MONITORING THE CANARIES OF OUR CATCHMENTS

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Abstract

Oysters play a key role in the ecology of estuaries as a result of their efficient filtration capacity, which assists in the maintenance of water clarity and aquatic ecosystems. Oysters are often referred to as the 'canaries' of our catchments, as healthy oysters reflect healthy estuaries. Therefore the oyster industry is a key indicator of the health and performance of our estuaries and important stewards of these environments. The industry is required to regularly monitor oyster/water quality as part of the intensive Shellfish Quality Assurance Program (SQAP) (valued at $17,000 - $43,000 depending on the estuary). The industry's diligence with this monitoring program means that any unexpected event entering the waterbody can be quickly identified and managed accordingly.

Value-adding onto the SQAP, oysters are being used in an innovative estuarine monitoring program that Southern Rivers Catchment Management Authority and researchers at the Shoalhaven Marine and Freshwater Centre are undertaking in direct partnership with the oyster industry. Using commercial automated oyster graders (already in use in the industry and tested as potential monitoring tools) pilot trials have been monitoring oyster growth and mortality at different locations within NSW estuaries for a year (May 2010 to 2011).

Through the surveillance of growth and mortality in different growing areas of an estuary, sites can be characterised and changes in performance identified. This information is currently being linked to existing environmental data collected by the oyster industry and other estuarine/catchment managers. The information on husbandry techniques and environmental conditions can be used to improve management operations for the industry. More importantly this information can be used by other stakeholders and managers interested in understanding the health of our estuaries as oysters can be used as bio-indicators of these aquatic systems. This monitoring program is an innovative example of a cooperative partnership where effort and cost by different groups/agencies is maximised to achieve estuary wide benefits.

Oyster industry in NSW and its ecological role in our catchments

In NSW, there are 32 commercial oyster growing areas, between Eden in the south and Tweed Heads in the north, with around 328 oyster permit holders producing 5.2 million dozen oysters for a $31.5 million industry (NSW DPI, 2011). Oyster growers in NSW primarily farm Sydney rock oyster (SRO) *(Saccostrea glomerata)*. In some estuaries growers have diversified by also cultivating the Pacific oyster (PO) *(Crassostrea gigas),* and to a lesser extent the native Flat oyster *(Ostrea angasi)*.

SRO production is economically and culturally important, accounting for 62% of the total aquaculture production in NSW. This industry is also one of the State's most valuable agricultural enterprises on an area basis with long term gross average annual production of $8,000/ha across the state, reaching values as high as $35,000/ha in some NSW estuaries (White, 2001). SRO production has however, been in a state of decline since the mid-1970s.

This reduction has been attributed to many different factors such as disease outbreaks; degradation of water quality as a result of coastal development; depressed market price of oysters and/or competition by the growing Pacific oyster market.

Oyster farming is potentially one of the most sustainable forms of seafood cultivation, as it targets species with low trophic positions in aquatic food webs and requires no external food inputs. Oysters gather their food by filtering large amounts of water to extract microscopic particles including phytoplankton, bacteria, and suspended organic and inorganic particles. Oyster farming therefore relies on the environment to produce and supply the optimum food mix for oysters to thrive on. The natural resources of the catchment, the sediment of the waterways, as well as the local biological, physical and chemical characteristics of the oyster growing area determines the make-up of the food components available to oysters and subsequent rearing conditions.

Oysters not only trap suspended material but also regenerate and mineralise materials back into the water column, resulting in nutrient recycling. It is for this reason that oysters play a major part in many of the ecological processes taking place in estuarine systems (Ruesink *et al.*, 2005) and are widely recognised for their important role in the biological and chemical dynamics of coastal areas (Officer *et al.*, 1982; Dame *et al.*, 1989; Songsangjinda *et al.*, 2000). Oyster loss from a system, through harvesting, disease, water pollution or low food levels, may result in dramatic alterations in coastal ecosystems (Ruesink *et al.*, 2005). If pollution levels or suspended matter increase in the waterways (as a consequence of influences such as urban effluent discharges, agriculture run-off or fuel spills) oysters will quickly react to these conditions, in most cases reducing feeding, filtration and therefore nutrient recycling.

Fulfilling an important ecological role in estuarine environments, oysters are providing an indication of the state of the aquatic systems in which they live. The performance of the oyster industry reflects the health of the catchment within which the oyster growing estuary lies and is influenced by. Just as canaries were used to indicate the air quality of mines in days gone by, oysters can equally be considered the ‘canaries’ of our catchments.

Overview of Oyster Monitoring Programs

Long-term standardised oyster monitoring programs are fundamental for the industry as they monitor the status of the industry; characterise oyster growing areas; quantify oyster performance through time; and assist in improving the management of industry operations.
Through sustained monitoring, baseline information can be established that allows for the identification of unusual events (i.e. high mortalities, extreme changes in water conditions) and the identification of long-term trends and the potential causes attributing to these.

Oyster monitoring programs are, however, rare in Australia and across the world. Overseas, monitoring programs have mainly focused on oyster restoration efforts, historically targeting the recovery of oyster fisheries and the mitigation of losses from natural and man-made disasters (Beck *et al.*, 2011). Currently these programs are focusing on the need to restore wild oyster reefs to maintain the ecological services that they provide in aquatic systems (Coen *et al.*, 2007). Now that protocol standards have been implemented, extensive information is being collected in regards to oyster growth, mortality, impacts from predators and diseases, in addition to the collection of water quality parameters (Schrack *et al.*, 2012). Fewer programs have used wild oysters in combination with water quality parameters normally used in the assessment of the environmental health of waterways (Jones, 2007).

In France, on the other hand, a national network of monitoring programs exists, one of which targets the quantification of oyster larvae in oyster catching grounds and the growth and mortality of juvenile and adult oysters around the country (Marchand *et al*., 2010). This national program was designed to improve overall oyster production in France. Information from this program is being used by industry on a day-to-day basis to target the best grounds to catch oysters, and to compare individual oyster performance against the reference sites.

In Australia, oyster monitoring programs are largely focused on water quality testing to address food health safety. Oysters have been associated with numerous outbreaks of human disease as a consequence of an oyster's ability to bioaccumulate pathogens and toxins present at times in the surrounding waters. Managed by the NSW Food Authority, as part of the Australian Shellfish Quality Assurance Program (SQAP), NSW oyster growers are required to routinely test water quality and oysters in their harvest areas. For some parameters like harmful microalgae testing, samples are collected fortnightly (i.e. valued at $17,000 - $43,000 depending on the estuary). The primary objective of the SQAP is to protect the health of shellfish consumers through assessment of the risk of contamination to harvest areas.

