australia to New South Wales and around Tasmania, where it occurs from the intertidal to 30 m depths (Edgar 2012). Common names include the flat, mud, native, Port Lincoln or angasi oyster. It has been important in the diet of Australian aborigines for centuries, as evidenced by the distribution and abundance of angasi oyster shells in middens across southern Australia. Angasi oysters were also very popular with European colonists in the 1800's who harvested the flat oyster beds extensively and indiscriminately using metal dredges that took everything in their path. As a consequence, this low profile reef (bed) habitat was largely extinct across its wide distributional range by the turn of the twentieth century. Today the only known remaining angasi reef habitat in its entire distribution is a few hectares remaining in Georges Bay, Tasmania. Although angasi oysters do still occur in most areas, they are in low numbers and as individuals or in small clumps. Natural recovery has been inhibited by low recruitment and a paucity of suitable settlement substrate.

In recent years The Nature Conservancy (TNC) in Australia has been leading efforts to re-establish angasi oyster reefs across southern Australia as part of its *Great Southern Seascapes* Program (http://www.natureaustralia.org.au/our-work/great-southern-seascapes/). These reefs were once a keystone habitat in estuaries and coastal waters of southern Australia, supporting abundant marine life, high biodiversity and fish production, regulating water quality and providing protection for coastal landscapes. TNC, in conjunction with the Australian Government Department of Environment National Environmental Research Program, Marine Biodiversity Hub, has supported the production of a national review of shellfish reef habitat and detailed reports from each State (Gillies et al. 2015). These State reports review presumed historical and current extent of shellfish reefs, indigenous use and early settlement harvesting, ecological decline, and restoring and managing shellfish reefs; they are available at www.shellfishrestoration.org.au

This work in Australia by The Nature Conservancy, a world leading science-based not-for-profit conservation organisation, follows on from their successful shellfish reef restoration efforts in the USA. TNC has been working with local communities, industries and statutory authorities in the USA for several decades to restore native oyster reefs that had been demolished by over-fishing and habitat change. These projects have demonstrated that large scale reef restoration has major beneficial effects in estuaries and coastal waters by restoring ecosystem services and repairing ecological function. Shellfish reefs provide habitat, shelter and food for many estuarine and marine species; they also help keep the waters clean from excessive phytoplankton growth. These established reefs have also delivered economic gains to coastal communities by providing employment in restoration efforts and maintenance of reefs, increased recreational and commercial fishing, and diversified tourism opportunities.

Experimental and small scale farming of angasi oysters has been attempted in all Australian states except Queensland to develop an alternative species to Sydney rock and Pacific oysters in the marketplace and to supplement the European *O. edulis* market. Several major research programs have been conducted in southern States since the 1980's, providing substantial information on the biology and culture methods for angasi oysters. This knowledge is highly relevant to angasi reef restoration efforts, especially hatchery production methods, environmental tolerances of oysters in natural conditions, appropriate handling and management techniques and their susceptibility to diseases. TNC recognises that this information is also important to the expansion of the angasi farming, and as a consequence, they have funded a review of angasi aquaculture in Australia, with the information to be widely available to the aquaculture industry as well as reef restoration ecologists. The preferred modus operandi of TNC is to work in collaboration with partners and there are substantial overlaps between reef restoration and angasi farming.

The Terms of Reference for this project were:

1) Conduct a literature review of the available published and grey literature on historical aquaculture and current methods of producing the native flat oyster *O. angasi*;

2) Conduct in person interviews with *O. angasi* oyster farmers in Tasmania, Victoria, New South Wales, South Australia and Western Australia to ascertain past and current aquaculture methods, concerns and priorities for future research;

3) Produce a synthesis report (*this report*) on *O. angasi* aquaculture, detailing historical culture, current methods and future priorities.

This information will be used to inform future shellfish reef restoration activities of best practice methods for restoring *O. angasi* shellfish reefs and to ascertain the potential for future collaborative research projects and partnerships with the shellfish industry.

Historical culture

Natural spat collection/reproduction cycles

Flat oysters of the *Ostrea* genus are hermaphrodites and readily change sex. Their mode of fertilization and early development differs to Pacific oysters in that they produce fewer eggs which are not ejected into the surrounding seawater; instead the eggs are retained within the female's mantle cavity and are fertilized there by sperm which are brought in with the inflowing seawater. Flat oysters commonly produce about 1-3 million larvae, and survival rate is much higher and more consistent than Pacific oysters because the larvae are initially maintained (brooded) in the female oyster. After about 8 days when veliger larvae have a shell length of around 170-189 µm, they are released into the environment by vigorous movements of the oyster shell. These larvae drift in the currents for approximately two weeks until they find a suitable substrate for settlement and attachment using their byssus gland. They then complete metamorphosis into a juvenile oyster (called spat or seed). These larvae within the mantle give the oysters an unattractive appearance and a gritty texture, and they are not marketable while in this condition.

Traditionally, angasi oysters have been cultured by catching wild spat on collectors such as sticks and shells and then growing them on the seabed, often on a layer of shells (cultch). This was first attempted by Saville-Kent in Tasmania in the 1880's to replenish beds that had been depleted by overfishing with metal dredges. He established several government reserves of 2-5 acres where broodstock oysters were laid on the seabed and various types of collectors for catching spat were placed around the farm (Figure 4). This project was very successful and by 1887 there were 33 established oyster farms around Tasmania. Saville-Kent recommended that the breeding stock of oysters must not be less than 4,000 adult oysters per acre, in order to ensure recruitment (Sumner 1972). He also introduced elevage, the practice of growing oysters off the seabed, and considered this to be important to rapid and even growth of the oysters because they were able to obtain food from all sides, including beneath. He also recommended that clean spat collectors be placed in the water by September because if they were placed too early the young oysters would not settle on the fouled settlement substrate (Sumner, 1972).

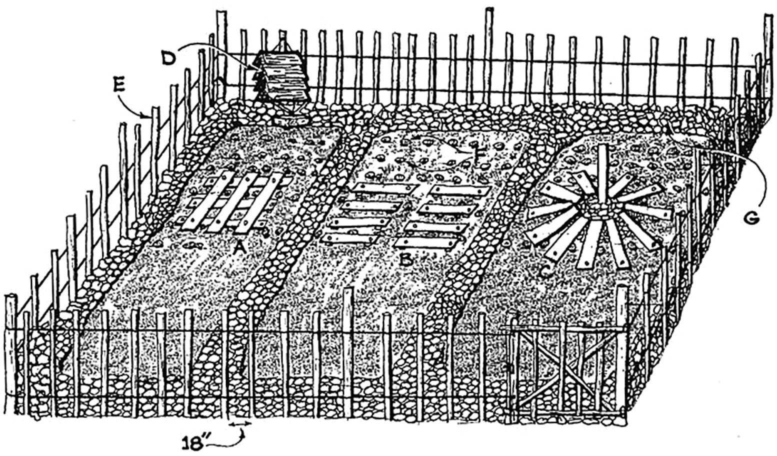

Figure 1. Saville-Kent's model oyster farm 1886 (1 acre, broodstock 6,500 oysters). From Harrison (1995) and Sumner (1972). A, B, C - 'single pale' spat collectors, D - 'ridge tile' collectors, E – protective fence, F - broodstock oysters, G – stones.

O. angasi (referred to as the Port Lincoln oyster) in West Lakes, South Australia were observed to spawn from mid-October to early March, when temperatures reached approx. 18 ˚C. (O'Sullivan 1980). Only oysters >68 mm in length contained larvae, and 5.6% -21.4% of these larger oysters (68-94 mm length) were incubating larvae. They had a mean of 1,210,000 larvae per brood and between 0.91 and 1.33 broods of larvae were produced per adult oyster. Shelled veliger larvae measured 137-187 mm length and the incubation period under natural conditions and approx. 18 ˚C was 15-18 days. Females were observed to change to males quickly after spawning (O'Sullivan 1980).

Collection of naturally released spat in the wild was trialled by Hickman and O'Meley (1988b) using PVC plates and French hat type collectors deployed in the Geelong Arm area of Port Phillip Bay. Although up to 600 oysters per collector was achieved, these oysters became heavily fouled and the settlement shell was very thin. Removal of the oysters was also time consuming and many were damaged in the process. This method of collecting spat was therefore deemed to be unsuitable for commercial mariculture operations. 'Natural' settlement in artificial 'spatting ponds' was also attempted but no settlement occurred.

A histological study of the reproductive cycle of *O. angasi* in Port Phillip Bay (Hickman and O'Meley 1988b) showed that the gonads developed from May to July, and over-lapped with maturation which extended from May to February. Oysters were brooding larvae from October to February, although the main brooding period was October to November. In 1985/86 the main larval settlement occurred in November and December in the eastern, Mornington Peninsula side of Port Phillip Bay, and during November and December in the eastern, Geelong Arm section of the Bay. Spent oysters occurred during summer and autumn (December to April).

A diving survey of angasis from five estuaries on the south coast of NSW found live oysters on hard substrates projecting above sand, silt and mud sediments as well as on other vertical substrates such as rocky outcrops, jetty piles etc. The vast majority were in a subtidal band of 1-4 m below low water (Heasman et al 2004). No live oysters were found on extensive shell beds in deeper waters, possibly because of higher levels of predation and smothering of small oysters by fine sediments after settling in deeper low current areas.

Hatchery production & growing methods

A detailed account of angasi hatchery and nursery production at the Marine Research Labs., Queenscliff, Port Phillip Bay, Victoria is provided by Hickman and O'Meley (1988a). This report includes comprehensive descriptions of the culture facilities and operating methods used for broodstock conditioning, larval rearing and settlement, spat rearing, and algal food production. A workshop on hatchery, nursery, farming and post-harvest handling techniques used to culture flat oysters in NSW during 1997-2000 and in Victoria between 1986 and 1992 assessed the prospects for flat oyster farming in NSW. In the report from this workshop it was concluded that there were "few if any serious technical barriers to the reliable production of seed juveniles" (Heasman and Lyle 2000). Information provided in these reports are summarised below.

Hatchery production of larvae became the preferred method in all southern states of Australia because of the increased reliability to produce large numbers of larvae, ability to produce larvae over a wider period of the year, and increased possibility for selective breeding. The spat produced from the hatchery were settled on small pieces of shell, making them individual, 'cultchless' oysters, which had the advantages over wild spat of not having to be removed from the settlement substrate and no over-growth (Heasman and Lyle 2000).

Broodstock:

In Port Phillip Bay Hickman and O'Meley (1988b) were able to produce spat 3-4 months earlier than 'wild' caught spat. They collected broodstock from the wild in Port Phillip Bay before the commencement of the breeding season, noting that the condition of the oysters can vary considerably between locations. Because oysters in good condition take less time to bring into breeding condition, they recommended that oyster stocks are monitored annually from different locations. Larvae were obtained earlier by placing the broodstock oysters in a conditioning system from late July to early August and raising the temperature from ambient sea temperature to 21 ˚C at a rate of 1 ˚C per day. The temperature was maintained at 21 ˚C and the broodstock were fed microalgae daily. When mature they released about two million oysters which were collected on mesh sieves. Hickman and O'Meley (1988b) found that the best months for conditioning for hatchery production of larvae were from July to October. Oysters were observed to spawn several times in one season; however, spat produced from spawnings later in the breeding season were found to grow at a slower rate when transferred to the sea.

