MONITORING THE CANARIES OF OUR CATCHMENTS. A cooperative and innovative monitoring program quantifying oyster performance and relationships with estuarine health.

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Abstract

Aquaculture, including oyster farming, is playing a major role in meeting the growing world demand for food. In New South Wales, Sydney rock oyster (SRO, *Saccostrea glomerata*) production is economically and culturally important, accounting for 77% of the total aquaculture production in the state (NSW Department of Primary Industries 2012). Not only economically important, oysters also 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. For these reasons, oysters are often referred to as the 'canaries' of our catchments, as healthy oysters reflect healthy estuaries.

With oysters being a key indicator of the condition of our catchments, monitoring the NSW oyster industry not only increases our knowledge of the factors influencing the performance of this important industry, but also leads to an appreciation of the role oyster farming plays in managing catchment health. Monitoring oyster performance therefore achieves a two-fold goal in gathering information on the productive capacity of oyster growing areas and indirectly monitoring catchment health.

Two data sets vital to the oyster industry are oyster performance and water quality. Since this data is scarce and in some instances confidential, there is a need to establish estuary-wide long-term monitoring programs that facilitate collective monitoring within and across key oyster growing estuaries.

In this project oysters were monitored using an innovative approach by Southern Rivers Catchment Management Authority and oyster researchers in direct partnership with the NSW oyster industry. Commercial automated oyster graders (already in use in the industry and tested as potential monitoring tools) were used to quantify oyster performance in terms of growth and mortality at a total of 23 different locations within five NSW estuaries during two years (May 2011 to May 2013). The effect of cultivation units, stocking densities and oyster species on oyster performance was also assessed at some of the study areas. Oyster performance information was linked to environmental data collected by the oyster industry and estuarine/catchment managers.

Through the surveillance of growth and mortality in different growing areas of an estuary, sites were characterised and changes in performance identified. Defined patterns in overall mortality levels were found across the estuaries. SROs in the Shoalhaven had the highest annual mortalities (average 29%±9 in 2011/12 and 32%±10 in 2012/13) over both years of monitoring, with similar high levels across all sites within this estuary. Clyde River oysters also had significantly high annual mortalities (29%±6) compared to the other three estuaries of Wapengo (13%±5), Merimbula (13%±2 in 2011/12 and 16%±7 in 2012/13) and Pambula (18%±4 in 2011/12 and 16%±4 in 2012/13). Mortality levels were found to be the lowest in autumn independent of estuary or location within an estuary.

Growth rates at the end of each monitoring program showed distinct patterns across estuaries. Across all sites in the Clyde River annual shell increments for SRO were extremely low (0.4±0.12 mm/month), followed by the Shoalhaven (0.47±0.2 mm/month in 2011/12 and 0.6±0.12 mm/month in 2012/13). In comparison SROs in the other three estuaries grew on average more than 1.2mm/month. However, with only one year of data in most of these estuaries it is hard to conclude if these patterns in oyster performance are the norm or if they are a result of abnormal occurrences and/or particular environmental influences. This issue emphasises the essential need for on-going monitoring of oyster performance in order to determine and distinguish between baseline information and unusual events.

Through time oyster growth at most locations increased dramatically between the warmer months of November to January, in correlation with increased water temperatures. During this period high algae activity was also observed resulting in increased levels of phytoplankton productivity. Overall diatoms and dinoflagellates were found to increase with temperature while small flagellates were found to increase with slight decreases in salinity, in most cases as a result of medium to small rain events. Therefore, shell growth increments were found to increase in association with increasing water temperature and with increasing number of phytoplankton cells. Shell increments were also found to be larger in estuaries where frequent small rainfall events took place in comparison with estuaries with drier conditions. Oyster growth was minimal during the winter months once water temperatures reached on average 12°C.

The effect of the type of cultivation on oyster performance varied per estuary resulting in higher oyster shell growth in floating cultivation units than in intertidal trays in Pambula Lake but having minimal effect on SROs at Wapengo Lake in two different methods. Stocking densities used in this project did not result in overall significant differences except in Pambula Lake where low densities of SROs in floating cultivation units resulted in a higher overall oyster batch weight. Triploid Pacific oysters (TPO, *Crassostrea gigas*) were included in the monitoring program at Shoalhaven River. In general TPOs in the Shoalhaven River had significantly lower mortality levels and around 25-30% higher shell growth increments than the SROs grown at similar locations in this estuary. This indicates that the different species of oysters have different adaptations to the same environmental growing conditions.

While the Southern Rivers Oyster Monitoring Program (OMP) is an example of a cooperative partnership where minimal effort and cost can be maximised to achieve estuary-wide benefits; its continuation is vital in identifying and establishing long term performance baselines. The initial results of this monitoring program and the application of some outcomes, indicates there is direct benefit for the industry in improving its production. Continuation will only further enhance oyster grower’s ability to manage their practices based on known characteristics of an estuary and its relationship with environmental influences, the product of which will be a more robust and viable industry into the future.

In order to maximise profitability oyster growth must be maximised while mortality levels minimised. Data collected through the OMP can assist industry in improving profitability by understanding differences in oyster performance across different growing areas and cultivation methods. Annual returns during the 2012/13 program did not vary markedly across locations in Wapengo and Merimbula but did in the Shoalhaven and Clyde. Annual returns in Pambula varied for both location and method of cultivation resulting in different levels of lease profitability.

Overall results from the OMP indicate that oyster performance and profitability are site and infrastructure specific. The more data that is collected, the more accurate calculations and forecasts on the profitability of an area over the cultivation life cycle can be made. By taking advantage of localised environmental conditions favourable to stronger oyster performance (higher growth and lower mortality) improvements in profitability/lease can be achieved.

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Oyster growers from Merimbula and Pambula assisting with grading oysters

Oysters at Wapengo being graded by the Shellquip automated machine

OMP coordinator, with Clyde grower Ewan McAsh and Dr Ana Rubio

1. Introduction

1.1 Oysters and their ecological role in our catchments

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 surrounding 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).

Bivalve molluscs are commonly used as bio-monitors of marine and estuarine pollution because, as filter-feeding organisms, they are efficient accumulators of organic and metal contaminants and display great sensitivity to pollutants (Romeo et al. 2003; Dondero et al. 2006; Lobo et al. 2010). These animals have a high ecological value due to their sedentary life and filtration capacity and they provide numerous ecosystem services in estuaries (Coen et al. 2007; Maria et al. 2009). 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). For instance, if pollution levels or suspended matter increase in the waterways (as a consequence of urban effluent discharges, agriculture run-off or fuel spills) oysters will quickly react to these conditions, in most cases reducing feeding and nutrient recycling and in some cases dying.

The performance of the oyster industry can reflect the health of the catchment in which it lies. 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.