The NSW oyster industry's diligence with this intensive monitoring program has meant that any unexpected event entering the waterbody is quickly identified and managed accordingly. However, little recognition has been given to the important role of the oyster industry, through the SQAP, in monitoring and managing estuaries up to now. Publically sharing this information through a new online Oyster Information Portal (an initiative by University of Wollongong researchers) has provided industry with a way of sharing SQAP data with catchment stakeholders and managers (Rubio *et al*., 2012). The collation and accessibility of SQAP and other information (e.g. local councils) can be used to great advantage by government and industry in planning and deciding upon future management strategies.

Adding value to the SQAP, oysters in the Southern Rivers region of NSW are being used in a new estuarine Oyster Monitoring Program (OMP) that the Southern Rivers Catchment Management Authority (SRCMA) and researchers at University of Wollongong's Shoalhaven Marine and Freshwater Centre (SMFC) are undertaking in direct partnership with the oyster industry. The need for the OMP was largely driven by an industry desire to improve coastal & estuarine monitoring programs in order to understand better oysters and ecosystem performances (Leith and Haward, 2010).

Southern Rivers Oyster Monitoring Program (OMP)

To increase handling efficiency, many growers in NSW are investing in automated commercial oyster graders that sort oysters photographically for pre-market. While these graders are primarily used for sorting purposes they have the potential to be used to assist in monitoring the performance of oyster cohorts and the different growing areas of an estuary (Rubio, 2010). Using oyster graders is an innovative method that overcomes the laborious effort of traditional methods to track oysters (i.e. weighing and measuring oysters one by one). As demonstrated in the pilot trials, these graders have the capacity to deal with large volumes of oysters, store data efficiently and operate under predetermined protocols, all at a consistent performance level.

In May 2011, estuary-wide trials were established at three main oyster producing estuaries in the Southern Rivers region; Shoalhaven River, Merimbula Lake and Pambula Lake. These programs have been running for 18 months now and are assisting in building baseline data on oyster performance that can be linked to environmental information and catchment processes.

Methods

The OMP requires access to an automated grader (all OMPs currently use a Shellquip SED oyster grader http://shellquip.com.au/) to count live oysters and to measure shell length. In order to minimise inherent variability, oysters used in the OMPs are chosen from a pre-selected oyster batch (i.e. oysters share same origin, age and husbandry). Pre-defined computer proforma (referred to as a 'recipe') is used to keep grading size and oyster density per cultivation method consistent throughout the monitoring program so that growth assessments are comparable through time. The methodology used in the current OMP follows previous pilot studies (Rubio, 2010).

The current OMP monitors SRO and, where cultivated such as the Shoalhaven River, Triploid Pacific Oysters (TPO). The sampling sites within a river are chosen by industry with the aim of targeting a range of growing areas that are known to perform differently. A summary of the set-up information for each of three monitoring programs is provided in Table 1. Oysters were graded approximately every 2 months (note that where data is missing in the figures this reflects oysters were not graded at this time). After each grading, reports were compiled presenting the latest results and disseminated to industry members electronically and online via the Oyster Information Portal (Rubio *et al*., 2012).

Mortality rates were calculated by counting the number of dead oysters at each grading by hand. Growth, measured by shell length, was quantified by the number of oysters counted in each grade size by the machine. Overall batch growth rates were calculated by taking into account the number of oysters, the shell length and mortality rates per grade and integrating this information into an oyster performance indicator, (referred to as weighted average shell length) that was compared through time.

In the early stages of establishing links between the data and water quality parameters, oyster performance data has been correlated with available water temperature and salinity data collected by growers through the SQAP 'event' sampling protocols (i.e. after a pollution incident or high rainfall). Additional data collected by local councils has been used to fill in SQAP data gaps but only if these council locations existed in close proximity to the OMP sites.

Results

This paper includes reference to results gathered over 12 months (May 2011-2012) on oyster growth and mortality levels as well as preliminary relationships on oyster performance with environmental data (water temperature and salinity) from three oyster growing estuaries (Shoalhaven River, Merimbula Lake and Pambula Lake).
Careful consideration must be given when comparing results between estuaries as each monitoring program was set-up using different oyster batches as described in Table 1. Here, preliminary results are presented comparing estuaries, however long-term monitoring is required to obtained robust results.

Table 1: Set-up of the first three oyster monitoring programs in the Southern Rivers region of the NSW south coast (for more information on set-up and locations please refer to reports at http://www.oysterinformationportal.net.au/oyster-monitoring-program)

Estuary	Sampling Sites	Species	Number of oysters	Cultivation method	Oyster origin
Shoalhaven River	Berry's Bay Crookhaven Goodnight Comerong	SRO	4,000 (1,000/site)	Floating bags	Wild spat locally caught. Shell length at start 58mm.
	Comerong Curleys	TPO	2,000 (1,000/site)	Floating bags	Hatchery batch spawned September 2010. Shell length at start 65mm.
Merimbula Lake	Front Lake Mid Lake	SRO	2,000 (1,000/site)	Floating bags	Wild spat locally caught. Shell length at start 45mm.
Pambula Lake	Front Lake Mid Lake	SRO	2,000 (1,000/site)	Floating bags	Wild spat locally caught. Shell length at start 45mm.

Oyster Mortality

At present the OMP does not determine the cause of mortality but simply records the levels of loss in each estuary at every grading interval. Quantifying mortality levels assists growers in matching their qualitative observations on oyster performance.

Estuary scale

After 12 months of monitoring, cumulative mortality levels for SRO ranged from 13 to 30% across the three estuaries, while for TPO at the Shoalhaven River mortality levels remained under 2% for the entire year (Table 2). This difference could be attributed to the difference in oyster sizes at the start of the monitoring program (Table 1). However mortality differences were expected at different times of the year rather than as a result of oyster size. It is known that common oyster diseases like winter mortality will impact oysters during the cold months. Despite this, mortality rates of up to 30% per annum are considered extremely high, particularly when the average commercial life cycle of a SRO is three years.