A study of the genetic structure of wild flat oysters collected from southern NSW estuaries, Port Phillip Bay, Victoria, Bicheno, Tasmania, Streaky Bay, South Australia and Albany, Western Australia found very little or no difference between sites, and as a consequence Heasman et al (2004) concluded that there was no genetic reason to limit the movement of broodstock or spat around NSW and beyond, provided the genetic diversity of broodstock is maintained at a high level.

Larval rearing:

The first reported attempts at rearing *O. angasi* in a hatchery were by Dix (1976) in Tasmania. Larvae were released from parents at about 190-200 µm in shell length and spat began setting at about 300 mm when 12-20 days old at 17°C. Few pelagic larvae larger than 320 µm were observed. Success rates varied but one batch yielded a significant spat catch on scallop shells which were kept in a recycling system before transfer to the sea.

Hickman and O'Meley (1988a, b) collected larvae that were released naturally from the broodstock at approximately 180 mm in length. Larvae were commonly released at night and collected on the retaining sieve. They found that a 1000 L tank was suitable for rearing larvae released from one oyster; i.e. approximately two million oysters at a density of 2 larvae/ml. Synchronised spawning of multiple oysters rarely occurred, and in their large conditioning system, the maximum number of simultaneous larval releases that could be expected was five, so a 5,000 L tank was sufficient.

The larvae were reared in tanks containing 1 mm filtered seawater at 21° C, and initially fed *Isochrisis galbana* (Tahitian strain T.ISO), at a concentration of 50,000 cells/mL. *Pavlova lutheri* was added to the diet a few days later if available. Hickman and O'Meley (1988a,b) monitored the larval food consumption using a fluorometer, ensuring the larvae were given the correction ration. They found that this was a very effective means of assessing the health of the oysters, and if a decrease in food consumption was detected, they immediately changed the water and fed the larvae with a new source of algae. They also regularly monitored the growth of the larvae, and observed that this along with optimum algal feeding greatly improved husbandry methods and hatchery production. The *O. angasi* larvae took 12 -15 days to reach settlement size of 320-340 mm when fed as described above and held at 21° C. When a large percentage of the larvae had developed eye-spots, clean scallop shell was placed on the bottom of the tank and when the shell became covered in newly settled spat, the larvae were transferred to the settlement system.

According to Heasman and Goard (2000), larvae for rearing in the hatchery can be obtained by stripping larvae from brooders by vigorously flushing the gills and mantle cavity to remove them. Larval broods in the mantle and gills are recognised as either white-sick (trochophore larve), grey-sick (intermediate larval stage) or black-sick condition (indicative of advanced, ready-to-release larvae 180 mm). Otherwise larval culture of angasi larvae largely followed standard Pacific oyster culture techniques.

Table 1. Summary of hatchery rearing data for *Ostrea angasi* at Port Stephens Fisheries Centre NSW. From Heasman and Goard (2000).

Date	25/10/1996	19/11/1996	23/12/1997	16/12/1999
Source of broodstock	Pambula	Pambula/Tuross	Pambula	Pambula
Total number of broodstock examined	6	?	?	140
Number of Brooders	1	8	6 grey/black	2 black / 3 white-sick
Number larvae stripped (million)	2.28	12.1	14	3.62 / 4.44 (1.28'D')
Mean fecundity (million)	2.28	1.51	2.33	1.81 / 1.48
Hatchery Tank volume (litres)	2 x 1000	10,000	20,000	20,000
Number of larvae to set (million)	0.85	4.22	8.18	2.885 (combined)
Larval survival %	37.3	34.8	58	46.8
Number of spat (million)	0.443	3	3.78	1.4
Set rate %	66	71	46	48.5

General: Black-sick larvae have been stripped from oysters 75 mm to 150 mm shell height.
Fecundity of individually stripped black sick oysters ranges from 0.475 to 2.28 million.

Metamorphosis and larval settling:

At the hatchery in Queenscliff the larvae were settled onto crushed scallop fragments about the same size as the larvae, approximately 340 mm. The larval settlement system consisted of mesh-based PVC 'pots' suspended in a tank, with each pot receiving ready to settle larvae and enough scallop shell fragments to cover the base of the pot. Metamorphosis occurred during settlement and the feeding rate slowed down as the larval feeding organ (velum) was lost and the gills of the spat developed. Most larvae settled within 48 hours and changed shape with rapidly growing shell. Selection of the faster growing larvae in the hatchery did not result in improved growth rates in the nursery phase (Hickman and O'Meley 1988a, b).

At Port Stephens hatchery metamorphosis occurred at approx. 320-340 µm shell height, 16-20 days after stripping at 25oC. Cultchless settlement was prompted using epinephrine (Heasman and Goard 2000). Metamorphosed spat were then transferred to downwellers fitted with 220 µm mesh.

Juvenile culture/nursery phase:

Newly settled spat were transferred from the hatchery at Queenscliff to indoor upwellers (PVC tubing with mesh on the bottom) at 20° C for at least four weeks. Water with algal food flowed upwards through the mesh into the tube at a controlled rate which fluidised the oysters. Spat larger than 3 mm were transferred to outdoor upwellers. The production of nursery spat was greatly enhanced by routinely monitoring feeding and growth rates so that the spat were fed the optimum ration, and by grading the oyster seed before the average size varied by more than 20% (Hickman and O'Meley 1988a,b). Spat maintained an optimum feeding rate when the T.ISO concentration was 40,000-75,000 cells per ml, or equivalent fluorescence from a mixture of algae. A dose pump was used to introduce algae into the system at the rate that it was being consumed, which resulted in spat growth rates of ~ 1mm per week. Optimum feeding rates were maintained for spat up to 4mm in size, but this became progressively more difficult as the spat increased in size after 4mm. Best spat growth rates were achieved when the diet consisted of at least 30% of the diatom *C. gracilis* (now *C. muelleri*) (Hickman and O'Meley 1988a,b).

At the Queenscliff Labs algal species routinely cultured as food for larvae and recently settled spat were *Isochrisis galbana* (Tahitian strain T.ISO), *Chaetoceros gracilis, Pavlova lutheri* and *Tetraselmis seucica*. They were grown axenically in glassware to the 2L stage, then in 0.2 mm filtered seawater in 200L sterile plastic bags. Larger, non-axenic outdoor cultures of algae in 1000 L and 5000 L tanks were fed to broodstock and older spat in the outdoor nursery. Details of the algal culture systems are provided in Hickman and O'Meley (1988a), including using repeated inoculations from the same culture and maintaining large volume outdoor cultures.

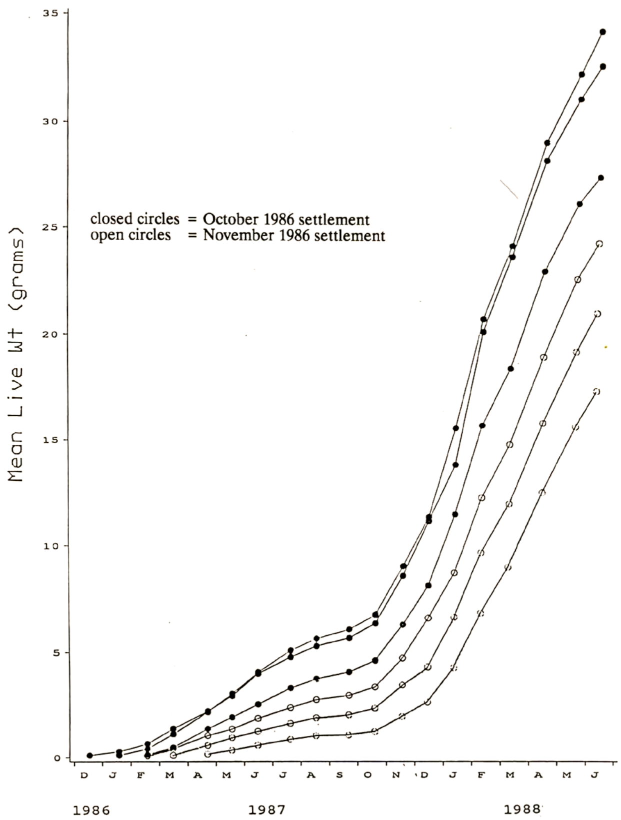

Figure 2. Growth of angasi spat sent to sea in Port Phillip Bay at monthly intervals at a size of 10 mm. From Hickman and O'Meley 1988b.

Hickman and O'Meley (1988a, b) emphasised the importance of feeding algae that were in the actively growing (log) phase as this reduced problems associated with bacterial contamination of larvae and spat. After algal cells had stopped growing (stationary phase), large quantities of exudates excreted by the algae were observed and these are the main substrates for bacterial growth. Other factors that they considered influenced minimised bacterial contamination were using 'oceanic' type water of high salinity and low turbidity, and operating the hatchery when seawater temperatures (and probably bacterial numbers) were relatively low.

In NSW juveniles were transferred to downwellers and grown in these of increasing sized mesh until retained on a 350 um screen 7-10 days later. They were fed a mixed diet of diatoms *Chaetoceros sp*., *Pavlova lutheri* and *Isochysis* sp. The spat were transferred to upwellers for on-rearing at ambient temperatures and fed mixed algal blooms either from ponds or in field nurseries. Nursery rearing and associated grading onto larger mesh screens continued until spat were 8-10mm in length and suitable for sale to commercial oyster farmers (Heasman and Goard 2000)

Husbandry, including feeding, growth and environmental conditions

In Tasmania early trials using hatchery reared angasi spat settled on scallop shells (Dix 1976) were not overly successful. After two years of ongrowing suspended from a raft in North West Bay, south of Hobart, oyster mean shell length was 78.7 mm but mortality was high at 43%, although the remaining *O. angasi* were in very good condition (Dix 1980). Growth showed a tendency to decrease with increasing water depth. Dix (1980) considered that wild caught spat would survive better, especially if they were collected during early summer when initial growth increments would be greater than those for the experimental oysters which were not placed in the sea until early autumn.

An in situ study of growth and survival rates over 12 months of three size groupings of *O. angasi* held in plastic mesh envelopes at 2-4 m depth in three areas of existing oyster beds in Georges Bay, Northeast Tasmania found that weight changes over the 12-month period for each of the size classes were comparable, but the relative increase in live weight was markedly higher for the small oysters (Mitchell et al, 2000). Mean increase in shell length ranged from 7 to 28 mm and live weight from 40.3 to 47.0 g for large to small oysters, respectively. Instantaneous mortality rates were variable between sites and sizes with percentage mortality ranging from 6.43% to 22.95% (Mitchell et al, 2000).

Some observations from a long-term harvester and farmer of angasi oysters in Georges Bay Tasmania over many years included that angasi oysters like to settle on their own shell and the best oysters were obtained when they were placed on the bottom in clean substrate areas where they live naturally. On the lease the growth rates were too slow and if suspended in the water column, the shells became chalky. In mid water suspension, fouling was a problem, and oysters could be overgrown by ascidians in three months. He experienced good natural settlement in Georges Bay in some years, but also mass mortality due to flooding from the Georges River. He tried spreading clean clam shells from a nearby beach over an area of the bay and added angasi spat collected from the wild. However, the juveniles were moved around during storms and many were lost. The ideal mature oyster stocking density was observed to be 20-40/m^2. Also, the habitat of Georges Bay was observed to have changed, and many areas are now covered in seagrass and mud. He suggested that suspended sediments contributed to high mortalities, also when the oysters were weak, especially after spawning. Predators of oysters included the green crab (*Carcinus maenas*) and whelks. The oysters were also not marketable for 4-5 months each year because they contained larvae in their mantle.