1.2 New South Wales oyster industry

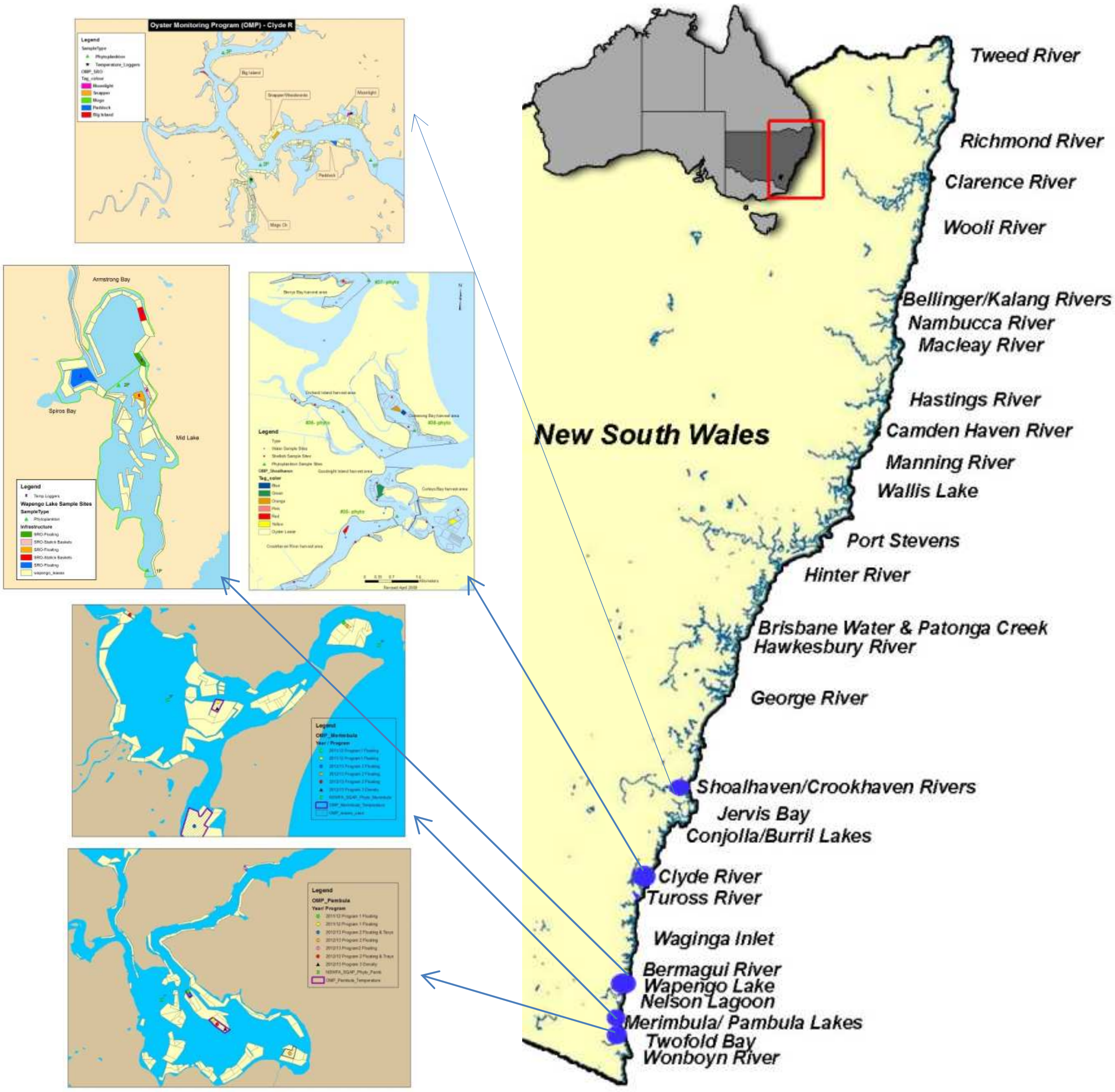
In NSW, there are 32 commercial oyster growing areas, between Wonboyn in the south and Tweed Heads in the north, with around 322 oyster permit holders producing 4.6 million dozen oysters in a $28.2 million industry (NSW Department of Primary Industries 2012). Oyster growers in NSW primarily farm Sydney 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 77% 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 annual production of $30-80,000/ha (industry member *pers. communication 2012*).

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 PO market. Over the last decade, however, SRO production levels have stabilised as a result of progressive action towards new technologies and new management systems. This has led to significant improvements in oyster supply, environmental and disease management, and the coordination of stakeholders within catchments to protect water quality and environmental systems.

This study is focused on the Southern Rivers region of the far south coast of New South Wales with five oyster growing estuaries between Shoalhaven and Pambula engaged in the OMP (Figure 1).

Figure 1: Map showing the geographical location of the five estuaries involved in the Southern Rivers estuary-wide oyster monitoring program. Maps of each estuary included in Appendix 1.



1.3 Overview of international and national oyster monitoring programs

Long-term standardised monitoring programs are fundamental for the oyster industry as their implementation allows for the following issues to be explored:

- the status of production in relation to environmental patterns.
- the characterisation of different oyster growing areas.
- the quantification of oyster performance through time.
- possible improvements in the management of industry operations.
- options for focusing research and management priorities.

Through sustained monitoring, baseline information can be established that allows for the identification of unusual events (e.g. high mortalities, extreme changes in water conditions) and the identification of long-term trends as well as the potential causes attributing to these patterns. Building and sharing knowledge about the characteristics of certain growing areas and the drivers potentially affecting oyster performance across different environments, can lead to improvements in management techniques and decisions.

Oyster monitoring programs are, however, rare in Australia and limited 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). However, most shellfish industries world-wide are involved with health sanitary monitoring programs which require intensive sampling of water quality around cultivation leases and of the shellfish itself. The existence of this type of monitoring program has in some countries led to an expansion in the scope of these programs to include oyster performance in the form of growth, condition and survival (Sonier et al. 2011). The largest and better established network of monitoring programs exist in France, which target 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, with information 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 reference sites.

Although bivalves have been extensively used as sentinel species in a large number of international monitoring programs their use in Australia is still limited. SRO, have however been shown to be a reliable indicator of pollution (Scanes & Roach 1999; Andrew et al. 2010; Dafforn et al. 2012; Edge et al. 2012). In Australia, oyster monitoring programs are mainly focused on water quality and oyster 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 (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. Unlike other countries, Australia's monitoring programs do not collect information on oyster performance. This information has however been highlighted by NSW oyster industry members as being particularly important.
Quantifying the capacity and performance of cultivating areas (i.e. oyster leases) will assist growers in managing their cultivation space in a more sustainable and productive way. This oyster monitoring program has attempted to fill this knowledge gap and provide important information in addition to that derived from the SQAP. 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.

1.4 The Southern Rivers estuary-wide 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. The grader not only cleans and sorts the oysters but also allows growers to be much more accurate and consistent regarding oyster sizes and quantity sent to market. The frequent grading of oysters is an essential part of the cultivation process to optimise production. By keeping similar size oysters together, inter-oyster competition can be minimised. Any larger oysters in a batch can 'hog' the shared resources, starving smaller nearby animals. Most oyster growers only start using the grader on marketable-size oysters.

While these graders are primarily used for sorting 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 used to track oysters (i.e. weighing and measuring oysters one by one). As demonstrated in pilot studies (Rubio 2010), 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.

By monitoring oysters through the years a baseline or 'the norm' can be established (i.e. an average yearly performance) that can be used as a reference point by industry and managers. Shifts away from this norm will help to identify potential problems that growers/managers/researchers can quickly act upon. Through the implementation of this simple baseline monitoring a wide range of important information can be collected and collated, contributing towards:

- a standard and simple annual assessment of oyster performance and mortalities;
- an assessment of trends over time;
- spatial differences across leases or estuaries (i.e. characterisation of sites);
- identification of periods of high mortalities and/or high growth; and
- correlations to climatological or hydrological data in order to determine factors limiting growth or conditions exacerbating mortality levels.

The OMP was designed and set-up to cause as little interference as possible with the day-to-day husbandry and production protocols that growers are currently undertaking. The less the experiments differ from normal growers' practices, the more likely oyster farmers will be able to integrate these monitoring methods into their daily routines.

2. Aims

The main aim of this monitoring program was to record growth and mortality rates of oysters in different growing areas of important oyster producing estuaries in the Southern Rivers region. This program was developed with the end objective of reaching a better understanding of the naturally-occurring variability (both spatial and temporal) in oyster growing areas. The monitoring program also quantified the effect that different species, cultivation methods and stocking densities could have on oyster performance.

In addition to oyster performance data, the OMP was designed to collect (where possible) environmental data including water temperature, salinity and phytoplankton community composition and abundance. The inclusion of these parameters allows for exploration into the environmental conditions characterising different estuaries and growing areas. A greater understanding of oyster performance and environmental variability was considered important in order to gauge the effectiveness of management decisions based on how different growing areas respond to different influences.

3. Methods

In May 2011, estuary-wide monitoring programs were established at three main oyster producing estuaries in the Southern Rivers region; Shoalhaven River, Merimbula Lake and Pambula Lake. This was the first component of the OMP and is referred to as Program 1 (May 2011 to May 2013). Due to industry interest, the OMP continued into its second year at the existing locations, and in January 2012, two more estuaries joined the program; Clyde River and Wapengo Lagoon. This part of the OMP is referred to as Program 2 (January 2012 to May 2013). Overall the Southern Rivers OMP ran for a period of 24 months and covered 23 sites across the five estuaries before concluding in May 2013. A summary of the set-up information for each monitoring program undertaken in this project is provided in Table 1. Refer to Appendix 1 for maps of the five estuaries and the locations of monitoring sites within each estuary.

The OMP required access to an automated grader (here Shellquip SED oyster graders were used (http://shellquip.com.au/) to count live oysters and to measure shell length. These graders are common in NSW with a third of the oyster producing estuaries having access to one. It is also frequently used among the oyster growers in South Australia and Tasmania. These graders can accurately grade oysters of 30mm shell length (approximately one year old) and above.

In order to minimise inherent variability within each monitoring program, oysters used in the OMP for that estuary were provided by an industry member and chosen from a pre-selected oyster batch (i.e. oysters that shared the same origin, age and husbandry). Pre-defined computer proforma (referred to as a ‘recipe’) was 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) and is outlined in Appendix 2.

Table 1: Set-up of the oyster monitoring programs in the Southern Rivers region of the NSW south coast (refer to maps in Appendix 1).