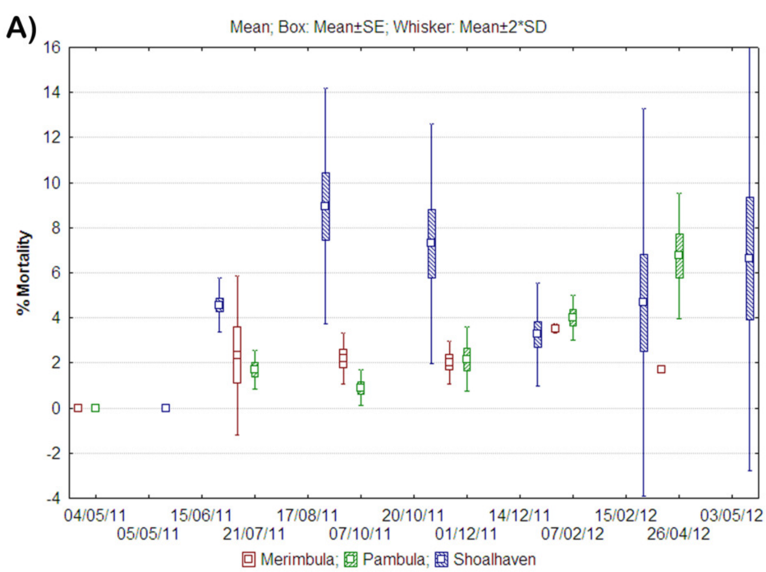
Table 2: Cumulative mortality levels (%) in Sydney Rock Oysters and Triploid Pacific Oysters after 6 and 12 months of monitoring in three Southern Rivers estuaries

Sydney Rock Oysters	in 6 months	in 12 months
Merimbula	7 ± 2	13 ± 2
Pambula	5 ± 0.1	18 ± 4
Shoalhaven	18 ± 6	30 ± 11
Triploid Pacific Oysters	in 6 months	in 12 months
Shoalhaven	1 ± 0.1	2 ± 0.1

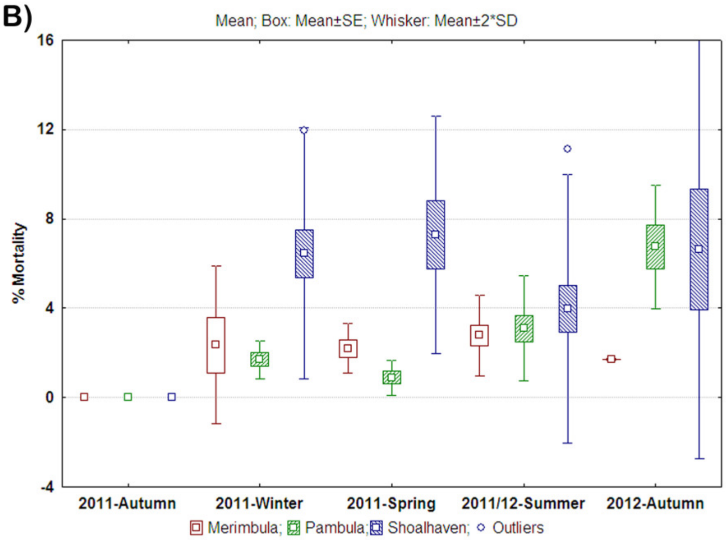
At most of the grading intervals, significantly higher SRO mortality rates were recorded at Shoalhaven River compared with Pambula and Merimbula lakes. Mortality levels across the different monitoring sites in the Shoalhaven River were quite variable with no temporal consistency documented. There was a slight increase in SRO mortality rates at Shoalhaven River and Pambula Lake during autumn of 2012 but this increase was not observed for Merimbula Lake. Mortality levels at Shoalhaven River were consistently high through all the seasons. Therefore, seasonality (i.e. water temperature) did not seem to be a strong factor influencing mortality levels.

High mortality rates are expected when oysters are stressed. This may be a result of natural environmental conditions (e.g. extreme high temperatures, sustained low salinity levels, high turbidity from run-off) or, as a result of pollutants in the waterways (e.g. pesticides or chemicals coming through in stormwater). Overall, the Shoalhaven catchment has more activities potentially affecting the oysters in this waterway (e.g. flood gates, paper mills, old sewage drainage) than in Pambula and Merimbula.

Figure 1: Percentage mortality recorded over 12 months of monitoring in three Southern Rivers estuaries, by grading interval A) and by season B).



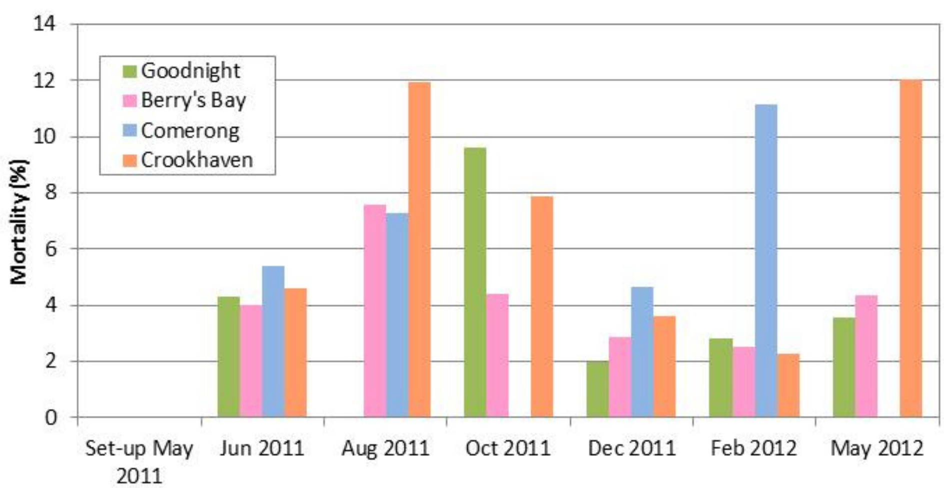
B)



Location scale

The Shoalhaven River showed large variability in SRO mortality across each of the monitoring locations. At each grading interval one location would record high mortalities but this was not consistent over time (Figure 2). Over 12 months of monitoring, oysters located at Crookhaven were the most severely affected with an annual mortality level of up to 42%, followed by Comerong with 35.6%. Interestingly, oysters at Berry's Bay also had high mortality levels (26%) but these were not as high as two years prior to the OMP, when growers in this location were severely affected by winter mortality reportedly losing up to 90% of SRO from the Berry's Bay area (O'Neill, 2011). In addition, extremely low salinities were sustained for prolonged periods in some parts of the river, including the Crookhaven, potentially affecting the oyster's filtering capacity and therefore, overall health.