In Port Phillip Bay Victoria *O. angasi* showed a strong seasonal pattern of growth and Hickman and O'Meley (1988b) observed that while food needed to be above a certain threshold to allow shell growth, food availability had a much greater effect on meat yields. In summer shell growth often occurred even though oyster meat condition was in decline. Also, summer shell growth could not be slowed by trimming the shells during rumbling, as the trimmed shell was rapidly replaced. They also found no evidence for reduced shell growth improving meat yields.

The husbandry technique which had the greatest effect on improving growth rate was a reduction in the density of oysters. Although grading by size appeared to accelerate the growth of larger oysters, the gains in growth were small compared to halving the density. The variability in growth rate which is common in oysters was found to not be greatly reduced by grading. Also, growth rate and time to harvest was significantly improved by producing hatchery seed early in breeding season which was then placed out on the farms in early summer. These oysters had two summers of grow-out and could be harvested for the domestic market at 70 g after eighteen months. In Port Phillip Bay flat oysters were in good condition from April to October, with best condition from May to August. However, considerable variation was observed between years in the months when oysters were in best condition, in oyster condition between sites, and availability of particulate oyster food (Hickman and O'Meley 1988b).

The growth rate of oysters was similar between those grown on bottom- mounted racks and those in mid-water with sub-surface floatation, and was much lower in oysters grown in bags attached to surface longlines in exposed waters. When the fastest growing oysters were selected in the nursery for ongrowing in the sea, the growth rate of the resulting adult oysters was not better than that of the slowest growing siblings in the nursery. Also, holding oyster seed in the nursery upwellers for several months did not affect their subsequent growth at sea. The different growth treatments had the greatest effect on oyster condition during the summer months, when food levels were often low and metabolic rates high. Hickman and O'Meley (1988b) suggested that if oysters cannot completely cease shell growth in summer even when they are in poor condition, this may exacerbate summer mortalities, along with post-spawning stress in larger oysters.

Extensive trials were conducted to develop commercial field nursery and on-growing systems for flat oyster production in the open waters of Port Phillip Bay (Reilly and Hickman 1994). After major mortalities of mature two year old stock due to Bonamia, it was decided that traditional bottom and rack culture growing methods were unlikely to be viable, and new suspended culture methods that produced very fast growth rates and low mortalities were developed. By growing oysters rapidly they were able to harvest them within two years and before the first spawning when the incidence of Bonamiosis increases. Reilly and Hickman (1994) proposed this as a management technique to minimise the effect of Bonamiosis, Suspended culture methods also enabled more oysters to be grown per area of seabed but at lower densities because they were grown in layers throughout the water column (three-dimensional culture).

For nursery stage angasi spat 3-10 mm in size, Reilly and Hickman (1994) developed a deep-water self-cleaning rotating mesh cylinder system. Oysters were held in mesh cylinders which had an attached sail that utilised current flow to rotate the cylinder. This was held in a supporting framework which had rows of brushes attached to clean the meshes as the cylinder revolved. This system was completely submerged and moored on the seabed. They also designed and trialled a nursery 'corf' system which consisted of a stack of interchangeable nursery boxes that could be positioned directly on the bottom. Although not comprehensively trialled, both systems showed superior performance of oysters with less maintenance than a traditional bag and tray system.

A new grow-out system was also developed where individual angasi oysters were attached to 5m long tapes, or longer in deeper water, and were suspended from longlines which were moored to the bottom and supported by appropriate floatation (Reilly and Hickman 1994). Oysters of mean length 37 mm and 8 months old which had grown rapidly over the summer months in fine plastic mesh bags, had a mesh tag glued to the cupped valve and were attached to polyester tape using commercial plastic tag pins applied with a tag applicator gun through the mesh tag and the tape. Oysters grown on a subsurface longline had significantly faster growth than those attached to surface longlines, and growth rates were the fastest over the summer months. At harvest mean lengths were not significantly different between oysters grown at a density of 50 per metre and those at 100 per metre, nor was there a strong relationship with position on the dropper. The advantages of suspended culture were considered to be (a) increased availability of food to each oyster as not crowded together, and (b) the flexibility of the tag pins enabled the oysters to move over one another, resulting in a self-cleaning action by limiting the colonisation of fouling organisms. These oysters grown under suspended culture also were perfectly shaped and had low incidence of mudworm (Reilly and Hickman 1994).

The Victorian Government prepared a pre-feasibility study for flat oyster farming in Victoria to stimulate a developing industry. This report provided information on potential markets, infrastructure requirements, capital and operating costs, revenue and return on investment, and sensitivity analyses (Anon 1991). It also included proposed site details and technical assumptions, and described the latest ongrowing technology of attaching juvenile oysters to suspended tapes hanging from a suspended longline. Using these assumptions it was estimated that up to 30,000 dozen oysters per hectare could be grown in good growing areas with plenty of food, allowing for 10% mortality. Thus a good 3 ha site (recommended start-up pilot scale size) could produce a maximum of 60-75 tonnes. At the proposed sites they predicted that the oysters could be harvested for local markets after two summers, and after 3 summers for export markets at the preferred weight of 100 g. Risks to production included financial risks, slower than predicted grow rates, community pressures for recreational use of the water, ability to scale up to commercial production, and mortality from Bonamia (see Anon 1991).

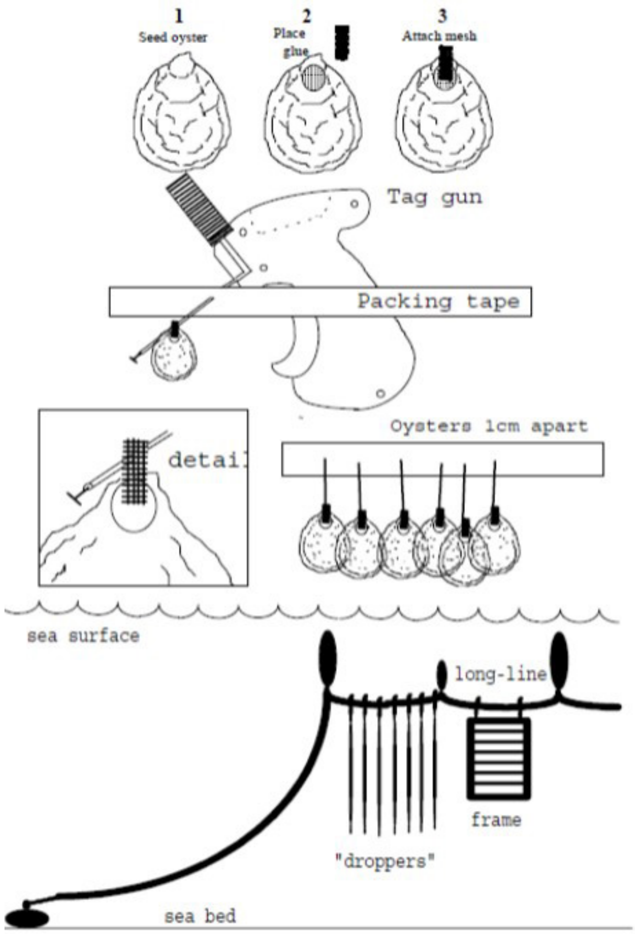

Figure 3. Method of attaching oysters to tape and hanging them as droppers on longlines. From Reilly and Hickman 2004.

Figure 4. Angasi oysters grown in the Clyde River, NSW.

In south-western Western Australia Ocean Food's Pty Ltd (Ocean Foods) received approval in 1990 to farm oysters on leases in both Oyster Harbour and Princess Royal Harbour and to develop a hatchery. In 1992 after angasis were being produced, Bonamia was found in the oysters and annual mortality of around 90% per annum in stock growing-out in leases was observed. The farms persisted until 1996 but mortality from Bonamiosis was too high (J. Bilton. pers. comm.).

In the report from the workshop on problems of producing and marketing flat oysters in NSW, Heasman and Lyle (2000) noted that angasi oysters could be grown to market size of 70 mm (80 g) in 18 to 24 months in intertidal tray culture in NSW, and even quicker in suspended culture on deeper sub-tidal leases. At optimum growing height of 25-30 cm below that for Sydney rock oysters, angasi oysters showed low susceptibility to mudworm and biofouling, especially if air dried in the shade for 2-3 days each month during November to May. Practical experience of several growers of angasi oysters in NSW were also provided in the Heasman and Lyle (2000) report. These included stocking spat at 8-10 mm length in 35 L Stanway cylinders and growing them at about 0.5 m above zero datum, which reduced protracted exposure to drying or extreme heat. This phase took 3 months for spat stocked in summer that benefited from high growth promoting temperatures to 6-9 months for spat stocked in autumn and overwintered in the cylinders. At above 20 mm they were transferred to mesh baskets or trays for growout to harvest. The tumbling action of the cylinders resulted in a good cup shape of the oysters and reduced biofouling and overcatch. Little mortality due to mudworm, disease or predation occurred; most deaths were due to poor farm management, with baskets falling on the bottom and overcrowding leading to starvation (Heasman and Lyle (2000).

Disease and predators

Bonamiosis is consistently identified as the greatest potential disease risk to long-term sustainable angasi oyster culture (Heasman and Lyle 2000). *Bonamia* spp. are small protozoan microcell parasites 2-3 μm in diameter found within the haemocytes (blood cells) of flat oysters. They can occur singly or as many as 10-20 microcells within an individual haemocyte (Adlard 2000). Infected haemocytes aggregate and form lesions in the tissues, especially in the connective tissues of the gills, mantle digestive gland. Heavily infected haemocytes become necrotic and die, releasing the *Bonamia* microcells to be ingested by other haemocytes. Many of the infected oysters eventually die, probably because they cannot replace infected blood cells when energy reserves are low, such as after spawning. Transmission of Bonamiosis is direct, without the need for an alternate host and can spread rapidly under dense culture (Adlard 2000). Transmission by infective stages carried passively on currents between oyster beds is suspected.

Bonamia sp have been transmitted between flat oyster species and can also infect other bivalves including Pacific oysters *Crassostrea gigas* (see Lynch et al 2010) . In New Zealand distinct seasonal patterns have been observed in *Bonamia exitiosa*, with an incubation phase in spring when the oysters become infected by parasites taken in during feeding; this phase is subclinical and difficult to diagnose. In the proliferation phase after spawning (summer and autumn) the parasites divide by binary fission and proliferate and result in the greatest mortalities. During the winter plasmodial phase most parasites become dense and necrotic (Hine 1991).

Bonamiosis has caused major losses of natural beds and farmed stock in Port Phillip Bay and Western Port Bay, and to a lesser extent in southwest Western Australia and in south and eastern Tasmania. This was significant as *Bonamia exitosa* and *ostreae* are notifiable diseases under the Office International des Epizootics (OIE) regulations that governs seafood imports into the European Economic Community. *Bonamia* sp. was first detected in the summer of 1991 in angasi in Victoria, then in Tasmania and Western Australia (Adlard 2000). In Western Australia, significant mortality in cultured oysters was often compounded by a herpes-type viral infection (Hine and Thorne 1997). It was particularly lethal in larger reproductively active oysters (Heasman and Lyle 2000).

A survey of angasi oysters in south coast NSW estuaries of Merimbula Lake, Pambula Lake, Bermagui River estuary, Wagonga Inlet at Narooma and Clyde River estuary at Batemans Bay found *Bonamia* sp. at all locations sampled but at varying levels between estuaries, with an overall average of 26%. However, no outbreaks of Bonamiosis were recorded. A possible viral infection was observed in up to 10% of sampled oysters (Heasman et al 2004).