Estuary	Program	Program duration	Sampling Sites	Species	Number of oysters	Cultivation method	Oyster origin	Initial shell length
Shoalhaven River	1	May 2011 to May 2011	Berry's Bay Crookhaven Goodnight Comerong	SRO	4,000 (1,000/site)	Floating baskets	Wild spat locally caught.	58mm
	1	May 2011 to May 2011	Comerong Curleys	TPO	2,000 (1,000/site)	Floating baskets	Hatchery batch spawned September 2010.	65mm
	2	May 2012 to April 2013	Berry's Bay Crookhaven Goodnight Comerong	SRO	2,800 (700/site)	Floating baskets	Wild spat locally caught.	55mm
	2	May 2012 to April 2013	Comerong Curleys Goodnight	TPO	2,250 (750/site)	Floating baskets	Hatchery batch spawned 2011.	Comerong: 53mm Curleys/ Goodnight: 50mm
Clyde River	2	Jan 2012 to April 2013	Big Island Moonlight Mogo Snapper Paddock	SRO	6,000 (1,200/site)	Floating baskets	Single seed spat from Northern Rivers 2011.	55mm
Wapengo Lagoon	2	Jan 2012 to May 2013	Mid Lake Sprios Bay Armstrong Bay	SRO	5,250 (1,050/site)	Floating baskets Static baskets	Wild spat locally caught 2011.	43mm
Merimbula Lake	1	May 2011 to Feb 2013	Front Lake Mid Lake	SRO	2,000 (1,000/site)	Floating baskets	Wild spat locally caught 2012.	45mm
	2	May 2012 to May 2013	Front Lake Mid Lake Golf Lake Boggy Creek	SRO	2,000 (1,000/site)	Floating baskets	Wild spat locally caught 2011.	45mm
	3	Jun 2012 to May 2013	Mid Lake	SRO	360 (2 x 70/bag 2 x 110/bag)	Floating baskets	Wild spat locally caught.	54mm
Pambula Lake	1	May 2011 to Feb 2013	Front Lake Mid Lake	SRO	2,000 (1,000/site)	Floating baskets	Wild spat locally caught.	45mm
	2	May 2012 to May 2013	Entrance Front Lake Mid Lake Back Lake	SRO	2,000 (1,000/site)	Floating baskets Trays	Wild spat locally caught.	41mm
	3	June 2012 to May 2013	Mid lake	SRO	360 (2 x 70/bag 2 x 110/bag)	Floating baskets	Wild spat locally caught.	41mm

The OMP monitored SRO in all estuaries except in the Shoalhaven River where Triploid Pacific oysters (TPO) were also monitored. The sampling sites within an estuary were chosen by industry with the aim of targeting a range of growing areas that are known to perform differently. In Pambula and Wapengo industry participants also choose to compare a number of cultivation methods to assess performance of different methods used in that estuary. In Pambula the cultivation gear used were floating baskets and intertidal tray cultivation units, while at Wapengo floating baskets were compared to static baskets (Figure 2). In Merimbula and Pambula, industry participants also elected to compare stocking densities that might assist in finding an optimum density for production. The levels of stocking density per cultivation unit were also chosen by the industry.

Figure 2 Examples of the different types of cultivation units used in the comparison of performance across different methods. Floating baskets (a) were compared to static baskets (b) in Wapengo, while in Pambula tray (c) cultivation was compared to floating baskets (a).

a. Floating Baskets **b. Static Baskets** **c. Trays**

Oysters were graded approximately every two months. This involved growers bringing oysters in from the lease for grading by the OMP coordinator following a standard process (note that where data is missing in the figures means oysters were not brought on time to be graded at this time, Figure 4).

Oyster farmers were responsible for cleaning cultivation units of fouling by ensuring aeration days throughout the program duration. Units where replaced if too heavily covered in foul or when damaged (Figure 3).

Figure 3. Growers involved attending to oysters in Shoalhaven River, Merimbula and Clyde River

Figure 4. Steps involved in grading oysters with an automated ShellQuip grading machine in order to collect information on shell length

a. Dead oysters are removed and counted before oysters travel along the conveyor belt for grading.

b. Oysters travel along the conveyor where they are rinsed then passed through a separator.

c. A 2D photo is taken of each oyster which measures shell dimension/size to classify into a pre-determined grade, which has been established at the start of the program to ensure consistency in measurements.

d. Depending on the measurement the oyster will be sent through the corresponding chute for its grade, into the floating cultivation baskets (if used) ready to go back to the lease.

At each grading event (Appendix 3), mortality rates were calculated by counting the number of dead oysters per oyster batch by hand. Oyster size was determined photographically by the grader based on shell dimensions. 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 addition to shell measurements, oysters in Program 3 (Merimbula and Pambula only) were also weighed. Here the effect of different stocking densities was monitored, with the whole batch contained in each cultivation unit weighed at each grading using commercial scales. The overall wet weight of an oyster batch was then averaged according to the total number of oysters in that batch. Incremental increases in shell length (expressed as mm/month) were calculated based on the final shell length measurement less that of the initial shell length proportioned across the number of monitoring days for that program.

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).

In order to establish links between the data and water quality parameters, oyster performance data was correlated with available water temperature and salinity data. This data was obtained from a number of monitoring programs like data collected by growers through the SQAP ‘event’ sampling protocols (i.e. after a pollution incident or high rainfall) and by in-situ temperature loggers. Some of the loggers are maintained by Manly Hydraulics Laboratory and others by the coordinator of this monitoring program. The OMP temperature loggers were deployed across a number of sites in each estuary to record temperature readings on an hourly basis (refer to Appendix 1 for site locations). The loggers comprise of a DS1921G Thermochron iButton attached to a yellow fob sealed in canisters and attached to the inside of the cultivation unit (e.g. to a floating basket, static basket or tray, Figure 5). The loggers were downloaded at each grading and hourly readings averaged to provide a daily average temperature for each of the sites between July 2012 and May 2013.

Figure 5: Temperature loggers used in the OMP to monitor hourly water temperature at sites across the Southern Rivers region

a. Thermochron iButtion loggers were sealed inside canisters.

b. The canisters were attached to the inside of cultivation units and set to record hourly temperature.

c. at each grading event loggers were removed from the canisters and data downloaded.

Full counts and taxonomical identification of phytoplankton were monitored at one of the pre-defined sites representing a harvest area per estuary during a year. As part of the SQAP, the presence of harmful algae is identified using a 300ml water sample collected. The 300ml sample is used to obtain counts per algae type. The sample is sent to a laboratory where it is concentrated by 100 times using membrane filtration (ie. the 300ml sample is concentrated down to 3ml). A 1ml sample of the concentrated matter is counted in a Sedgwick glass chamber using Zeiss Axiolab or Zeiss Standard microscopes, equipped with phase-contrast. A second water sample is also collected using a phytoplankton net that is dragged for a certain amount of time at the same site. This sample is used for qualitative purposes only, to identify any organisms that are in low numbers and to get a more accurate ID of harmful species as the concentration of organisms is much higher in the net sample. As part of the OMP, analysis was extended to include identification of non-harmful species of phytoplankton. These analyses were carried out between June 2012 and May 2013.

3.1 Data analysis

Data was analysed using Statistica software. Where data did not follow a normal distribution it was normalised using Arcsin transformation for mortality data and logarithm transformation for oyster growth and phytoplankton counts. Despite transformation, some data was analysed using non-parametric analysis. Significant difference are referred to when $p<0.05$.

4. Results

This paper includes reference to results gathered over 24 months (May 2011-2013) on oyster growth and mortality levels, as well as preliminary relationships on oyster performance with environmental data (water temperature, salinity and phytoplankton abundance/composition) from five oyster growing estuaries (Shoalhaven River, Merimbula Lake and Pambula Lake, Clyde River, Wapengo). For more details on the results of individual programs refer to the monitoring tab on the Oyster Information Portal website (www.oysterinformationportal.net.au).

Mortality levels for each oyster batch were monitored approximately every two months. While the assessment of mortality levels did not include the determination of the cause of the mortality, growers were encouraged to contact the biosecurity branch of NSW DPI if mortality levels were found to be higher than 10%.

Careful consideration must be given when comparing results between estuaries, especially growth data, as each monitoring program at each estuary was set-up using different oyster batches as described in Table 1. Here, general comparative results are presented for primary use and interpretation by the oyster industry according to the set-up of each program. However long-term monitoring is required to obtain robust results.