Figure 2. Percentage mortality levels for Sydney Rock Oysters in the Shoalhaven River between May 2011 and May 2012

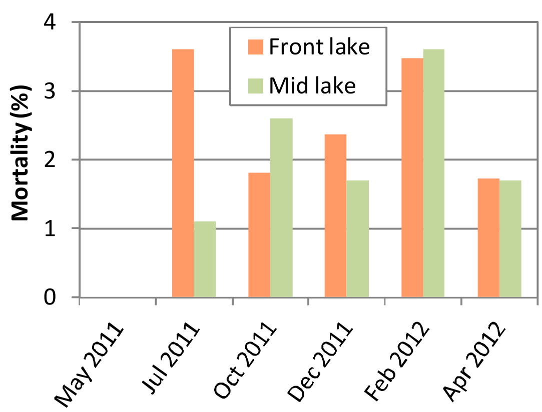


Annual SRO mortality levels at Merimbula Lake ranged from 10-12%. The two locations within Merimbula Lake recorded similar mortalities throughout the year, with a peak recorded at both sites in February 2012 (Figure 3A). The Mid Lake location at Pambula Lake (red bar

Figure 3B) recorded slightly higher SRO mortality levels throughout the majority of the program. An increase in mortality at both Pambula locations was observed from December 2011 to April 2012. Overall, annual mortality levels at Pambula Lake ranged from 14-17%. This program has continued for another 6 months and mortality levels in Pambula have decreased significantly to an average of 3% in June 2012 and 1% in August 2012. By collecting additional information in following years a baseline of mortality levels including temporal patterns can be established for the experimental locations and the lakes as a whole.

Figure 3. Percentage mortality levels for SRO in A) Merimbula Lake and B) Pambula Lake between May 2011 and May 2012

A)



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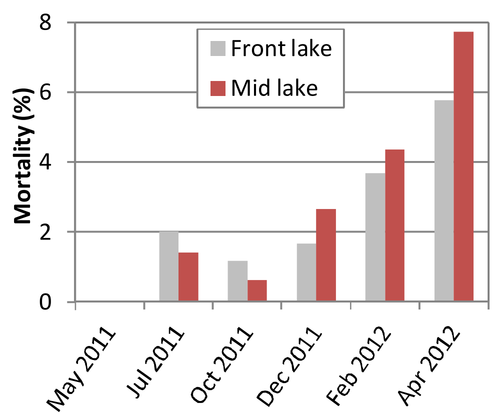
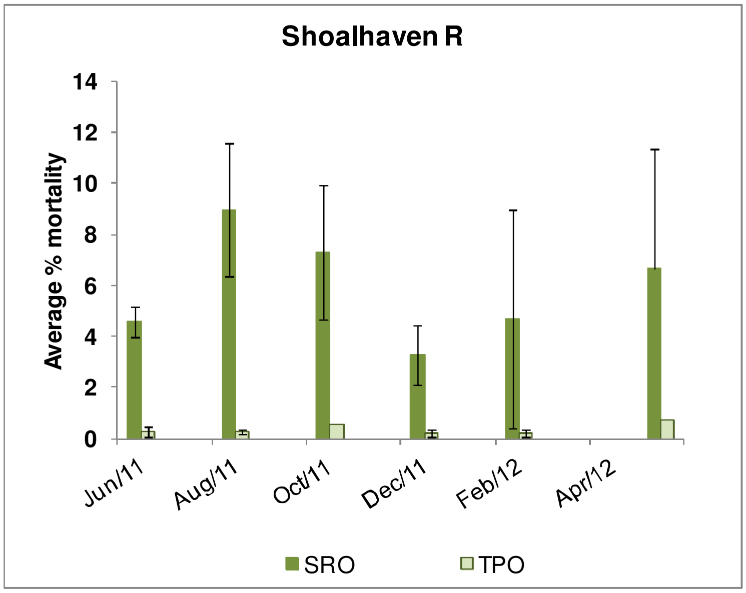


Species scale

In the Shoalhaven River, oyster growers have diversified the species they are growing, and for the past four years have been trialling the cultivation of TPO in some areas of the river. TPO are sourced from commercial hatcheries, while SRO used in the OMP were caught locally in the river. Throughout the monitoring year, SRO mortality levels in the Shoalhaven River (averaged across four locations) were significantly higher than for TPO (averaged across two locations) (Figure 4). This difference may have been reduced if hatchery-sourced SRO with disease-resistant lines had been used. However, there is still a large percentage of the NSW industry that uses wild stock (82%) compared to hatchery stock (18%) (NSW DPI, 2011).

In the Shoalhaven River, the OMP monitored both species of oyster at Comerong Bay. As the environmental and water quality conditions influencing both species in Comerong were expected to be the same, this allowed for direct comparison of SRO and TPO performance. The annual mortality level however, for SRO in Comerong was 35%, while the level for TPO was only 2%. This suggests there is something affecting the survival rate of SRO on a much greater scale than TPO. It is accepted that some species within the same taxon could exhibit different tolerances to the same environmental conditions, thus, resulting in the differentiation of species distribution (Shumway, 2011).

Figure 4. Average mortality levels for Sydney Rock Oysters compared to Triploid Pacific Oysters in the Shoalhaven River between May 2011 and May 2012.



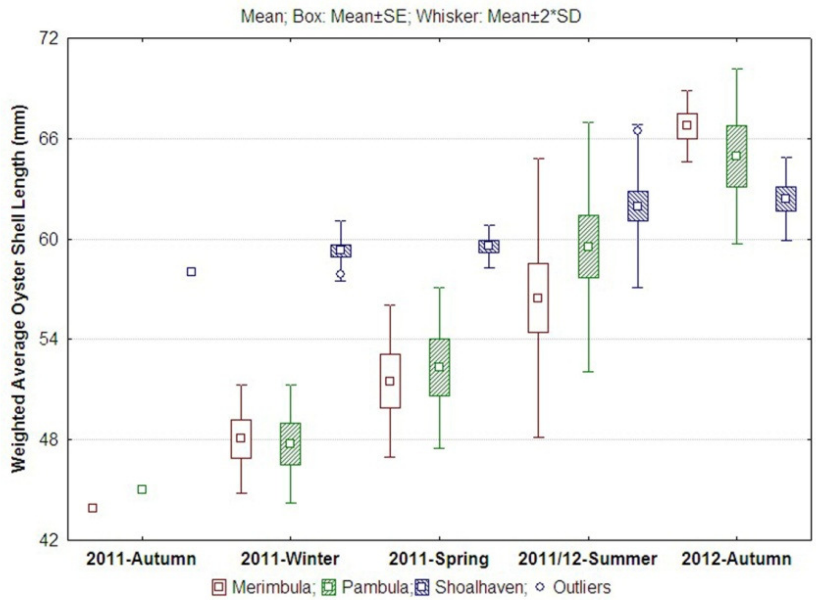
Growth

The OMP used oyster shell length as a proxy for oyster growth in each estuary but did not consider growth by weight, a measure commonly used in research. When using scales, weight measurements are more accurate than shell measurements however, when employing machinery like oyster graders, shell measurements can be as accurate and consistent as the ones collected by weighing oysters on a scale. Faster growth rates was expected in smaller oysters while larger oysters will show growth at a slower rate (Gosling, 2003).