In Tasmania a Government-initiated program in 1991 that allowed harvesting of wild native oysters from Georges Bay and on-growing them to market size on marine farms in other areas of Tasmania (Mitchell et al 2000) ceased abruptly in 1994 with the onset in translocated oysters of the disease Bonamiosis. *Bonamia* sp. was first identified in Tasmania in 1992 in a sample of flat oysters from Georges Bay (Wilson et al., 1993) but the prevalence was low and no elevated levels of mortality were reported. Subsequent research showed that *Bonamia* sp. had a low prevalence (3-35%) in Georges Bay oysters compared with stocks in Victoria, and mortalities were low both amongst cultured and wild oysters (Wilson et al 1993). Bonamiosis was thought to be more prevalent in translocated oysters because of the stress of handling and relocation (DPIW 2007). Research at that time found that angasi oysters grew faster with higher survival in the subtidal than high intertidal zones (Wilson et al 1993).

An investigation into commercially viable ways for monitoring for disease outbreaks in flat oysters in Victoria based on the standard protocols of OIE which requires examination of histological sections or tissue smears from 150 oysters from 3 sites annually for two years, except for Bonamia which required samples to be collected twice a year for two years, concluded that the costs were not commercially viable. The minimum program recommended was testing for Bonamia at one site using heart smears and was costed at $36,000 (in 2000) (Hickman et al 2000).

After the demise of *Ostrea edulis* in Europe, juvenile angasi oysters were assessed as a potential replacement oyster to culture in France (Bougrier et al (1986). However, angasi oysters were found to be susceptible to *O. edulis* parasites *(Marteila refringens* and *Bonamia ostreae*) and also very sensitive to a haplosporidian pathogen (*Haplosporidium* sp) endemic to Brittany. Early mortalities were attributed to this haplosporidian because mortalities due to *B. ostreae* in excess of 50% are not normally observed until 10 months after the beginning of the culture period and *M. refringens* requires 12-14 months (Bougrier et al. 1986).

Flatworms *Imogine mcgrathi* were identified as a threat to oyster production in NSW in the early 1900s. This has been exacerbated by the use of fine mesh trays, cylinders and baskets for oyster nursery culture because the flat worms can find protection from desiccation at low tide in the fine mesh and continue to predate on the oyster spat. Flatworms can consume about one oyster per worm per month and when occurring in high densities they have a major impact. Regular inspection of spat during the nursery phase and increasing mesh size helped to control them. Oysters can be treated for worm infestations by exposure to freshwater; for two days for mudworms and 5-15 minutes for flatworms (Nell 2001). In Tasmania, mudworm infestations have generally only been an issue when the oysters have become covered in silt or the baskets of oysters have come in contact with the substratum. Cleaning the oysters of mud and raising them off the bottom have generally been effective control methods.

A mudworm of the *Polydora*- complex species, at the time thought to be *Polydora websteri,* was considered by Nell (2001) to be the most damaging of four spionid polychaete worms which infest and kill large numbers of Sydney rock oysters as well as flat oysters. The adult worm which is up to 25 mm long and red in colour, lives inside the oyster shell but maintains external contact through a tube across the lip of the shell. Poor conditioned and weak oysters die from infestations of mudworms and losses can be high. Healthy oysters often cover the worm with shell, forming a mud blister, but this makes these oysters unsaleable because the blister ruptures easily when the oysters are opened, releasing a foul smelling and unsightly mud patch with shell shards on the oyster meat.

Introduction of a new and virulent species of mudworm in oysters translocated from New Zealand in the late nineteenth century was postulated by Ogburn et al (2007) as causing the permanent destruction of natural subtidal oyster reefs in temperate and sub-tropical eastern Australia. They suggest that this has led to profound and most likely irreversible change to the structure and function of these estuaries. These mudworms of the polydorid complex of spionid polychaetes, include the genera Polydora, Boccardia, Pseudoploydora and Dipolydora. Based largely on Sydney rock oysters, evidence was presented that a new and foreign species of mudworm was responsible for subtidal oyster mortalities rather than overharvesting and increased siltation. Ogburn et al (2007) concluded that active restoration of subtidal oyster reefs will not be successful in south-east Australian estuaries because of the mudworm. They argue, however, oyster populations can be restored/maintained through aquaculture which concentrates on growing oysters off the bottom in the intertidal zone. If placed on racks at approximately mean low water neap tides, the oysters will be out of the water for approximately 30% of the tidal cycle, which limits mudworm infestation. Air drying procedures in floating oyster cultivation are also used by industry to control mudworm infestations. However, the theories of Ogburn et al (2007) have been questioned in recent publications which consider mudworms as a symptom of ecological change, rather than a cause (Diggles 2013).

Post harvest, transport and marketing

A study of the storage and shelf life of angasi oysters by Mantzaris et al (1991) found that shelf life depended on storage temperature, humidity and extent of gaping by oysters. Oysters at 20 oC under normal conditions had a shelf life of only 2 days but this could be extended to up to 23 days by chilling oysters to 1.5 oC in iced water and weighed down by a 1.5 kg load to reduce gaping. They stressed that the most important factor is effective chilling to minimise the growth of bacteria, and recommended that oysters should be chilled to 0.5 -2oC immediately after harvest with either a high humidity chiller or a 'curtain of ice'. Refrigeration should not be relied on to bring the temperature of packaged oysters down the chilled temperatures. Chilling should be continued and the ice never allowed to melt completely until the product reaches the consumer. Oysters kept moist, prechilled to less than 3 oC and tightly packed in polystyrene boxes and stored at 4.5 o C remained fresh for 14 days. Mantzaris et al (1991) also recommended that the oysters should be layered into the container which is completely filled so that the lid has to be forced shut, to ensure that the oysters are packaged under pressure. *E. coli* bacterial counts and analysis of reducing substances were not useful indicators of spoilage. Oysters oriented with the heavier, more curved '-shaped' shell on top had higher survival than oysters oriented in other ways, presumably because it was more difficult to gape with the heavier shell on top. Storage life was not increased with the presence of coolants.

Participants at a workshop discussing problems of producing and marketing the flat oyster in NSW identified that a major impediment to the development of angasi culture was postharvest and marketing (Heasman and Lyle 2000). The biggest challenges were the short shelf life of 2-3 days when handled the same as Sydney Rock oysters, highly variable meat quality and presence of larvae (black-sick and grey-sick brooders) in otherwise marketable oysters. The need for angasi growers (and not marketers) to collectively ensure uniform high quality product with a standard attractive name and to develop markets and promote farmed flat oysters was highlighted at the workshop (Heasman and Lyle 2000).

Advice from marketers and compiled by Heasman (2000) included:

- Define flat oysters relative to other seafood and have them recognised as a distinctly different product to other oysters
- Develop and apply minimum flesh quality standards.
- Develop a marketing strategy for angasi oysters.

Summary of state differences, major successes, limitations and concerns

During the twenty year period from mid 1980's to mid 2000's major efforts were extended by both governments and industry to developing viable angasi oyster aquaculture industries, especially in Victoria and NSW. Attempts were also made in Tasmania and Western Australia, but these were terminated after major mortalities caused by Bonamiosis. The protozoan parasite *Bonamia* sp. also caused major mortalities in Victoria, especially in post-spawning adult stock. New growing techniques were recommended in Victoria to minimise losses; these involved growing oysters attached to tapes in deeper water on submerged longlines where they grew quickly and could be harvested within two years, and before the oysters spawned and became more susceptible to Bonamiosis. This suspended culture system also enabled more oysters to be grown at lower density because they were layered through the water column. Mortalities due to Bonamiosis were not an issue in NSW and angasi oysters were successfully grown in small quantities on Sydney rock oyster leases where they generally grew best at a growing height of 25-20 cm below that for Sydney rock oysters. Limited air exposure for several days each month was recommended to reduce biofouling. In South Australia research on angasi aquaculture was limited and primarily related to site selection up until about five years ago when industry requested SARDI to provide angasi stock.

Gaping very quickly after harvest and a short shelf life of 2 days was recognised as a major issue for the industry. The Victorians developed methods to extend this shelf life to 2-3 weeks by keeping the oysters constantly chilled and weighing them down to prevent gaping; however, this was time consuming and costly. Marketing was also seen as an issue, especially the need to identify the position for flat oysters in the market place and for the growers to collectively ensure a consistent high quality product was available to the market.

No attempts at reseeding or restoring reefs occurred during this time, except for a few farmers who scattered angasi spat on the seabed as a means of trying to culture them, generally with limited success.

Current farming

The synthesis below has largely been obtained from interviews with current growers and government researchers and managers in the five states of southern Australia where angasi occurs naturally.

Natural spat collection/reproduction cycles

In southeasten Tasmania, angasi spat have been successfully collected in the wild by Intertidal Oyster Solutions (IOS). They hang 'Zapco' spat catching slats from their double backbone longlines in a venetian blind-style configuration for the larvae to settle on, and the settled juveniles can be removed by flexing the slats. Their observations are that as few as one in fifty animals spawn when examined in a batch, and spawning occurs primarily from mid-November to mid-January, although they have had had grey/black sic animals in early March. IOS are now developing their own broodstock and are looking to hatchery production of spat in the future. Natural spawning of spat in 2016 has been extremely successful. IOS advices that overcatch could potentially cause problems if husbandry events are not handled in a timely manner around the spawning season.

Figure 5. Slats used to collect Sydney rock oyster spat in the Georges River, similar to those used by IOS.

Hatchery production and growing methods

In Port Phillip Bay, Victoria the hatchery at Queenscliff (formerly MAFRI) is conducting at least one spawning of angasi oysters per year, although the primary purpose of their hatchery is to produce mussel spat. They have found that angasi oysters are difficult to condition during the year and hard to trigger to spawn, so spawnings occur in the summer months. They collect broodstock that are ready to spawn, i.e. release larvae, but have observed that larvae aren't released from all oysters at once. The metamorphosing spat are settled onto old scallop shells, with several oysters per shell; around 5 oysters per shell is considered suitable. Research is required on conditioning broodstock so multiple spawnings can be obtained throughout the year. Low survival rates in the hatchery at times has been attributed to time when spawning can occur, as mussels are a priority, rather than hatchery methodology. If spawning is delayed, problems can occur with larvae and algae because of declining water quality over the summer months.

Settling oysters on longline rope and growing them to around 1 cm, approximately 3 months, before placing the longlines in the sea was also suggested. The oysters can be grown-out on the rope until 50-60 cm diameter and then retrieved and placed in cages for final grow out to harvest as this provides a better looking oyster for the marketplace.

Shellfish Culture Pty Ltd at Bicheno and Pipe Clay Lagoon have conducted trial production runs for angasi on a number of occasions, including in the 1990's, early 2000's and more recently, 2010's. Only small numbers were produced on each occasion and the performance of these oysters both in the hatchery and on the farms was variable and not considered to be commercially viable. However, they acknowledged that their hatchery methods are based on large scale production of Pacific oyster seed, and have not been refined for angasi culture, which likely explains their lower survival rates compared to other hatcheries in Australia which are dedicated to the production of angasi spat.

The trials at Shellfish Culture have shown that larvae were available in the wild in December, but if broodstock were conditioned in the hatchery, larvae could be obtained over a longer 4-5 month period. As it is not possible to sex the oysters externally, Shellfish Culture conditioned approximately 200 oysters in a tank. Larvae were generally released continuously from an oyster over approximately two weeks. They were collected and grown in larval rearing tanks for approximately 10 days. The diet consisted mainly of flagellates (in contrast to mainly diatoms for Pacific oyster larvae). Difficulties were experienced in the settlement to 5 mm juvenile stage, as techniques were designed for Pacific oysters, but performance of 5-50 mm oysters was good. In 50 -100 mm length oysters, however, ongoing mortality of 70% or more was observed. They also suggested that low genetic diversity in the oysters may have affected the low recovery rate.