4.1 Performance by estuary

4.1.1 Program 1: Shoalhaven, Merimbula and Pambula (May 2011- May 2013)

After the first 12 months of Program 1, cumulative mortality levels for SRO ranged from 13% to 30% across the three estuaries. The Shoalhaven River concluded Program 1 with the highest cumulative SRO mortality (n.b Shoalhaven River was monitored for 12 months compared to Pambula and Merimbula, where Program 1 continued for 20 months in these locations). In comparison to high SRO mortality in the Shoalhaven, TPO experienced very low mortality rates reaching a cumulative loss of just 2% (Table 2).

Table 2: Average cumulative mortality levels (%) in three Southern Rivers estuaries for Sydney rock oysters and Triploid pacific oysters after 6, 12 and 20 months of monitoring between May 2011 and May 2013.

Location	Oyster species	Cumulative SRO mortality (%) after:		
		6 months	12 months	20 months
Shoalhaven	SRO	18 ± 6	30 ± 11	-
	TPO	1 ± 0.1	2 ± 0.1	-
Merimbula	SRO	7 ± 2	13 ± 2	19 ±6
Pambula	SRO	5 ± 0.1	18 ± 4	28 ±4

Slightly higher mortality levels were recorded in Merimbula than in Pambula during the first six months of Program 1, however during the second half of the program oysters in Pambula had consistently higher mortality levels than Merimbula (Figure 6 and Figure 7).

At most of the grading intervals during the first 12 months of Program 1, significantly higher SRO mortality rates were recorded at Shoalhaven River compared with Pambula and Merimbula lakes, except for the period between summer-autumn 2012 when mortality levels in Pambula almost reached averaged levels in Shoalhaven (Figure 7).

Figure 6: Cumulative SRO mortality after each grading event for three Southern Rivers estuaries during Program 1 (May 2011 to May 2013). N.B Shoalhaven program finished in May 2012

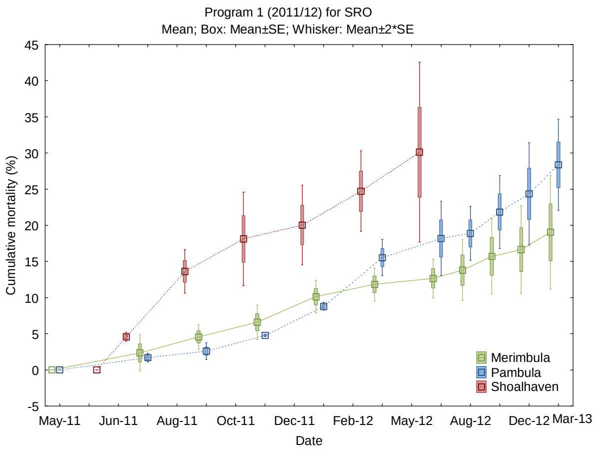
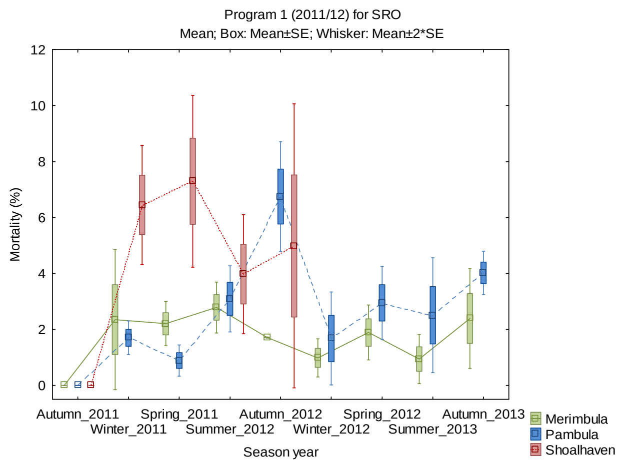


Figure 7: SRO mortality rates by season for three Southern Rivers estuaries monitored during Program 1 (between May 2011 and May 2013). N.B Shoalhaven program finished in May 2012



SROs used in the set-up of Program 1 at Shoalhaven River were larger (58mm) than those oysters used for the Merimbula and Pambula lake programs (45mm). This resulted in slower SRO growth in the Shoalhaven than for SRO in the other two estuaries (Figure 8).

Oyster growth in Merimbula and Pambula stabilised after summer 2012 with slight negative shell growth probably a result of mortalities in the larger size oysters during this period. The high shell length values recorded in April 2012 for Merimbula and Pambula are believed to be an error, overestimating the actual values during this grading. Despite different origins of the two batches (refer to Table 1), SRO at Merimbula and Pambula lakes performed in a very similar manner through time (Figure 8). In the Shoalhaven high growth was recorded for TPO particularly over the 2011 summer (Figure 9).

Figure 8: Weighted average shell length for SRO across three Southern Rivers estuaries over Program 1 (May 2011-May 2013).

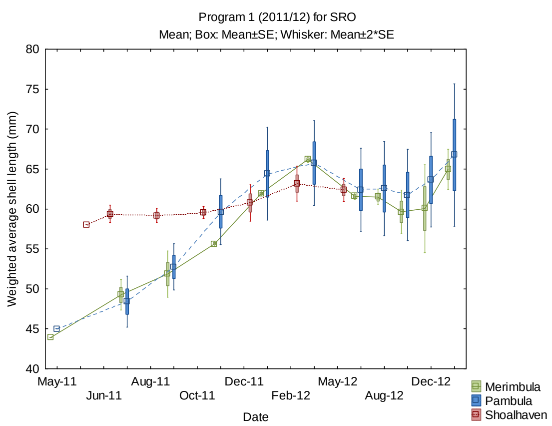
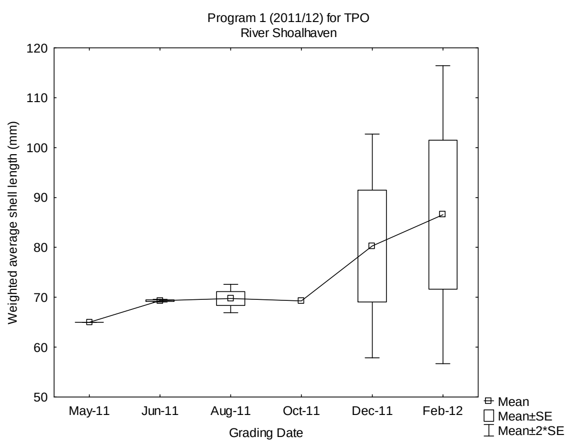


Figure 9: Weighted average shell length for TPO in the Shoalhaven River over Program 1 (May 2011-May 2012).



4.1.2 Program 2: Shoalhaven, Clyde, Wapengo, Merimbula and Pambula (January 2012-May 2013)

Program 2 commenced in 2012 with two new estuaries joining the OMP. Monitoring in the Clyde River and Wapengo Lagoon began in January 2012. In Shoalhaven River, Merimbula and Pambula lakes Program 2 started in May 2012.

At the completion of Program 2 (May 2013), cumulative mortality levels for SRO ranged from 12 to 32% across the five estuaries with Shoalhaven again recording the highest SRO mortality (Table 3). Similarly the lowest cumulative loss was again recorded in the Shoalhaven River for TPO.

Table 3: Average cumulative mortality levels (%) for Sydney rock oysters and Triploid Pacific oysters after 6 and 12 months of monitoring in five Southern Rivers estuaries during Program 2 (January 2012 to May 2013).

Location	Oyster Species	Cumulative SRO mortality (%) after:	
		Mid (6 months)	End (12-15 months)
Shoalhaven	SRO	18 ± 4	32 ± 9
	TPO	4 ± 1	9 ± 5
Clyde	SRO	9 ± 2	29 ± 6
Wapengo	SRO	2 ± 1	13 ± 5 (*)
Merimbula	SRO	5 ± 3	16 ± 7
Pambula	SRO	6 ± 3	16 ± 4

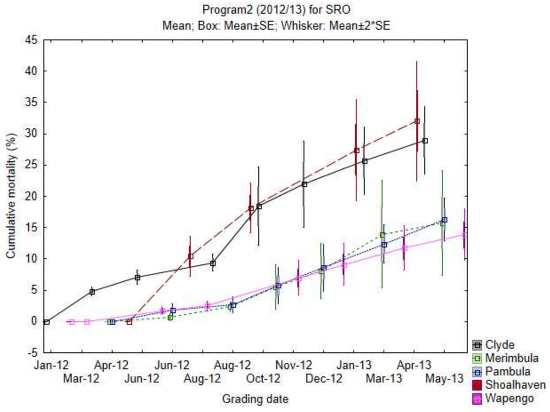
(*) Extremely high mortalities were recorded after the initial set-up in Wapengo believed to be a result of mis-handling oysters. Oysters were not returned to the water on the same day and the elevated air temperatures, plus the stress of grading such small oysters resulted in 14% mortality levels at the first grading. These mortality levels have not been included.