Estuary scale

SROs used in the Shoalhaven River OMP were larger (58mm) than the oysters used for the Merimbula and Pambula lake programs (45mm). Over the year of monitoring oysters at Merimbula and Pambula lakes performed in a similar manner, despite the different origins of the two batches (Table 1). As expected, the smaller size SROs at Pambula and Merimbula grew at a faster rate than the larger SROs at the Shoalhaven River (Figure 5).

Figure 5. Seasonal differences in weighted average shell length for Sydney Rock Oysters at three Southern Rivers estuaries



It was also anticipated that SRO growth would be slower during the winter months as water temperature is well known to affect oyster metabolism, in particular growth (Gosling, 2003; Shumway, 2011). Indeed growth in the Shoalhaven River was depressed over winter. Oysters in the Shoalhaven increased in shell length from spring to summer. However, overall growth rates were extremely low potentially being constrained by environmental parameters such as consistent low salinities during most of the year (as a result of La Nina influenced conditions). Merimbula and Pambula SRO did, however, grow during winter despite the colder water temperatures during this time of the year. General growth rates patterns of oysters in Pambula and Merimbula reached expected sizes after a year of monitoring. A larger proportion of oysters in Merimbula reached slightly larger sizes than in Pambula Lake.

Location scale

In the Shoalhaven River, SRO growth was highly variable across the four sites, with Comerong recording significantly faster growth from eight months onwards (Figure 6). This burst in growth was also observed in TPOs growing at Comerong (Section 2.3). Since oyster growth in the Shoalhaven was minimal it is hard to characterise each experimental site from a growth performance point of view.

Minimal growth differences were recorded between the two monitoring sites at Merimbula Lake. However, slight growth differences occurred after 2 and 4 months of monitoring corresponding to the winter period. Oysters at the front lease in Merimbula grew slightly more during the winter months than oysters in the middle of Merimbula Lake (Figure 7). In Pambula Lake, higher growth rates throughout the year were recorded in SROs at the lease closest to the front of the lake in comparison with the lease located further inside of the lake. Oyster growers in this lake have already seen differences in growth potentially attributing better environmental conditions for the lease at the front that receives first inflow of oceanic water compared to the lease at the back on the lake (Figure 7).

Figure 6. Weighted average shell length for SRO at four locations in the Shoalhaven River between May 2011 (set-up) and May 2012.

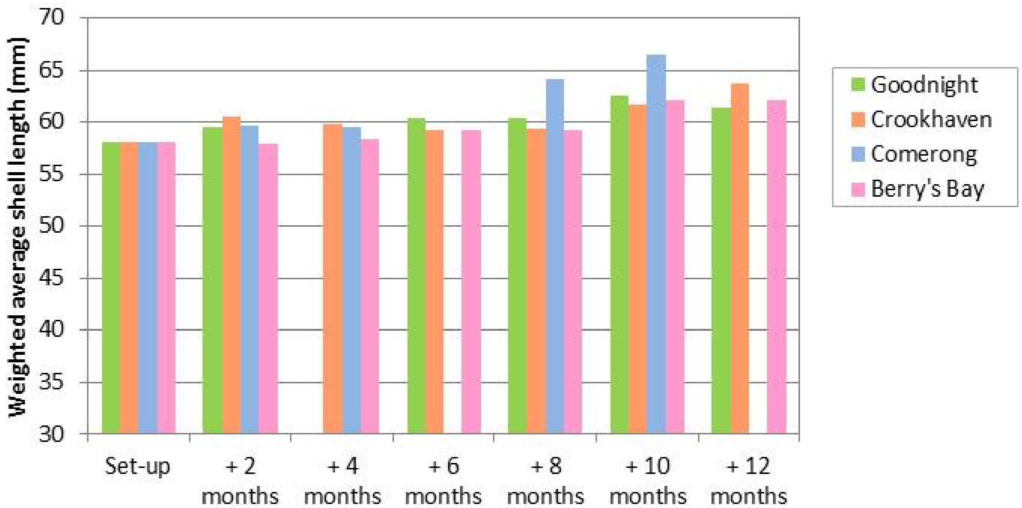
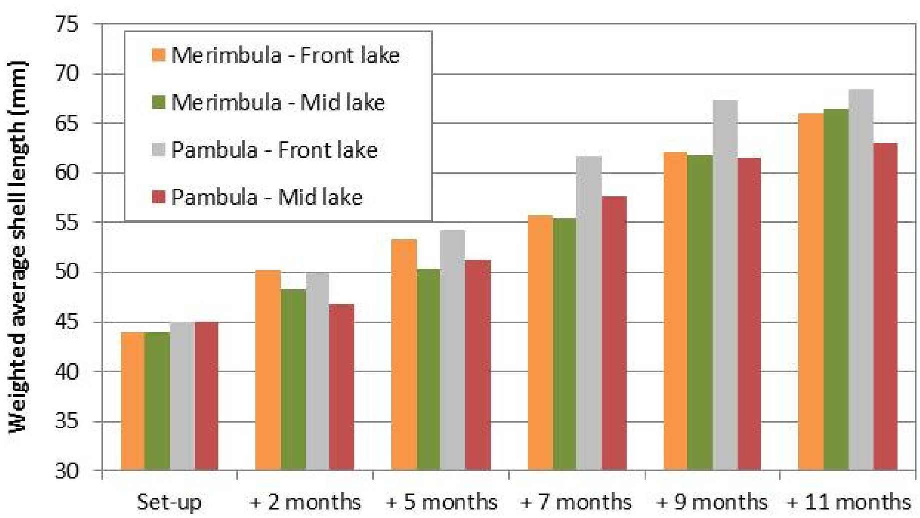


Figure 7. Weighted average shell length for Sydney Rock Oysters in two locations in Merimbula Lake and in Pambula Lake between May 2011 (set-up) and May 2012.