At the South Australian oyster hatchery near Port Lincoln, angasi larvae were first produced using NSW broodstock about five years ago. However, now only local broodstock are permitted, although wild stocks are low. Larvae are generally available from early October, but best time is late October/early November. In the wild most angasi oysters are attached to razor fish. Of 120 broodstock collected in late 2014, only three had larvae attached (sic) and they produced one million larvae. In 2015 five million larvae were spawned and 1 million spat were produced, i.e. 20% survival in the hatchery. Subsequent mortality has only been 1% in 5-10 mm spat. At the SARDI hatchery oysters have been found to be spawning for about six months of the year, but generally < 10% of all oysters release larvae at any one time. Thus a high proportion of the spat is from only a few broodstock. They suggest that genetic studies are required, including cryopreservation of sperm, to be able to control spawning.

At the SA hatchery larvae are released at the Pacific oyster equivalent of day 7-8, and black sic larvae take approximately 14 days to settlement at 23-24 oC. The larvae are settled using epinephrine, and the majority go to the nursery at 3 ml screen size. According to SA Oyster Hatchery, angasi spat require different handling to Pacific oysters to toughen the shell and provide a better seal, as well as developing greater resilience to changing environmental conditions. This includes trimming fast growing frill on the shell using water pressure.

SARDI have been producing angasi spat from their hatchery for ongrowing by farmers in South Australia for several years, and they plan to continue this. They believe that management of broodstock and selective breeding are critical issues in improving the performance of angasi stock. This is difficult to achieve because angasi are not broadcast spawners. Angasi eggs are fertilised within the female and the developing larvae are maintained within the mantle for over a week, before they are collected for rearing in hatchery tanks. This makes it difficult to manipulate the broodstock and increase genetic diversity or select for particular traits. Currently the quality of spat based on genetic selection is random, and can result in growth rate to market size varying between two and four years. SARDI are keen to develop techniques to manage broodstock, spawning and larval rearing over the first few days, and hence control breeding.

In contrast, researchers at Port Stephens, NSW consider spawning and larval rearing of angasi oysters to be straightforward and reliable, and hatchery production has been consistent since 1999. In the warmer waters of NSW broodstock with larvae are available for at least 9 months, and mostly 11 months of each year. They have also developed techniques where they can anesthetise broodstock using magnesium chloride, inspect them for larvae and flush the larvae out of the oysters, which can been transported for ten hours or more back to the hatchery for larval rearing (O'Connor et al 2015). After removing the larvae the broodstock are returned to the lease to continue growing. Generally only a small proportion of the broodstock have larvae at any one time. If need be, they could hold broostock in aquaria and feed to instigate pair mating or remove embryos to manipulate genetic stocks, but this is very time consuming and expensive. They have tested various algae for growing broodstock and found that they do well on different species to Sydney rock oysters and Pacific oysters. For example, angasi oysters grow well on *Tetraselmis* sp.

At Port Stephens, all broodstock are maintained off the bottom on leases, which may assist the broodstock to maintain good condition and not succumb to Bonamia. In southern NSW, broodstock can spawn for 9 months of the year even at temperatures of 12-13 oC, whereas in South Australia and Victoria warmer waters of 18+ oC are often required to instigate spawning. Early-mid spring spawnings can take 6-9 months off growout time as the oysters get maximum growth in the first season - spat to 1ml in 1-2 months, upwellers to 5 ml by end of summer and then out to the leases on trays or baskets by end of summer. Fine mesh on the upwellers foul quickly so the aim is to get to next mesh size in 1-2 weeks. For re-establishing reefs in estuaries, setting oysters onto scallop shell or ropes for distribution as a base was suggested.

In the hatchery the larvae are settled as single seed using epinephrine. A study of several chemicals to induce metamorphosis in hatchery-reared angasi found that daily treatment with 10-4 M epinephrine or 10-3 M epinephrine bitartrate for 1 hour when approximately 60-80% of the larvae were eyed increased the rate of settlement and metamorphosis, and number of cultchless spat produced (O'Connor et al 2009). Further experiments showed the greatest percentage growth, survival and development of larvae occurred when they were reared at 26-29 ˚C and salinities of 30-35, and an optimal temperature for angasi larvae to undergo metamorphosis was suggested at ca. 23 ˚C (O'Connor et al 2015). Twenty four larval algal diets were also examined, and ternary diets of *T. chuii* + T. Iso combined with either *P. lutheri or Nannochloropsis oculata* were the best diets to maximise the growth rate, development and survival 24 h post metamorphosis of hatchery-reared *O. angasi* lavae (O'Connor et al 2012).

Several angasi farmers in NSW operate their own hatcheries to produce angasi spat for their farms. These hatcheries are add-ons to their oyster depots, and although very basic, they can successfully produce several hundred thousand spat each year. Ideally 500-1000 broodstock are collected from the wild and raised up in the water column in a good nutrient area so that they build up glycogen and produce healthy larvae. The best broodstock are approximately 60-80 ml in length and around 3 years of age. Larger oysters have been observed to produce fewer and less competent larvae.

One such hatchery consists of several 1000 l tanks, seawater is filtered to 1 mm for both larvae and algae, the tanks are cleaned every day and the most competent larvae are selected and fed daily with *Isochrysis* and *Pavlova*, with *Chaetoceros mulleri* also added for larger larvae. The larvae are released from the mother at approximately 120 microns and take around 18 days at 20-21 oC to reach settlement, which is triggered using epinephrine when the larvae look competent to set. The broodstock are often stressed to trigger spawning, e.g. 18+ oC for 24 hours or leaving them out of water for 24 hours.

Ocean Foods hatchery in Albany Western Australia has successfully conducted a spawning to provide spat for reef restoration efforts. The angasi oysters were settled on abalone and scallop shell following standard hatchery procedures.

Husbandry, including feeding, growth and environmental conditions

According to most oyster farmers interviewed, fast growing angasi oysters can reach market size of 75-100 mm in two years, however, the majority of angasi oysters take two to three years, and the slower growers take four years. Compared to Pacific oysters, many growers have found that angasi oysters are slower growing, have higher mortality rates and require a lot more effort to get them to market size in good condition.

The sensitivity of angasi oysters to handling and environmental range was recognised by all oyster farmers. Some farmers successfully grade angasi oysters in the large industrial graders which pass the oysters through the grader with gentle motion in water; whereas other farmers will only grade angasi oysters by hand, which is very labour intensive

In south east Tasmania IOS have developed a new technique for growing angasi oysters which is based on a mussel double backbone system. The oysters are in trays or baskets on rafts on top of a double backbone buoy system. This system is anchored to the seabed in 10 m depth of water and the height can be adjusted so that the oysters can be fully submerged or exposed at low tide. In effect this is an intertidal system but in 10 m deep water over a muddy seabed. As a result, the oyster shells are exceptionally clean with minimal biofouling. IOS gradually increase the extent of intertidal exposure before harvesting to strengthen the shell and extend shelf life. The oysters also rumble more in the intertidal, which improves their shape and increases the depth of the cup. Mortality has also been extremely low, and grow-out time is 2.5 – 3.5 years, producing a very clean and presentable product for the market. ISO have also developed a ladder system with a new arrangement of clips for growing juveniles. This has been developed over several years to improve efficiency of handling the oysters and a patent for this system is currently in progress. IOS are currently developing markets with restaurants in Hobart at a premium price.

At Pittwater in Tasmania angasi oysters being grown low in the intertidal have also gown well and remained healthy after the POMS outbreak in Pacific oysters (Ian Duthie, pers. com.). This agrees with observations in NSW where angasi oysters where not affected by OsHV uvar1 in the field, nor in laboratory infection trials where they were exposed to lethal concentrations of the virus (W. O'Connor, pers. com.)

Figure 6. Angasi juveniles being grown at Intertidal Oyster Solutions in south eastern Tasmania.

In Port Phillip Bay Advance Mussel Supply (AMS) has found by trial and error which areas grow good oysters, and where they are slow producers, although this is not thought to be due to different food levels. Bonamia parasites are found in oysters in much of the western side of PPB, but Bonamiosis has not been found in oysters from the Mornington area around Bay Sea Farms' (BSF) lease. For AMS angasi production is still in the developmental stage. They have recently opened a shop and small restaurant at their processing facility and most of their angasi oysters are sold as direct door sales.

Both farmers in Port Phillip Bay have been trialling gluing oysters to tape and hanging the tape below buoys moored in water approx. 10 m deep. One company grows the spat from the hatchery in baskets for up to two years to a size of 50-60 mm, then glues them to tape for approximately 8 months until they reach harvest size. If they are attached to the tape at a small size they are likely to be overgrown by mussels that spawn in the wild and settle on the tape. Fouling can be an issue with oysters becoming overgrown in 6-10 weeks, necessitating a lot of work to keep the oysters clean and growing. Relatively high mortalities have been recorded in deep water, possibly because Bonamia is present in their area and in some locations the food supply is low and the oysters are in poor condition. They have observed better growth and survival if the oysters are off the bottom.

Two current companies farming angasi oysters in Coffin Bay, South Australia, Pristine Oysters and Pure Coffin Bay Oysters have found that angasi oysters are much more difficult to grow than Pacific oysters, and require much more work to grow them to market size. They take longer to reach harvest size, and are more susceptible to unfavourable environmental conditions producing higher mortalities. Angasi oysters also have much shorter shelf life and markets are poorly developed. As a consequence, both farmers consider that angasi farming is not economically viable at present, but they will continue to trial a small number of angasi oysters, as an alternative species to Pacific oysters. Both farmers also commented that their current angasi oysters were from poor quality stock (runts) and this likely influenced their poor growth and survival. They both emphasised that good quality stock is very important.

Pure Coffin Bay Oysters (PCBO) initially had very good survival over first one to two years, around 5-6 years ago, but then they became more susceptible to disease and mortalities increased. Also, time to reach market size increased from 2+ years to approximately 4 years. They have tried various ways of culturing angasi oysters, including intertidal in BST baskets with some success, subtidal, in sand with mesh over the oysters, in baskets on the sand, and currently they are getting best results with oysters in prawn bins with lids on, or with oysters directly on the sand. They have also tried different amounts of exposure to air and to rumbling, but no obvious differences were observed. Normally the angasi oysters are out of the water for 2-3 hours per day. Their first seed came from NSW, but translocation from NSW to South Australia ceased, so their next batch was from mature oysters on their farm which were taken to a South Australian hatchery to collect and rear the larvae, and then return to the farm as spat. However, these home-produced oysters were not as successful as the previous spat from NSW.

Figure 7. Adjustable longline system with submerged baskets in Coffin Bay, South Australia.

Pristine Oysters (PO) in Coffin Bay grow their angasi spat in a similar manner to Pacific oysters, except a bit lower in the water column. They have tried placing oysters of various sizes on the bottom in 1-7 m depth range and observed that those in shallow water were eaten by stingrays, and all deeper water oysters died, also probably eaten by stingrays. Very high mortalities of angasi oysters have been observed, overall approximately 85%, although current stock are considered to be poor quality. They suggest growing angasi oysters in subtidal areas, protected from sting rays, and finishing them off in the intertidal to harden up the adductor muscle, except in mid-summer when they are susceptible to over-heating. PO consider that a combination of factors are involved in causing high mortalities, not just disease. These include high water and air temperatures, quantity and quality of food available, and amount of rumbling in the baskets. PO have also found that the quality of oysters is lower when they have been held close to the surface compared with lower in the water column. Angasi oysters need more protection from rough conditions than Pacific oysters, and don’t like being rumbled as much. PO observed that angasi oysters eat similar food to Pacific oysters.