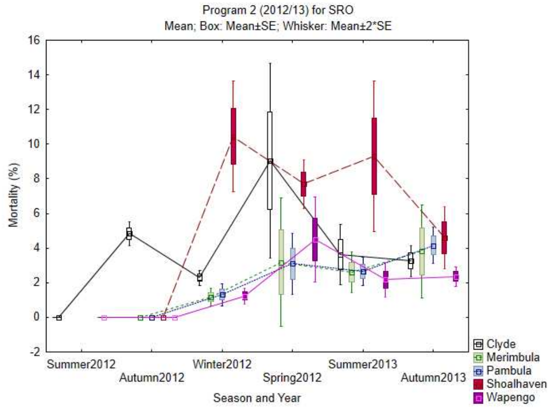
During Program 2, cumulative mortality was noticeably different across the estuaries with the Shoalhaven and Clyde rivers recording much higher mortalities than Merimbula and Pambula lakes. Cumulative mortality results for Wapengo were higher than Merimbula and Pambula as a result of very high mortality at the beginning of Program 2. This mortality level was attributed to the handling of the small oysters used for the set-up and the high rainfall experienced in the area at this time. Removing this mortality event from Wapengo, cumulative loss from this estuary would be approximately 13±5%, comparable to the losses experienced at both Merimbula and Pambula lakes (Figure 10 and Figure 11).

During Program 2 mortalities tended to be higher in spring independent of the estuary (Figure 11). There were also significant seasonal interactions within each estuary. Mortalities during autumn in the Shoalhaven were significantly lower than rates across the rest of the seasons. Wapengo mortalities in autumn and spring were higher than in summer and winter. In the Clyde, all seasons had similar mortalities except during spring where mortalities were noticeably higher at this time. Merimbula and Pambula experienced very similar and overall low mortalities across all seasons.

Figure 10: Cumulative SRO mortality after each grading event for five Southern Rivers estuaries during Program 2 (January 2012 to May 2013).

Figure 11: Seasonal SRO mortality rates after each grading event for five Southern Rivers estuaries during Program 2 (January 2012 to May 2013).



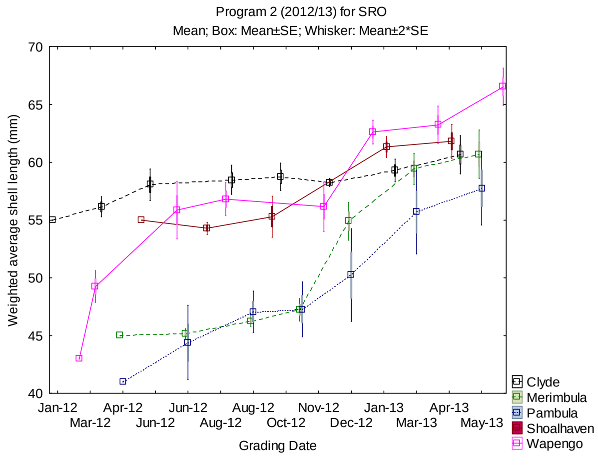


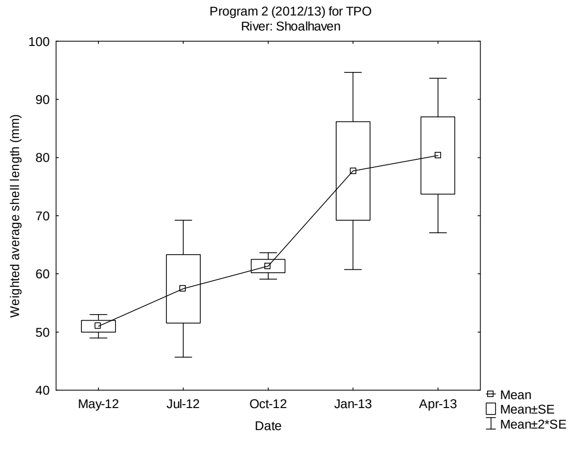
N.b results shown in Figure 10 and Figure 11 do not contained extreme mortality rate recorded at the start (March 2012) of the program in Wapengo.)

Noting the difference in starting shell length (refer to Table 1), SROs at Wapengo experienced the greatest increase in weighted average shell length over the duration of Program 2, increasing by more than 50% over 18 months (from 43mm to 66mm). An increase in shell growth was seen at most estuaries after November 2012, except in the Clyde (Figure 12). Oysters at the Clyde experienced the least amount of growth, possibly as a result of oysters being larger in size at the start of the monitoring. In the Shoalhaven, TPO growth during Program 2 was greatest over the warmer months of October to January 2013 (Figure 13).

Figure 12: Weighted average shell length for SRO across five Southern Rivers estuaries during Program 2 (January 2012 to May 2013).

Figure 13: Weighted average shell length for TPO in the Shoalhaven during Program 2 (May 2012 to May 2013)

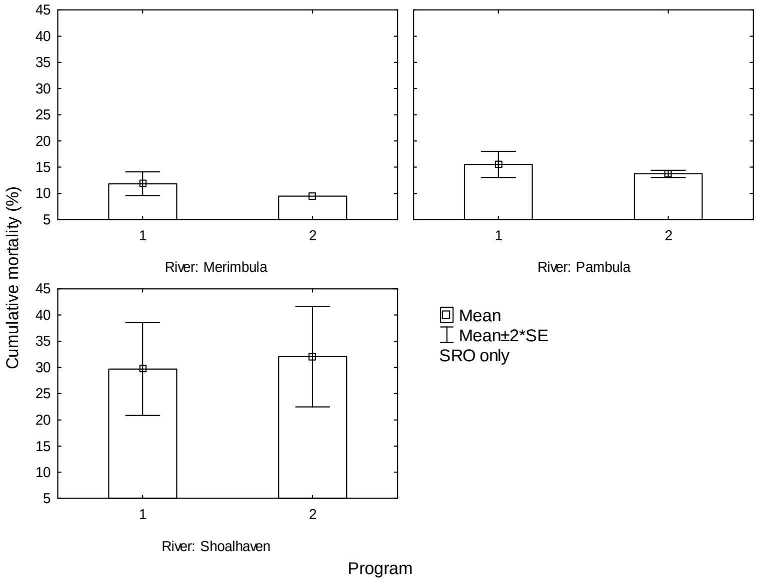




4.1.3 Comparison of oyster performance between Program 1 and Program 2

Similar range in SRO cumulative mortality between the first and second programs was found with loss in Merimbula and Pambula half that of Shoalhaven. For those estuaries in which SRO were monitored during both programs, there was no significant difference in mortality over the years. Cumulative SRO loss in Merimbula and Pambula was slightly lower in Program 2 than in Program 1, while in the Shoalhaven SRO mortality was in Program 2 than Program 1 (Figure 14).

Figure 14: Comparison of final cumulative SRO mortality for three Southern Rivers estuaries over the duration of two monitoring programs (Program1- May 2011 to May 2012 and Program2-May 2012 to May 2013).



Overall higher shell growth was recorded for SROs in the Shoalhaven, Merimbula and Pambula during Program 2 than Program 1 (Figure 15).

Figure 15: Comparison of growth in terms of average shell increment per month between estuaries over the duration of two monitoring programs