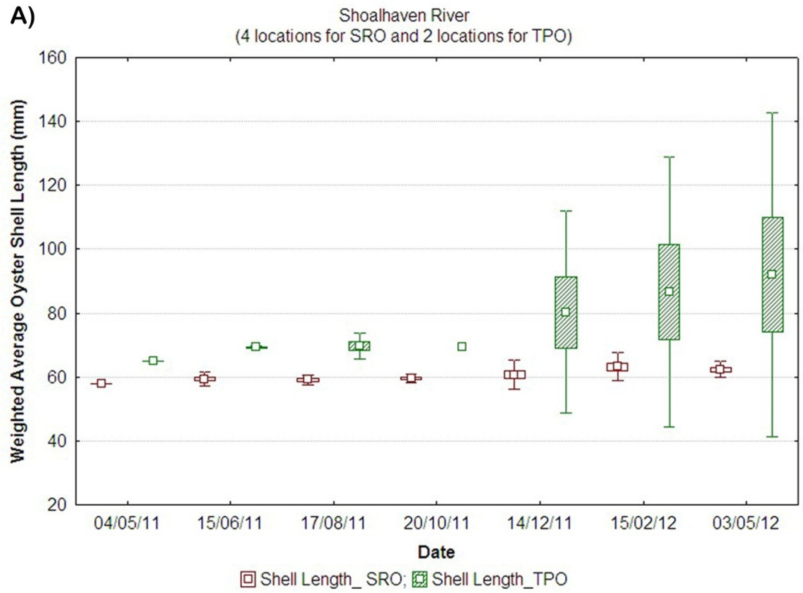


Oyster species scale

In the Shoalhaven River, significantly higher growth was recorded for TPO than SRO, especially from December 2011 onwards (Figure 8). A higher growth rate was expected for TPO than for SRO as Pacific Oysters tend to have the highest growth rates of the two species (Bayne, 1999). In addition Triploid Pacific Oysters are sterile and have the capability of growing even faster than the diploids as they divert most of their energy resources towards growth instead of reproduction.

Figure 8. Weighted average shell length for A) Sydney Rock Oyster and Triploid Pacific Oyster in the Shoalhaven River between May 2011 and May 2012, and for B) Triploid Pacific Oyster at two locations in the Shoalhaven River between May 2011 and May 2012.

A)



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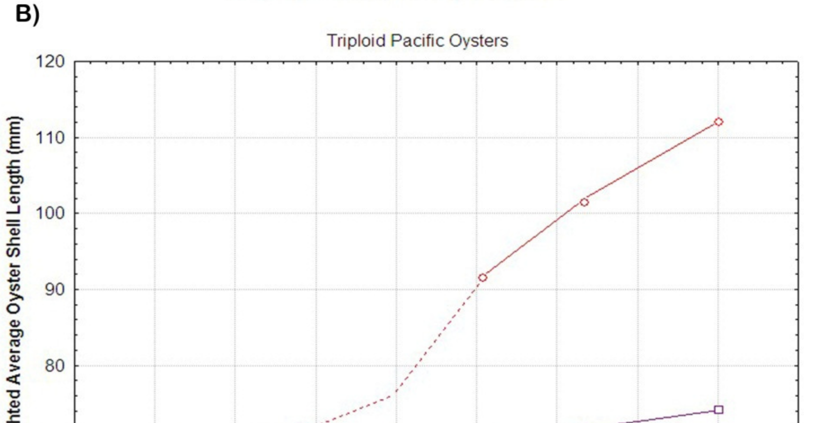


Shoalhaven TPO growth was predominantly driven by the performance of TPO at the Comerong location (Figure 8B). As described before, some growth for SRO was also observed in December 2011, although at a much lower rate. TPO growth in Curley's Bay only increased slightly after November 2011, 8 months after the monitoring program started. Oyster growth at this location was suppressed by the lack of water flow based on growers' observations.

Oyster performance relationship with environmental parameters

Temperature and salinity levels are known to influence the maximum feeding rates of suspension-feeders like oysters (see references in Shumway, 2011). These parameters have been explored here. A range of other environmental parameters such as chlorophyll-a (a proxy for calculating available food for oysters or phytoplankton biomass), suspended organic matter and dissolved oxygen have been suggested to influence oyster performance.

Salinity

Although it is highly likely that rainfall would have influenced oyster performance over the duration of the OMP, no significant relationship was found between salinity and oyster growth or mortality. The particularly wet conditions over the 12 month monitoring period may have compromised the detection of any linkages due to consistently low salinities. In addition, the grading of oysters every 2 months may restrict the ability to identify growth limitations as a result of low salinities, unless these conditions are maintained for the entire 2 months.

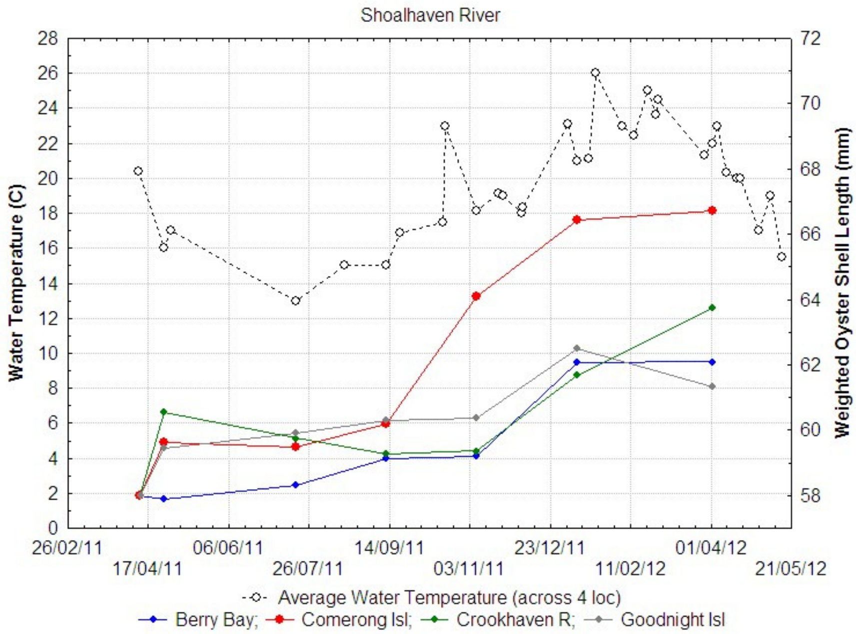
Available salinity data is limited to that collected by growers through the SQAP and local council data, which has a low and inconsistent sampling frequency. Higher frequency and more consistent salinity data is needed in order to confirm any links between salinity and oyster performance. Protocols in the collection of fortnight harmful algae sampling through SQAP, now integrates the recording of both water temperature and salinity levels.

Water temperature

Existing literature reports that higher growth rates as a result of high filtration rates are expected for oysters growing at higher temperatures (Shumway, 2011). However this relationship is not linear in most cases with defined temperature thresholds influencing overall oyster growth. In addition, growth is also influenced by a number of metabolic processes like oyster reproductive cycle, and environmental variables like oyster food supply (see references in Gosling, 2003). An overall increase in growth rates towards the warmer months have been shown in the three rivers used in this OMP for both species (Figure 9) (refer also to Section Growth). Although oyster performance data is responding to seasonality, extreme values (high and low) in water temperature can severely affect oyster growth and survival rates.