Oyster growers and hatchery operators in South Australia emphasised the importance of better understanding the local food supply available to their oysters, both temporally and spatially. Because most growing areas in South Australia are in oceanic waters and are heavily dependent on upwellings and oceanic currents to bring in nutrients, the density of phytoplankton food for the oysters can change rapidly in a matter of days. It is also often very site specific within a bay, depending on localised water movements. Thus to maximise production, each grower needs to manage the density of oysters in baskets according to the availability of food to their oysters.

Other Pacific oyster growers in South Australia and Tasmania have been trialling small numbers angasi, either using spat that they have purchased from hatcheries, or ongrowing overcatch from their lease. General comments have been that the oysters are slow growing and mostly low levels of mortality at low culture densities. Some success has been obtained on intertidal farms where the angasi oysters were grown low in the water column. If angasi oysters are grown in the same manner as Pacific oysters they tend to have a thinner shell and are not as hardy. Angasi oysters generally need to be grown at lower densities than Pacific oysters. Size and timing (season) of placement in the sea has also been observed to be important, so that the oysters reach harvest in the quickest time and before they succumb to Bonamiosis.

A recent grower of angasi oysters in the central NSW region since the POMS outbreak buys spat at 1 ml and grows them in upwellers until 3 mm. The upwellers have continuously flowing seawater and are cleaned every day. At 3 mm they are put on 1.7 mm mesh trays and out onto the lease. He is using both cylinders and trays to on-grow the oysters and puts them in the low intertidal so that they are exposed approximately midway between spring and neap low tides. Angasi oysters have also grown well in trays on sandy bottom, but it was time consuming cleaning drift sand off oysters. He has had some losses but nothing significant.

A south coast oyster farmer grows his angasi oysters lower in the water column than Sydney rock oysters so that they are exposed only for a short period of time. From the hatchery the spat go into upwellers at around 1 mm and into baskets and out onto the lease when 4 mm in length. When mature, they are sometimes placed on the bottom for a day for the fish and other marine life to clean up the fouling on the shells. The highest losses occurred in smaller oysters, and management of their density and location around water temperature is important to minimise losses. SEPA/sabco mesh baskets with floats attached are often used to ongrow the spat in south coast estuaries. These baskets can be flipped so that any fouling dries out and they are generally placed in areas where the oysters are gently rocked around.

Figure 8. Floating oyster baskets on the NSW south coast.

Another south coast NSW farmer buys his spat from the Port Stephens hatchery or Southern Cross Shellfish at 500 microns length. These spat are grown in upwellers until they are larger enough to be placed on the oyster lease. They are placed in the low intertidal near *Posidonia* seaweed beds where they are exposed roughly once a month on big tides. These oysters are generally reared at lower densities than SROs. Before market the oysters are often placed on sand and higher in the intertidal to toughen up the adductor muscle and stop gaping so quickly. They can reach market size in two years. Fouling can be a problem, although angasi oysters do not develop as much fouling as Sydney rock oysters. To reduce mortalities angasi spat are handled carefully and not left out of the water overnight after grading.

An angasi farmer Andy Baker from the south coast of NSW was awarded an International Fellowship to study the harvesting and packaging techniques used for the European native oyster (*Ostrea edulis*) by farmers in those countries. From this study tour Baker (2008) made recommendations for production, harvesting and packaging techniques for angasi oysters including:

- Angasi should not be exposed to drastic changes in salinity, have reasonably high salinity levels in every tide and may need to be moved to deeper water with higher salinity during fresh water events.
- Harvest of angasi oysters should occur during the cooler water temperature months of April to September, when the oysters are unlikely to be in spawning condition.
- “Angasi oysters are very fragile. They should be handled like eggs.”

Baker successfully reared angasi oysters for several years, they were in good condition overwinter, had ready markets and were profitable; however, he has stopped growing them because his farm in Pambula Lake is subject to flooding and angasi oysters do not survive well in areas of sudden drops in salinity. Baker grew his angasi oysters about 45-50 mm below Sydney rock oysters and they were exposed only during spring low tides.

All NSW angasi farmers said that they could get many of their angasi oysters to market size in 2 years, although in some areas an additional six months is required to get them into good condition. They also all emphasised the need to treat them more carefully than Sydney rock oysters, especially during the juvenile stages when they are more fragile. Generally angasi oysters have been stocked at a lower density than Pacific oysters, mostly so they cover the floor of the basket but without stacking on top of one another. However, stocking densities need to be refined for each area, as it has been suggested that they also tend to grow poorly when understocked.

Disease and Predators

In Coffin Bay, South Australia (and also in other areas of southern Australia) predators of angasi oysters in the intertidal include mud worms, flat worms and starfish. However, mud and flat worms are normally managed through improved management by raising the oysters further off the bottom, keeping them clean and at the correct density for the environmental conditions. At depth the oysters grow more quickly but tend to get dirtier, whereas higher up they tend to be rumbled around more.

Predators of angasi oysters in NSW include flat worms and birds, e.g. pied oyster catches. The European shore crab *Carcinus maenas* also attacks angasi, and periodically oysters are eaten by bream and flathead.

According to Corbeil et al. (2009) Bonamia parasites in Australian oysters are usually found in or near epithelia and rarely become systemic, resulting in limited mortality and parasite multiplication. The parasites may be present in very low numbers and difficult to detect microscopically. For this reason, methods recommended by the OIE that are based on detection of systemic spread may not be applicable to Australian stocks. Clinical signs are limited and relatively non-specific. Diagnosis of Bonamiosis is therefore based on a range of procedures including histopathological observations and electron microscopy to confirm the identity of the parasite when it is abundant. Tests to detect the presence of the parasite when numbers are low include real-time Taqman polymerase chain reaction (PCR) and conventional PCR (Corbeil et al 2009). A comparison of the methods used to test for Bonamia species is provided in Diggle et al (2003). Costs of PCR tests are relatively high at approximately $100 per sample, but are likely to be more reliable than traditional heart smears (Tracey Bradley, pers. com.)

Surveillance undertaken by the South Australian Government as part of a collaborative FRDC project between Victoria, SARDI and CSIRO has identified *Bonamia exitiosa* in South Australia as well as in Victoria (Tracy Bradley, pers. com.), thus *Bonamia* has been identified as occurring across the entire range of *O. angasi*. The general consensus from fish health practitioners is than *Bonamia* is now endemic and most likely everywhere, possibly being introduced into Australia and New Zealand from Europe with movements of vessels (Morton et al 2003, B.K. Diggles, personal communication), but the disease Bonamiosis only occurs when environmental conditions and the health/stress levels of the oysters culminate in conditions for *Bonamia* to proliferate. The prevalence and severity of *Bonamia* sp. infestations has been observed to vary between years, but generally peaks in late summer to early autumn as it does in New Zealand (Hine 1991).

There is also a general view that improved husbandry practices, in particular those that reduce stress to the oysters, such as limited fluctuations in temperature and salinity, careful and possibly less handling, and lower oyster densities, will reduce the incidence of Bonamia and hence mortality rates. Stocking densities, fouling and handling stress were implicated in the mortalities of angasi oysters in Tasmania in the early 1990s (J. Handlinger pers. com). Only handling the oysters when they are not stressed, for example, no handling and grading when temperatures are high or food levels are low, is likely to improve survival rates. The current FRDC project in the Aquatic Animal Health Subprogram: 'Bonamiosis in farmed Native Oysters (*Ostrea angasi*)' aims to improve the understanding of Bonamiosis in angasi oysters, including determining which stressors induce the clinical disease in subclinically infected oysters. Stressors to be considered include stocking density, varying salinity and temperature, physical insult, reduced food, and competition from other aquatic organisms. From these studies farm management practices to manage and mitigate the risk of Bonamiosis will be recommended.

Although *Bonamia* sp is present in NSW angasi oysters, no episodes of Bonamiosis have been recorded. A survey of estuaries along the NSW coast found that some 25% were positive to Bonamia PCR but no deaths due to *Bonamia* sp. have been recorded (Wayne O'Connor, pers. comm.). It is currently not known whether the oysters in NSW have developed a resistance to the disease, or whether it is less virulent under NSW environmental and/or farming conditions.

The OIE has recently placed the first notification on its website of the confirmed occurrence of a clinical disease caused by *Bonamia exitiosa* in Australia. Specimens of angasi were examined by histopathology and indicated the presence of *Bonamia* parasites. Subsequent diagnostic tests to confirm *Bonamia* infection and identify the species occurred.

http://www.oie.int/wahis_2/public/wahid.php/Reviewreport/Review?page_refer=MapFullEventReport&reportid=19462 (11 February 2016)

Post harvest, transport and marketing

All oyster farmers interviewed considered that post-harvest handling and transport are much bigger issues with angasi oysters than Pacific oysters. Because they are largely subtidal, angasi oysters have a weaker adductor mussel and will quickly gape when out of water, releasing the liquid inside and rapidly dying. Even when stored in the fridge, many oysters gape after two days. Many farmers recommended that angasi oysters should spend some time in the intertidal before harvest, especially those grown subtidally, to strengthen the adductor muscle so the oysters stay closed for longer.

Baker (2008) reported on 'Harvesting and Packaging Techniques for the Australian Native Oyster', based on a study tour of *O. edulis* in Europe, and recommended that:

- Angasi oysters should be 'trained' for 1-2 weeks prior to harvest so that the adductor muscle is strengthened and the shells remain closed for longer, which extends the shelf life of the oysters. The oysters should be submerged for brief periods in every tide (4-6 hours daily) which forces the oysters to stay shut for longer.
- For transport to markets, they should be packaged in a padded polystyrene carton with the cup side down, and with no room for the oysters to move around.

One farmer extended the shelf life to ten days by storing his oysters in cryovac bags. However, his market was not accepting of cryovaced oysters; they wanted them live and fresh. Most angasi growers have found that the shelf life can be readily extended by storing the oysters in ice slurry or wet wood shavings and compressing them so they can't move around. Rumbling mature oysters was also reported to extend the shelf life. Angasi oysters are also sometimes transported with rubber bands over the shell to stop the oysters gaping and losing all their internal water. This can be problematic though, because there is no evidence if the oysters are deteriorating. All farmers agreed that these processes to extend the shelf life of angasi oysters are very time consuming and often not cost-effective.

Another farmer suggested snap frozen oysters would be a good alternative if the oysters can't get to the market fresh. Modified atmosphere packaging for oysters has been suggested as a possibility for extending oyster shelf life. Mussels from Spring Bay Seafoods in Tasmania can be stored for up to 10 days when packaged in a modified atmosphere. Phil Lamb from Spring Bay Seafoods suggested that the shelf life of angasi oysters could be extended to 8-10 days with modified atmosphere packaging but research would be required to develop and test a recipe and method for oysters (Phil Lamb, pers. comm).

NSW researchers considered that short shelf life and lack of markets to be the major issues facing angasi farmers in that state, and Australia generally. Currently markets are only for niche product and would need to be significantly extended if the angasi oyster industry is to expand.

Marketing was raised by many angasi farmers and researchers as a major issue. Currently most farmers are supplying angasi oysters directly to top end restaurants with fine dining reputations. This is a small and select market and new markets would need to be developed for larger scale production. Interest from Chinese buyers was mentioned by several angasi growers. However, at present there is not the volume or continuity of supply to get into this market.