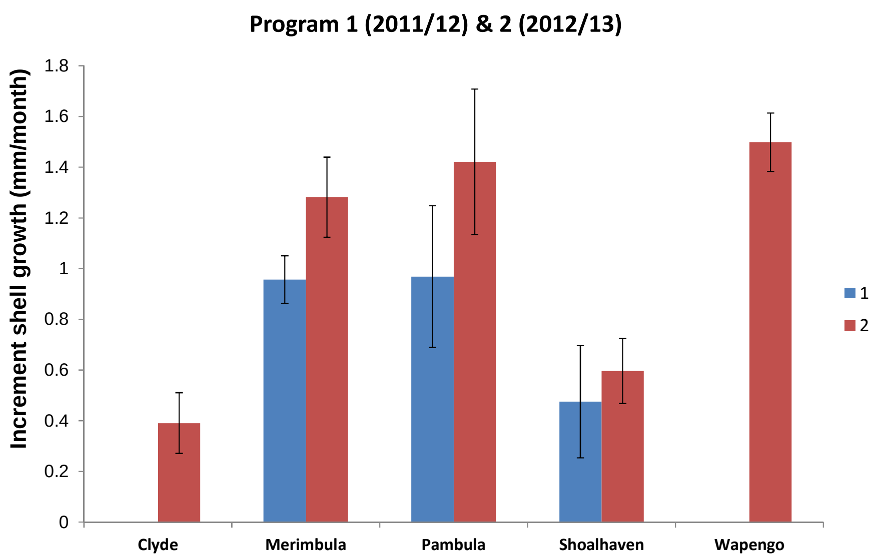
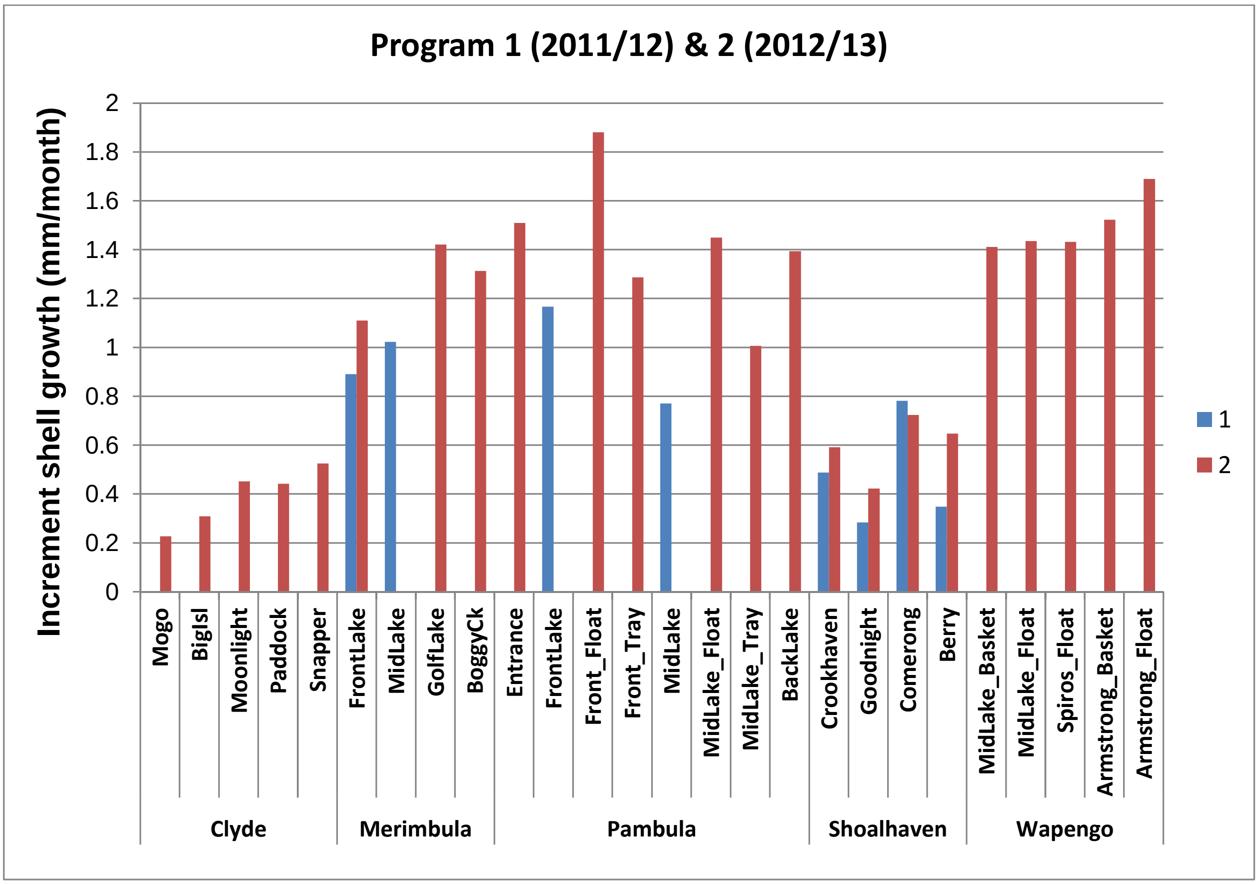


Figure 16Figure 16 shows the overall shell length increment for the entire length of the different programs standardised by time. In Program 1 and 2 consistently higher growth was measured at all locations in Pambula and Merimbula. While in the Shoalhaven all but one location recorded better growth over Program 2. It was also during Program 2, that the highest increments in shell length across one estuary were observed in Wapengo.

Despite having slightly different starting sizes, oysters used for each program belonged to approximately the same age-class. Therefore the increment in shell length was not standardised by the initial shell length. In the estuaries in which larger size oysters were used, less overall shell growth was observed. This slower growth pattern for the Shoalhaven in Program 1 and 2 was similar to the slower growth rates seen in Program 2 for Clyde SROs which were of a larger starting size than those used in Merimbula, Pambula and Wapengo.

Figure 16. Shell length increment for SRO over the whole duration of the two monitoring programs in five Southern Rivers estuaries for each location



There was a significant difference in the overall mortality levels for TPO in the Shoalhaven between the Programs. While very low mortality was experienced during Program 1 (2%) cumulative mortality was higher and more variable in Program 2 reaching 9% (Figure 17). In the Shoalhaven, TPO performance in terms of incremental growth rate per month was also slightly higher during Program 2 than Program 1 (Figure 18).

Figure 17: Comparison of final cumulative mortality for TPO in the Shoalhaven River over the duration of two monitoring programs (Program 1: May 2011 to May 2012. Program 2: May 2012 to May 2013).

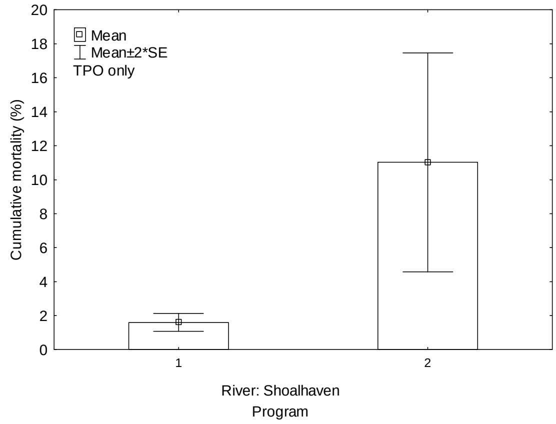
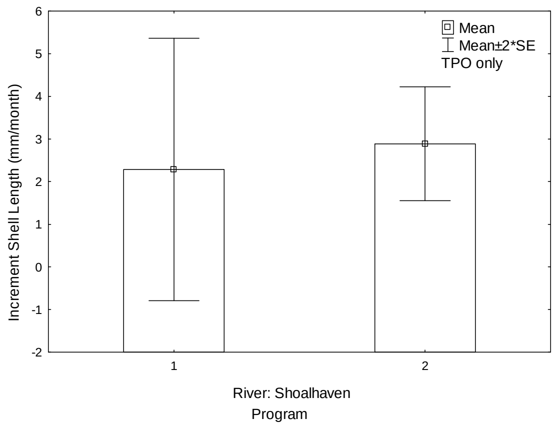


Figure 18: Comparison of incremental growth rates for TPO in the Shoalhaven over the duration of two monitoring programs (Program 1: May 2011 to May 2012. Program 2: May 2012 to May 2013).



4.2 Performance by growing area within an estuary

4.2.1 Shoalhaven River

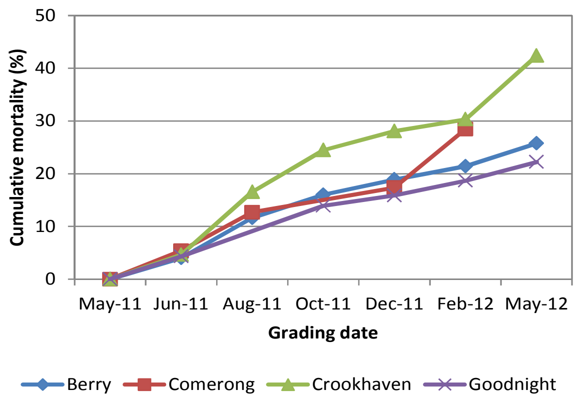
The Shoalhaven River showed large variability in SRO mortality across time and location. No one location in the Shoalhaven had consistently higher or lower mortality levels (Figure 19 and Figure 20)

During Program 1, SROs located at the Crookhaven were the most severely affected by mortality with an exceptionally high annual mortality level of 42%, this location was followed by Comerong with a 35.6% loss. On the other hand, cumulative mortality during Program 2 was highest for SRO at Comerong with 44% mortality, and lowest at Crookhaven at 20%. In both years SRO mortality at Comerong over January/February was higher than the loss recorded for the other locations during the same period.

Mortality levels across the four Shoalhaven monitoring sites were quite variable during both programs with no temporal consistency documented. Overall cumulative mortalities of SRO were higher during Program 2 than Program 1 for all locations except Crookhaven (Figure 21).