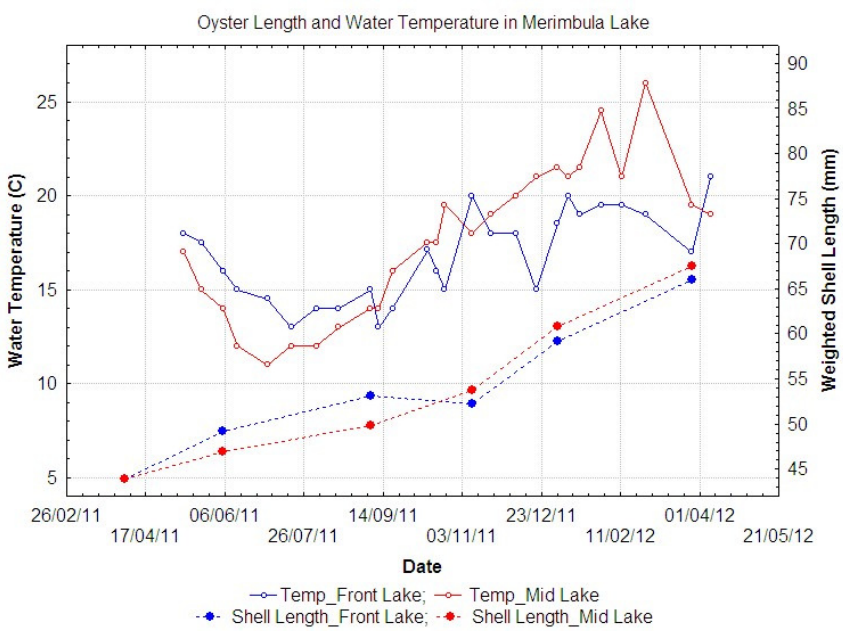
In Merimbula and Pambula lakes it was observed that during winter, water temperature at the front of the lake was slightly warmer (by 1-2ºC) than in the middle of the lake. This resulted in slightly higher SRO growth in the location closer to the entrance compared to the oysters cultivated further inside the lake. Water temperature in the middle of the lake during winter reached on averaged 11ºC, which is considered to be an extreme low threshold for SRO growth. In fact previous research with SRO in the Clyde River showed that sustained water temperatures of 13ºC during the winter period resulted in no activity in terms of oyster growth (Rubio, 2008). As the surrounding air temperature warms up towards spring, water temperature increases in the middle of the lake, becoming a few degrees warmer than water towards the front of the lake. Again an associated change in SRO growth between the mid lake and front lake was observed during summer when water temperature was higher in the body of the lake than at the entrance.

Figure 9. Relationship between water temperature (left axis) and weighted average shell length (right axis) for Sydney Rock Oysters in the four locations in the Shoalhaven River between May 2011 and May 2012.



This pattern was observed at both Merimbula (Figure 10) and Pambula lakes with similar growth responses recorded over the monitoring program. Further data is needed to confirm this pattern but should it exists the influence of seasonal water temperature on growth could be used to adjust husbandry techniques so that oyster performance is maximised in particular during the winter period.

Figure 10. Relationship between water temperature (left axis) and weighted average shell length (right axis) for Sydney Rock Oysters in the two locations in Merimbula Lake between May 2011 and May 2012.



Oyster Lease Profitability

The data collected through the OMP can assist growers in maximising profitability. In this paper only the first year of monitoring data has been included, however as more data is collected it will be possible to make more accurate calculations and forecasts on the profitability of an area over the three year SRO cycle.

Profitability can be increased by maximising oyster performance at the lease scale. This can be achieved through improved oyster growth, mortality levels and taking advantage of localised environmental conditions favourable to oyster growth. The more information on these parameters the better informed a grower will be.

Table 3 shows calculations on the annual return of each lease used in this OMP. As seen from the growth and mortality results, oysters cultivated in the front area of Pambula and Merimbula Lake grew more and had higher survival rates. This resulted in a 7.6% and a 2.5% increased in profitability at the front leases for Pambula and Merimbula, respectively.

A larger difference in the annual return was obtained across lease areas in the Shoalhaven River. This was predominantly a result of variable high mortality levels at all locations. Highest mortality was at the Crookhaven with 40% lost within the year of monitoring. This level of mortality is not sustainable for a business to operate with. Despite the high mortality levels, SRO at Comerong showed good profitability at the end of the year. This resulted from very high growth levels over the second half of the year. As such both mortality and growth levels are important factors.

Table 3 also shows the profitability values for the leases where TPO were cultivated in the Shoalhaven River. Since mortality rates for TPO are so low, oysters grown in an area of high production can achieve high returns in 1.5-2 years in comparison to wild SRO, which grow slower and appear to have significantly higher mortality.

Outcomes and future of oyster monitoring programs

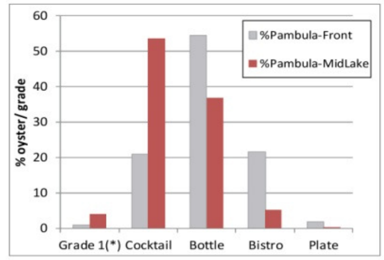
The oyster industry plays a key ecological role, helping to remediate potential negative local effects in bays and the downstream areas of estuaries, through balancing nutrient and maintaining good water quality levels. The industry is highly vulnerable to changes in terrestrial and oceanic environments, in particular as a result of increased coastal development. However, there is a lack of information on the drivers influencing oyster aquaculture. Therefore there is a need for increased waterway and oyster performance monitoring in order to improve oyster production levels and management of catchments.

Here a prototype oyster monitoring program has been trialled with the aim of building information on oyster performance across locations in an estuary. This will assist in the establishment of a baseline for oyster performance from which temporal and spatial changes in growth and mortality can be measured. This information has been shown to assist the oyster industry in refining husbandry techniques, select priority lease areas according to performance and improve production levels. Information from the 2011-2012 Oyster Monitoring Program presented here has been well-received by the oyster industry (O'Sullivan, 2012). Moreover the original scope of the program has been expanded by more than 200% in 2013 with more locations and cultivation methods. In addition two new programs have been established in two oyster producing estuaries of the south coast. In addition to oyster data, baseline environmental data is also required to assess extreme conditions and the associated effects on the aquatic ecosystems.

Table 3: Oyster Lease Profitability. Blue numbers correspond to the leases with higher profitability or low annual mortality within a river/lake. (*)Comerong oysters were not graded in May 2012 so data presented here corresponds to 10 months and not 12 months as it does for the other locations.