Education of wholesalers and restaurateurs on how to handle angasi oysters was also highlighted as a need for the industry. Many of these people have a poor knowledge of the biology of angasi oysters and don't realise that they are more susceptible to many environmental issues than Sydney rock oysters or Pacific oysters, and will die rapidly if exposed to stressors when they are at relatively high stocking densities. The need for chefs to be trained in opening angasi oysters and educated about them gaping much more quickly than other oyster species was also identified.

Summary of state differences, current successes, limitations and concerns

Currently only a handful of farmers are farming angasi oysters at a commercial scale in Australia, and even fewer have economically viable operations. Interest in farming angasi oysters in South Australia has waned, in Victoria and Tasmania a few farmers are trialling angasi culture, and only NSW has several productive farms, albeit in conjunction with culturing Sydney rock oysters.

There are a number of reasons why angasi aquaculture has not become a major industry even though State Governments have supported expansion of this industry through considerable R&D effort and funding. These include:

- Pacific oysters have been much easier and more reliable to culture than angasi oysters. This is because angasi oysters are very sensitive to changing environmental conditions, such as rapid changes in salinity or extremes in temperatures which can cause significant mortalities. Also, until the recent incursion of POMS disease, Pacific oysters were relatively disease free. By contrast Bonamiosis has caused major mortalities of angasi oysters in some areas.
- Angasi oysters are slower growing than Pacific oysters. On average Pacific oysters take 1-2 years to reach harvest whereas angasi oysters take 2-4 years.
- The shelf life of angasi oysters is much shorter than that of Pacific oysters or Sydney rock oysters; around 2 days compared with over a week and several weeks, respectively. This has a major influence on markets.
- Because of susceptibility to disease and heightened sensitivity to fluctuating environmental conditions, culturing of angasi oysters has been less reliable and not as cost-effective as growing Pacific oysters. Angasi oysters require specialised handling, culturing at lower densities, and significantly more effort to arrive in the market place in good condition.

However, many of these disadvantages of farming angasi oysters could be overcome, or at least minimalized, by developing methods and technology specifically for angasi oysters, and not just modifications of Sydney rock oyster or Pacific oyster culture methods.

Partnerships between *O. angasi* industry, tourism, education and conservation sectors

Current partnerships and future opportunities between the angasi aquaculture industry, tourism, recreation, education and conservation sectors were not examined in detail, but some successful partnerships and ventures were observed and the benefits that they confer.

Advantages of partnerships between the aquaculture industry and other sectors include increased promotion and hence markets for farmed oysters through tourism showcasing the natural beauty of areas where oysters are grown, as well as promotion of gourmet foods. Angasi oysters can be promoted as the native, 'clean green' and sustainable alternative which would appeal to some markets. Tours of oyster farms and oyster tasting events promote the industry and educate the general public on the complexities of oyster farming and the subtleties of eating oysters. A number of oyster farming companies are operating successful tours, aimed at different sections of the market including the drive-past tourist as well as luxury lodge visitors. Shopfronts at or near oyster processing facilities have also proven very popular with passing trade, especially when combined with other high quality local produce such as wines. This has led to award winning agri-tourism ventures.

Partnerships between conservation organisations, especially The Nature Conservancy and the shellfish sector are also developing in Australia. Hatcheries in several states are being supported by funding from the conservation sector to provide angasi spat for trials to restore angasi reef habitat. Assuming some success with these trials, requirements for angasi spat are likely to increase significantly, which could go hand-in-hand with the development of angasi aquaculture.

Restoration of angasi reefs will be a long term project, operating over several decades; however, it is likely to induce considerable publicity, which if supported by the aquaculture industry could provide the opportunity for oyster growers to separately promote their products. Conservation branding could also assist in promotion of sustainable oyster production.

There are also likely to be overlaps in R & D between restoration science and development of angasi aquaculture, such as an improved understanding of genetics, food availability, mixed species culture and disease. A study of why natural reefs persist (e.g. George's Bay) may also provide information relevant to angai farming. Angasi oyster aquaculture and conservation industries can work well together because they are both aiming for natural, high quality, unpolluted estuarine and coastal waters in which to operate.

Information on *Ostrea edulis*

Various studies have shown that angasi oysters are very similar to the European flat oyster, *Ostrea edulis*. A study of the population genetic structure of angasi from five estuaries in NSW and samples from each of the four southern states of Australia showed no significant genetic difference amongst the samples from NSW and all eastern Australian estuaries and little divergence from its northern hemisphere congener, *O. edulis* (Heasman et al 2004) Heasman et al (2004) and Hurwood et al (2005) suggest that *O. angasi* is a recent coloniser of Australia, perhaps following European settlement, or that these two taxa are in fact the same species. However, Moreton et al (2003), separated the two species and found strong evidence for *O. edulis* occuring in Albany Harbour, Western Australia. An examination of oysters using mitochondrical DNA markers showed a 30% occurrence of *O. edulis* in the sample with *O. angasi*. Further genetic studies on these Ostrea species are required to clarify their species status. They suggest that *O. edulis* may have been introduced from Europe and potentially brought the *Bonamia* parasite with them (Morton et al 2003). *O. angasi* was observed by Hickman and O'Meley (1988b) to have reproductive stages which were indistinguishable from reported stages for *O. edulis* and very similar seasonal growth patterns. The reported temperature of 11°C at which *O. edulis* shell stops growing was also very similar to the temperature at which *O. angasi* also stops growing. Similarities in the breeding biology of *O. angasi* and *O. edulis* have also been observed by Dix (1976) and O'Sullivan (1980).

Because of the similarity between the two species of flat oysters, a quick search of the literature was conducted for information on reef restoration efforts with *O. edulis* in Europe. In the process some reports on Bonamiosis in *O. edulis* and new farming methods were obtained and summaries of these have been included in this review.

A feasibility study of stock restoration potential for *O. edulis* in the U.K. by Laing et al (2006) concluded that it was feasible, especially in areas away from pests and diseases, except that these tend to occur in areas where seawater temperatures were lower so growth rates were slower and spawning less frequent and reliable. The disease Bonamiosis was identified as the biggest biological factor limiting the potential for stock restoration, although some resistance to this disease has been observed. Pests and competitors were other important limiting factors, along with declining water quality and degradation of recruitment area habitat. Relaying of cultch and the use of sanctuaries were thought to be important components of oyster restoration (Laing et al 2006). A cost-benefit analysis showed that the best option from an economic perspective for a native oyster restoration project was to import half-grown oysters from a disease free area. Recommendations for restoration of *O. edulis* from the report prepared by Laing et al (2005) are included as Appendix 2.

According to Culloty et al (2004) control and eradication of Bonamiosis in *O. edulis* in Europe has largely been unsuccessful. Their studies found Bonamiosis only in oysters > 2 years old, but once the infection appeared, it quickly spread and prevalence and intensity of infection and mortalities rose quickly in subsequent months. Also, although Bonamia has generally been found to be most prevalent in summer to early autumn, there was much fluctuation in prevalence and intensity of infection and mortalities over two years and no consistent patterns were detected. They discussed other research in Europe including intertidal oysters being found to be more susceptible to Bonamia disease than subtidal oysters, and exposing oysters in the intertidal zone of an estuary boosted infestation. Culloty and Mulcahy (1996) suggested that stress associated with first spawning may have made the oysters more vulnerable to infection, and winter stressors such as low food availability and environmental conditions may also exacerbate infection rates.

A study of the susceptibility of several European populations of *O. edulis* to the parasite *B. ostreae* found that an infected population which had been subjected to selective breeding to reduce susceptibility to the parasite performed significantly better in most trials in terms of prevalence and intensity of infection than other populations without any selective breeding (Culloty et al 2004). Differences in susceptibility to infection were observed between the different populations. Elston et al (1987) noted that oysters exposed to *B. ostreae* for several years had greater resistance to infection than naïve populations, and resistant oysters had lesions which suggested that they could contain the infection.

Baker (2008) observed that many *O. edulis* oysters were wild caught in France and Ireland using dredges. They are so fragile when they are caught that they are worked in one day, including dredged, graded, weighed and returned to the water with 12 hours. (Also, salinity levels at harvest are critical. Both *O. edulis* and *O. angasi* do not cope with sudden changes in salinity at this time, and mass mortality can occur if salinity levels fluctuate widely. Prior to harvest for market all edulis are trained to strengthen their adductor mussel by forcing the oyster to remain shut for 18 hours /day for 1-2 weeks. Using this technique the shelf life of the oysters increased from 24 hours to up to 7 days.

A comparison of *O.edulis* adult oysters cultured on elevated reef structures 80 cm above the seabed with oysters on the seabed in southern England found that filtration rates were significantly higher in oysters reared on the reef structure above the seabed; however respiration rates (and by inference metabolic rates) and condition indices were similar. Total suspended solids were higher at the seabed on all sampling occasions but bacterial abundance was only higher in summer and autumn samplings. Total number of haemocytes and the granulocyte population were higher in oysters 80 cm off the bottom during the warmest month sampled, and Sawusdee et al (2015) suggested that the elevated reef habitat would have benefitted the immune system and contributed to a reduced disease susceptibility.

A company growing *O. edulis* on Jersey and in Ireland, Jersey Sea Farms, has developed new growing techniques (see www.abblox.com). In these growing area with 12 m tides, the oysters are exposed for a maximum of 3 hours on spring tides. Exposure times are considered critical once the female phase is reached. New small plastic baskets, called 'Ortacs', which rock in the water and are periodically rotated by hand at low tide to remove fouling, have been used to grow *O. edulis* from 4 mm grade seed through to 85-120 g market size oysters.

In another system called 'Microreef', *O. edulis* have been reared from 15 g to 120+ g in individual containment units of 2000. Each small oyster is placed in a plate drainer-like compartment, in a rack for 10 oysters which can then be packed in a 1 m2 and 0.5 m deep steel mesh gabion. Water can flow freely through this system, the oysters are protected and it is designed for mechanical handling. The oysters in the microreefs can be left undisturbed for 2 years as they grow to market size. The farmer from Jersey Sea Farms claims he can rear 1000 T of oysters on a hectare with good current flow. He is also planning to use these microreefs to help restore *O. edulis* reef habitat in Europe (T. Legg, pers. com). More information on this work is available in the February 2016 issue of The Grower, a publication of the Scottish Shellfish Association; available at http://assg.org.uk/the-grower/4532754744

Additional information from Tony Legg (pers. com.) included his firsthand experience of the POMS virus (OsHV1 mu var) that it does affect survival of hatchery produced *O. edulis* spat, but not those from spatting ponds. Growth is more regular in a spatting pond, and growth from 1 mm to 30 g has been achieved in one year and with 100% survival in a OsHV1 environment but with no Bonamia present. (However, infection trials with the POMS virus and several sizes of hatchery produced angasi oysters in NSW have not shown increased mortalities (W. O'Connor, pers. com.).