Figure 19. SRO a) cumulative mortality and b) mortality rates at each grading for four locations within the Shoalhaven River over Program 1 (May 2011 to May 2012).

a)



b)

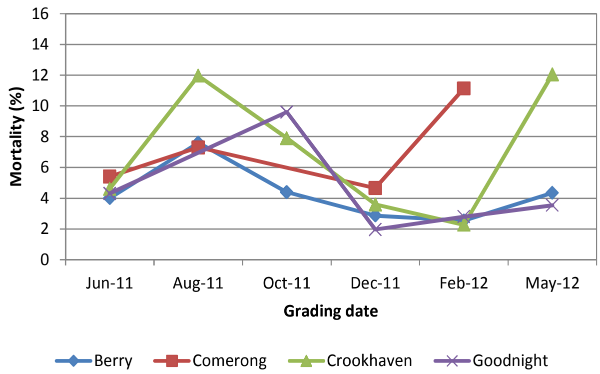
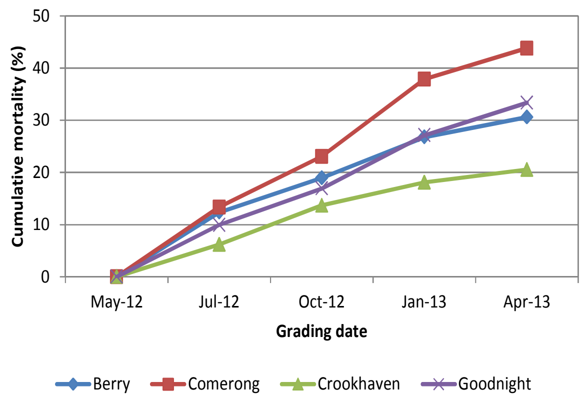


Figure 20. SRO a) cumulative mortality and b) mortality rates at each grading for four locations within the Shoalhaven River over Program 2 (May 2012 to May 2013).

a)



b)

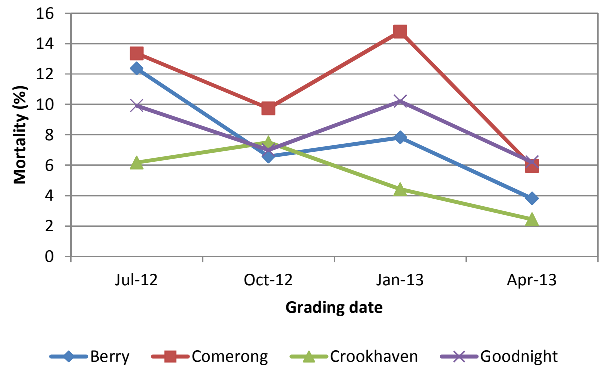
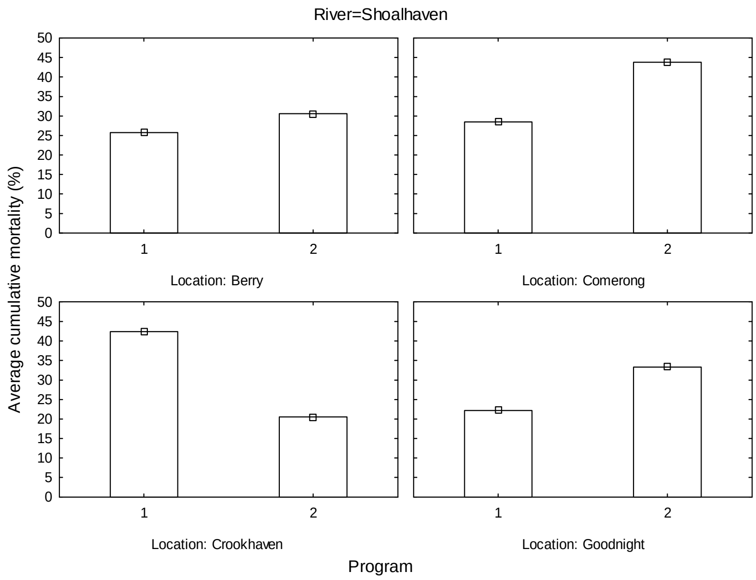


Figure 21: Comparison of average SRO cumulative mortality across four locations in Shoalhaven River during Program 1 (May 2011 to May 2012) and Program 2 (May 2012 to May 2013).



Unlike the inconsistency in mortality rates, the relative growth in one growing area versus another in the Shoalhaven was maintained through the monitoring years with oysters from Comerong Bay growing the most over both years, especially during the spring/summer months (Figure 22 and Figure 23).

Figure 22: Weighted average shell length for SRO through time at Shoalhaven River during Program 1 (May 2012 to May 2013)

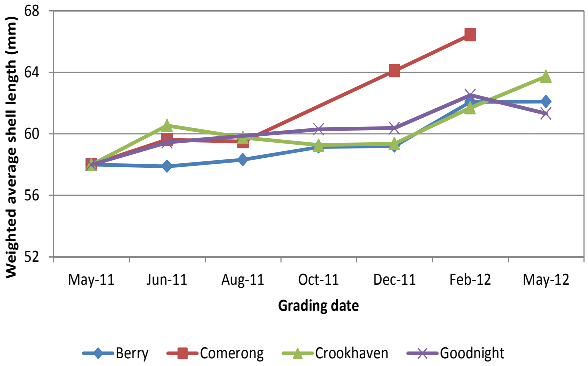
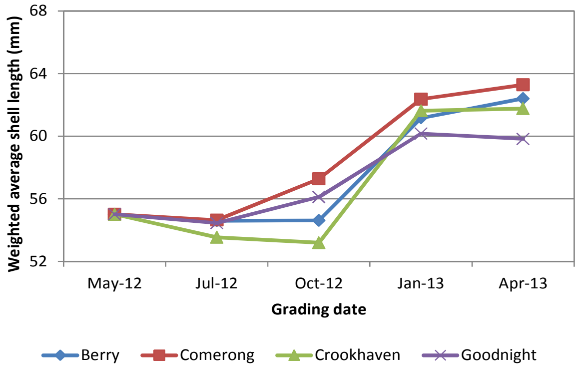
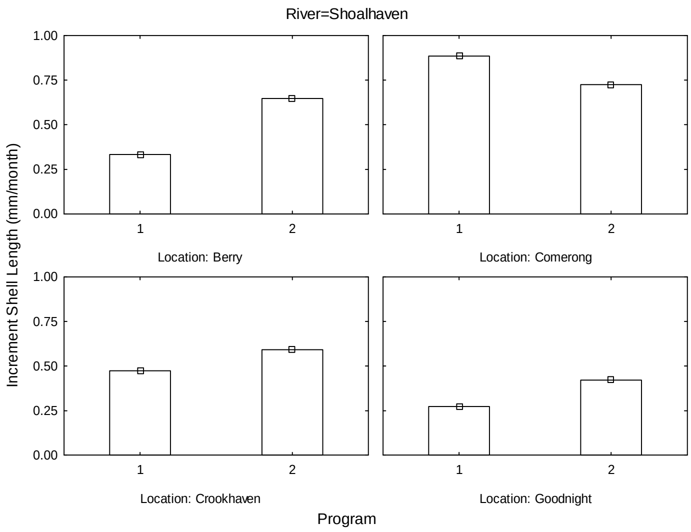


Figure 23. Weighted average shell length for SRO through time at Shoalhaven River during Program 2 (May 2012 to May 2013)



Despite an increase in SRO weighted average shell length at all locations over summer months, overall growth in the Shoalhaven was quite low ranging from just 0.25-0.8mm/month. Although SRO at Comerong recorded the highest growth over both programs, growth rates during Program 2 were slightly lower than during Program 1 (Figure 24). SROs at Berrys had noticeably higher growth rates in Program 2 than Program 1 (Figure 24).

Figure 24: Comparison of overall SRO shell growth increments across four locations in the Shoalhaven River over the two monitoring programs

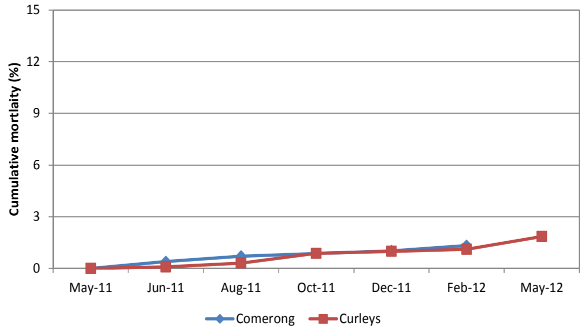


In the Shoalhaven TPO performance was monitored at two locations during Program 1, and at three locations in Program 2. Very low mortality rates were experienced during Program 1, while in Program 2 cumulative loss was much higher, especially for TPO at Comerong. During both programs, TPO performance was also predominantly driven by the growth of TPO at the Comerong location (Figure 25 and Figure 26).