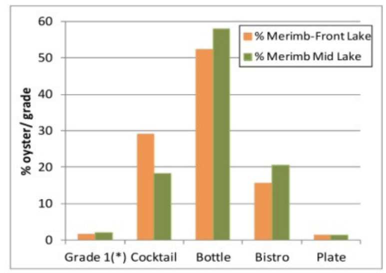
Sydney Rock Oysters

	Pambula Lake							
	average length	Front Lake %oysters/ grade	Mid Lake %oysters/ grade	$ farmgate/ oyster grade	Front Lake $ /Grade	Mid Lake $ /Grade	Front Lake Annual Mortality (%)	Mid Lake Annual Mortality (%)
Grade 1 (non-marketable)	49	0.8	3.9					
Cocktail	59	20.8	53.7	4	604	1,692		
Bottle	68	54.5	36.9	5	1,980	1,455		
Bistro	81	21.6	5.1	6.5	1,021	260		
Plate	97	1.7	0.3	8.5	102	17		
Total					$ 3,707	$ 3,424	14.3%	16.8%



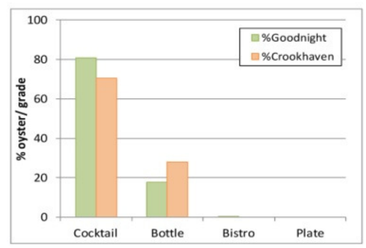
Sydney Rock Oysters

	Merimbula Lake							
Grades	average length	Front Lake %oysters/ grade	Mid Lake %oysters/ grade	$ farmgate/ oyster grade	Front Lake $ /Grade	Mid Lake $ /Grade	Front Lake Annual Mortality (%)	Mid Lake Annual Mortality (%)
Grade 1 (non-marketable)	47	1.5	2.0					
Cocktail	59	29.2	18.2	4	1,068	660		
Bottle	68	52.3	57.9	5	2,395	2,630		
Bistro	81	15.5	20.6	6.5	923	1,216		
Plate	93	1.3	1.3	8.5	102	102		
Total					$ 4,488	$ 4,608	13%	10.7%



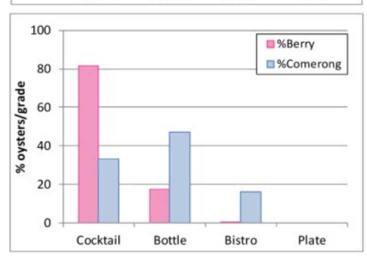
Sydney Rock Oysters

	Shoalhaven							
Grades	average length	Goodnight %oysters/ grade	Crookhaven %oysters/ grade	$ farmgate/ oyster grade	Goodnight $ /Grade	Crookhaven $ /Grade	Goodnight Annual Mortality (%)	Crookhaven Annual Mortality (%)
Cocktail	60	80.9	70.5	4	2,376	1,456		
Bottle	68	17.7	28.1	5	650	725		
Bistro	80	0.3		6.5	13			
Plate				8.5				
Total					$ 3,039	$ 2,181	22.2%	42.4%



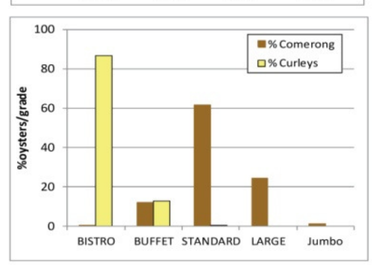
Sydney Rock Oysters

	Shoalhaven							
Grades	average length	Comerong %oysters/ grade (*)	Berry %oysters/ grade	$ farmgate/ oyster grade	Comerong $ /Grade (*)	Berry $ /Grade	Comerong Annual Mortality (%)*	Berry Annual Mortality (%)
Cocktail	60	33.2	81.3	4	860	2,144		
Bottle	68	47.3	17.3	5	1,530	570		
Bistro	80	16.4	0.3	6.5	689	13		
Plate				8.5				
Total					$ 3,079	$ 2,727	35.6%	25.7%



Triploid Pacific Oysters

	Shoalhaven							
Grades	average length	Comerong %oysters/ grade (*)	Curleys %oysters/ grade	$ farmgate/ oyster grade	Comerong $ /Grade (*)	Curleys $ /Grade	Comerong Annual Mortality (%)*	Curleys Annual Mortality (%)
Bistro	70	0.5	86.8	5.5	28	3,817		
Buffet	85	12.0	13.0	6.5	735	676		
Standard	99	61.6	0.1	7.5	4,350	8		
Large	114	24.3		9	2,061			
Jumbo	150	1.3		11	132			
Total					$ 7,305	$ 4,501	1.70%	1.90%



A large number of anthropogenic factors affect oyster performance. These include chemical contamination from pesticides (Gagnaire et al., 2007), pollutants from sewage treatment plants including estrogenic compounds (Andrew et al., 2008; Andrew et al., 2010), stormwater, suspended matter run-off and general pollution (Bayen et al., 2007; Ghedini et al., 2011). Most of these stressors originate in the catchment surrounding the waterways and have the potential to influence the oyster's physiology, immune system fitness and reproductive development. Consequently there is a need to minimize these inputs in order to avoid detrimental impacts to the oyster industry. By maintaining a healthy oyster industry, catchment managers can help maintain the health of the catchment as a whole.

A number of estuaries in NSW have recently lost their local oyster industry as a result of disease outbreaks or frequent pollution events, potentially link to anthropogenic catchment processes. Such loses can have dramatic socio-economic and ecological impacts on the area. As seen in Chesapeake Bay, increased eutrophication took place after the collapse of the local oyster fishery as a result of their capacity for grazing down phytoplankton abundance and nitrogen removal when harvested (Kemp et al., 2005).

Through greater understanding of the drivers modulating oyster performance, the oyster industry will be in a better position to respond to unexpected events and to allow the development of diverse adaptation options (Leith and Haward, 2010). Increased environmental monitoring has already been undertaken by the oyster industry along the south coast where 17 temperature loggers have been deployed and additional phytoplankton sampling is currently taking place. This additional sampling is funded by the SRCMA through the Australian Government's Caring for our Country. Other environmental parameters known to be important for oyster production are currently being monitored by most local councils. There is now an opportunity to integrate all this information adding value to the individual information streams.

The OMP is a pre-cursor for an Australian industry-wide monitoring program. By establishing oyster monitoring programs a two-fold benefit ensues 1) the oyster industry maximises its husbandry practices and 2) catchment managers ensure that catchment processes are well managed supporting, in turn, a healthy oyster industry.

Recognising the great benefit of monitoring the canaries of our catchments local councils, Catchment Management Authorities and other government agencies, are already showing support for this cost effective monitoring approach, which acts as an indicator for the productivity and health of estuaries and the wider catchments.

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