Figure 9 (a) Ortac and (b) Microreef growout systems for *O. edulis.*

Information relevant to re-establishing angasi reefs

The dot points below are a summary of information from current angasi oyster farmers and researchers that were provided to support the establishment of angasi reef habitat in southern Australia:

- Select locations with good supply of food for oysters but low wave energy conditions. Every site is different.
- Need to start with good quality spat and handle them very carefully.
- Spat can be readily collected in areas of wild broodstock using the venetian blind-type slats used by Sydney rock oyster farmers. The spat settle on the slats and are easily removed by flexing the slat.
- Place large quantities of oyster shells on the seabed and add broodstock or settled spat on top of the mound of shells. The crevices in the pile of shells will provide substantial protection from predators such as sting rays.
- Cultch with oyster spat attached would be easiest to add to the reef base if the cultch is accumulated in bags, but these bags should be biodegradable over 6-12 months, e.g. biodegradable mussel mesh. Wire gabions may also be suitable as they would rust over time. Folded rebar with dog mesh attached was also suggested as a suitable starting substrate to get the oysters elevated above the sea bed.
- The bags of oysters should also be not too thick so that water can readily flow through, providing food for all the spat.
- Placing the oyster spat in a secured and protected nursery area for the spat to increase in size before being transplanted to the reef site may result in much higher survival. Approximately 5 cm was recommended as a suitable size for transfer to the sea.
- Angasi oysters are sensitive to changes in environmental conditions, especially temperature and salinity. Don't attempt to re-establish reefs in areas that are periodically subject to flooding, and hence low salinities.
- For reefs in intertidal areas, angasi oysters will need to be in the low intertidal zone so they are exposed to the air only during spring low tides.
- Keep density of oysters low.

Government concerns about reef restoration

Several issues were raised by state government personnel that are potentially of concern to oyster farmers about reef restoration, especially if the angasi reefs and oyster farming occur in the same area. These include:

- carrying capacity – if reefs are re-established in oyster growing areas there may not be enough food in the water for farmed oysters to grow and condition.
- oyster reefs may harbour diseases
- Biosecurity translocation issues, need surveillance for new diseases.
- if oyster reefs are promoted as cleaning up the waters by removing nutrients, excessive algae and pollutants, this could lead to community perceptions that oysters are not safe to eat.
- They also emphasised the need to have clear objectives for reef restoration.

These issues suggest that reef restoration efforts should be located away from areas of commercial oyster aquaculture.

Other concerns relating to management that were raised include:

- Potential multi-use conflicts over allocation of areas for reef restoration (similar to allocation of marine reserves).
- Need better information on effects of reefs on environment –food chain/energy flow impacts, and implications on sensitive environments such as Posidonia beds
- Recognition that oyster reef restoration is a long term project, requiring several decades to succeed.
- The scale of the project is significant and to be successful will require substantial area of inshore coastal waters, which will need to be managed effectively.
- Ongoing funding could be an issue, especially as there is not the same culture of private company involvement in public good projects in Australia compared to the USA.

Additional research to support angasi aquaculture

- Better information on growth rates and availability of good food supply in the different growing areas, especially in South Australian waters. This includes an assessment of where they grow best and why, which growout techniques are best for each area and how to respond to low food situations.
- Growout techniques generally, and specifically, for different growing areas with different environmental conditions – including growing height, density of oysters and extent of handling (frequency and intensity).
- Timing and size of spat for transfer to field sites to improve growth and survival rates.
- Control of reproduction and hatchery production (South Australia, but not NSW).
- Selective breeding for growth and disease resistance.
- Better understanding of Bonamiosis disease, and how to manage farming around this disease (particularly for Victoria and Tasmania) (currently being addressed in a FRDC project).
- Learn from the experiences of the French oyster farmers growing *O. edulis* in France. They produce approximately 1000 tons annually.

Future priorities

(overview and synthesis obtained from interviews with current growers and key R&D individuals)

Future R&D priorities for angasi aquauculture:

- Develop growout techniques specifically for angasi oysters (and not methods modified from Pacific oysters)
- Determine improved farm management methods to reduce the effects of Bonamiosis disease.
- Develop a structured breeding program with selection for Bonamiosis resistance and improved growth and condition characteristics.
- Investigate cost-effective methods to extend the shelf life, such as modified atmosphere packaging or quick freezing.
- Develop and expand markets, including into SE Asia and to Europe as a substitute for *O. edulis*.

Further development of partnerships between the aquaculture industry, tourism, recreation, education and conservation sectors is also recommended because of the multiple advantages that these partnerships collectively can deliver to each sector.

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Appendices

Appendix 1: Farmers, government employees and researchers who provided information

Jon Poke, Smithton, Tasmania – farmer

Steve Lesley and Yvonne Young, Taranna, Tasmania – farmers

Scott Parkinson, Cremorne, Tasmania – shellfish hatchery and farmer

Phil Lamb, Triabunna, Tasmania – shellfish hatchery, mussel farmer and processor

Ian Duthie, Orford, Tasmania – shellfish hatchery and farmer

Rob Rodway, Dunalley, Tasmania – farmer

Alan Flintoff, St Helens, Tasmania – farmer

Robert Gott, Hobart, Tasmania – government manager

Peter Bold, Port Phillip Bay, Victoria – farmer

Peter Lillee, Port Phillip Bay, Victoria – farmer

Andrew Clarke, Queenscliff, Victoria – research

Mike Shipley Queenscliff, Victoria – hatchery manager

Neil Hickman, Queenscliff, Victoria – researcher

John Mercer, Queenscliff, Victoria – researcher

Adam Butterworth, Port Lincoln, SA – hatchery manager

Chris Hank, Coffin Bay, SA – farmer

Steve Bowerly, Eyre peninsula, SA – farmer

Brendan Guidera, Coffin Bay, SA – farmer

Heidi Alleway, Adelaide, SA – Government manager

Steven Clarke, SARDI – research

Marty Deveney, SARDI – research

Xiaoxu Li, SARDI – research

Wayne O'Connor, Port Stephens, NSW – researcher

Steve O'Connor, Port Stephens, NSW – researcher

Ana Rubio, Sydney, NSW – researcher

Keith Duggan, Georges River, NSW – farmer

David and Ewan McAsh, Clyde River, NSW – farmer

David Maitment, Narooma, NSW – farmer

Dom Boyton, Merimbuma, NSW – farmer

Andy Baker, Pambula – farmer

Jonathon Bilton, Albany, WA – hatchery manager

Eve Bunbury, Denmark, WA – Government manager

Peter Cook, Albany, WA – researcher

Tracey Bradley, Victoria – Government aquatic animal health veterinarian

Tony Legg, Jersey, Channel Islands – farmer

Ben Diggles, Banksia Beach, QLD – researcher

(N.B. Several industry personnel in Tasmania were not interviewed because of the POMS outbreak and other commitments)

Appendix 2: Recommendations for restoration of O. edulis from 'A feasibility study of native oyster (*Ostrea edulis*) stock regeneration in the United Kingdom' (Laing et al 2005)

RECOMMENDATIONS

1. The native oyster is a Biodiversity Action Plan Species and a significant driver for restoration of native oyster beds should be re-creating and conserving an ecological resource in order to re-establish a biotope that was once common and covered wide areas of the UK inshore seabed.
2. Any provisions for conservation of habitats in the proposed new Marine Bill should include native oysters beds, by establishing a system of marine spatial planning. A Marine Act should include provision for the designation and protection of Nationally Important Marine Sites so that locations where the native oyster occurs now or have occurred in the past can be protected from potentially damaging activities.
3. In the case of an oyster restoration project there are components in the benefits derived from it that cannot be estimated through market prices (i.e. benefits to the environment and society in general and the rural economy in particular). The study in the USA provides an idea of the high value that may be behind such non-marketable components, although this cannot easily be extrapolated to the UK. For this reason it would be useful to conduct a Contingent Valuation study for the UK. This would give an estimation of willingness to pay and so elicit the Total Economic Value of the programme.
4. While recovery of natural stocks has been noted in some areas, including those affected by disease, it is clear that real progress with restoration can only be made through an active programme. Restoration efforts and associated studies elsewhere have shown the potential for success of such an approach and the valuable information available from these studies should be consulted.
5. Restoration of offshore beds where security will be less, monitoring and management will be more difficult and the sites may be subject to damage from legitimate fishing activities or periodic natural storm events should not be attempted.
6. Careful consideration needs to be made of security of inshore restoration sites, to prevent accidental damage or deliberate poaching of stock.
7. Disease and, to a certain extent, pests, particularly slipper limpets, are major barriers to native oyster stock restoration and areas free from these should be selected, in the first instance, for attempts at restoration. Areas where residual concentrations of TBT remain at potentially harmful levels should be avoided.
8. Stocking selected sites with strategically located broodstock by using pond or hatcheryproduced oysters or half-grown stocks is an effective strategy for oyster restoration and should form an important component of the overall process.
9. While legislation will only allow stocks from disease-free areas there should also be a presumption against introducing pest species, where these are absent.
10. Selection of broodstock should be an important consideration when rearing stock for replanting. It may be advantageous to rear from stock from stressed survivors, kept at high density, to simulate reef conditions. Where available, older and larger broodstock oysters should be used, as these will be the hardier, more disease-resistant oysters. It is recognised that such stock may not currently exist, having been fished out long ago.

11. In addition to the above, broodstock from a similar physical environment should be used to allow for the fact that these oysters may be physiologically adapted to the local conditions. For example, oysters of a more northern origin may be adapted to spawn at lower temperatures.
12. Cultchless oysters should be the stock of choice in hatcheries and controlled outdoor rearing ponds with low velocity bottom flows.
13. Further work is necessary to determine if attachment to cultch confers any benefits in coastal waters, where bottom currents are sufficient to re-suspend spat, especially if not attached to a piece of heavier material.
14. The availability of background data on water movements should be investigated with a view to modelling larval distribution and thus strategic placement of introduced broodstock or relocation of local stock.
15. There is a need to be fully aware of the functional value of conserving genetic variability. The question of genetic management of broodstock must be addressed and measures must be taken to avoid the danger of inbreeding. Management policies that favour supportive breeding for replenishment of exhausted oyster beds should be planned carefully and must maintain pedigree records to avoid crossing even distantly related lines, and monitor donor (hatchery) and recipient (wild) populations to avoid damage to genetic resources. At least 50 per lot, and preferably 100, broodstock should be used to produce O. edulis larvae, in order to maintain genetic diversity.
16. Targeted hatchery-based selection programmes are not recommended as they represent too high a risk in respect of the probable success in relation to the costs. There are also inherent difficulties in the problems associated with the lack of a fully reliable method for rearing native oysters in the hatchery.
17. Some consideration should be given to establishing oyster breeding ponds in a disease free area as a source of seed for restocking in similar areas.
18. The habitat should be restored through relaying of cultch. Some care should be taken in selection of the source of shell for cultch in order to eliminate the risk of transferring disease. Ideally it should come from disease-free areas otherwise it is recommended that it be stored in air for at least one month prior to use.
19. Management must go alongside restoration. Management plans must involve all stakeholders in the area.
20. Management measures should ensure the return of larger, and therefore older and presumably hardier oysters so that these will remain as brood stock. These oysters will then also produce more larvae.
21. Exploitation of restored stocks must be strictly controlled and set at a level that does not exceed biological production above an agreed level of stock that is needed to sustain a viable biotope.
22. The use of sanctuary areas, where broodstock will provide for recruitment over a larger area, should be considered for appropriate sites.
23. Studies into the dynamics of oyster recruitment in areas affected by Bonamia are needed before attempts at stock restoration on any significant scale can be made in these areas.
24. Current initiatives to increase stocks in areas affected by disease, such as development of disease-resistant strains, should be encouraged to continue.
25. For Bonamia, further studies on the life cycle of the parasite and the immune mechanisms of the host would assist in understanding the potential for developing strains of oysters resistant to this disease.
26. There should be a presumption against deliberately introducing an alternative non-native species, to prevent it becoming established and replacing Ostrea edulis, as supported by the current legislative framework.

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