With an average monthly shell length increment of more than 3.5mm/month in both Programs, TPO at Comerong experienced much higher growth than TPOs at Curleys and Goodnight, which performed very similarly in Program 2. Note that the starting shell length for TPO at Comerong in Program 2 was slightly higher than those used in Curleys and Goodnight. There was some improvement in the performance of TPO in terms of growth at the Curleys where monthly growth rates increased from less than 1mm/month in Program 1 to more than 2mm/month in Program 2 (Figure 27).

Figure 25. TPO a) cumulative mortality and b) weighted average shell length at Shoalhaven River during Program 1 (May 2011 to May 2012).

a)



b)

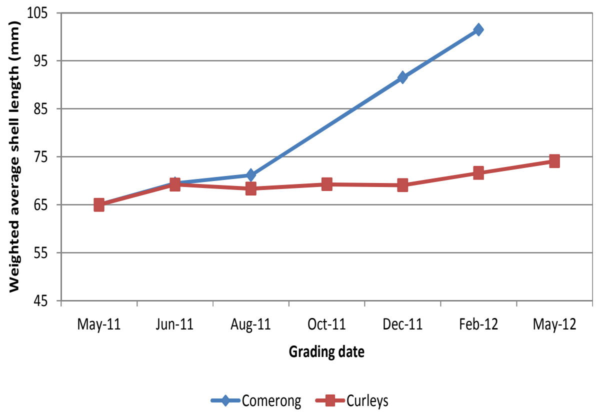
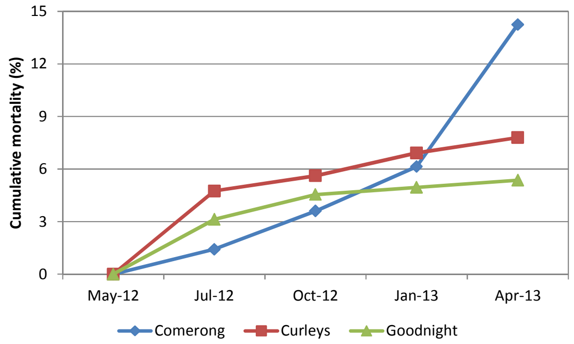


Figure 26. TPO a) cumulative mortality and b) weighted average shell length at Shoalhaven River during Program 2 (May 2012 to May 2013).

a)



b)

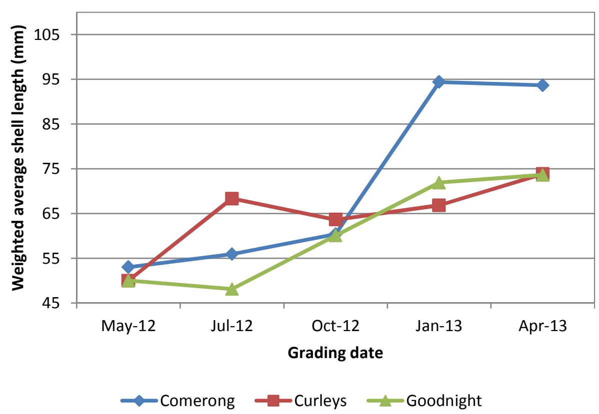
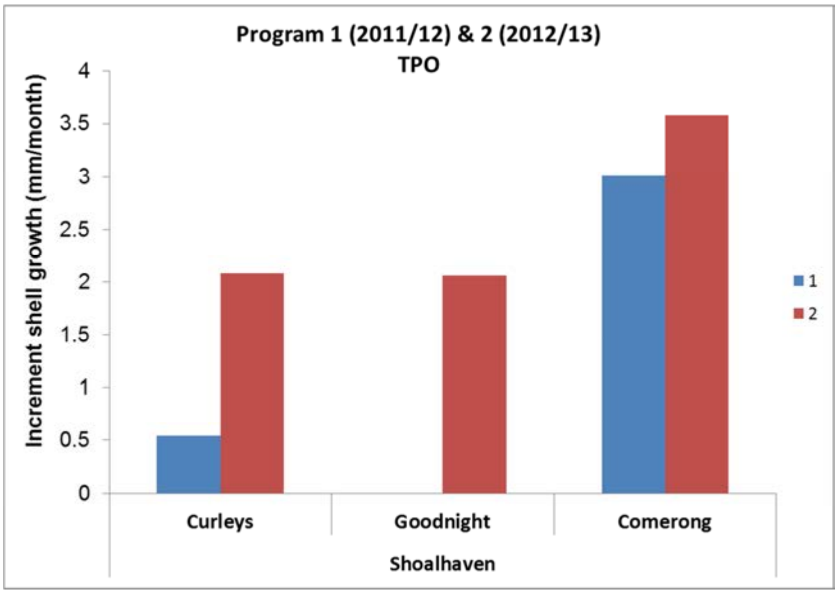


Figure 27: Overall incremental shell length for TPO at two locations in the Shoalhaven River over the two monitoring programs (May 2011 to May 2012 and May 2012 to May 2013).



4.2.2 Merimbula Lake

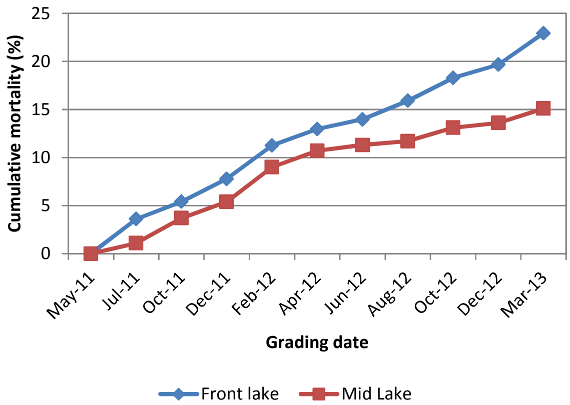
Cumulative SRO mortality levels at Merimbula Lake ranged from 15 to 23% at the conclusion of Program 1. The two monitoring sites at Merimbula Lake recorded similar mortalities throughout the first half of Program 1, but it was the Front lake location that experienced higher mortality during the latter half of the program finishing with higher overall loss (Figure 28).

During Program 2, cumulative mortalities ranged from 10 to 24%. High mortalities experienced at Boggy Creek in spring of 2012 and autumn of 2013, resulted in the highest amount of cumulative loss in Merimbula. Throughout Program 2 Mortality levels for the Golf lake location were just higher than those recorded at the Front lake (Figure 29).

During Program 1 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. Growth then stabilised with little increase is shell length occurring over the second half of the program (Figure 30). SROs at Mid Lake ended the program with overall more shell growth increment than Front Lake (Figure 31).

Figure 28: SRO a) cumulative mortality and b) mortality rates through time at two locations in Merimbula lake over the duration of Program 1 (May 2011 to May 2013).

a)



b)

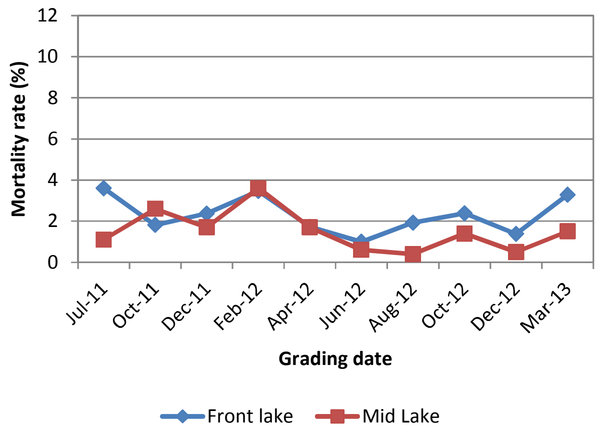
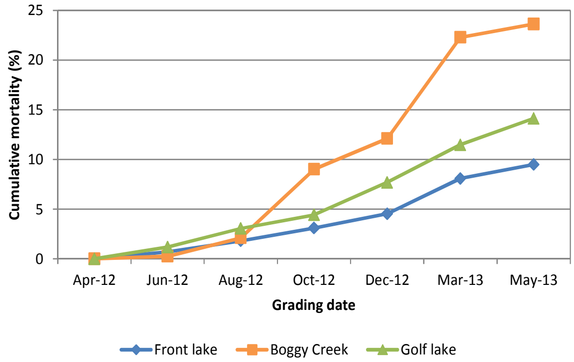


Figure 29. SRO a) cumulative mortality and b) mortality rates through time at three locations in Merimbula lake over the duration of Program 2 (May 2012 to May 2013).

a)



b)

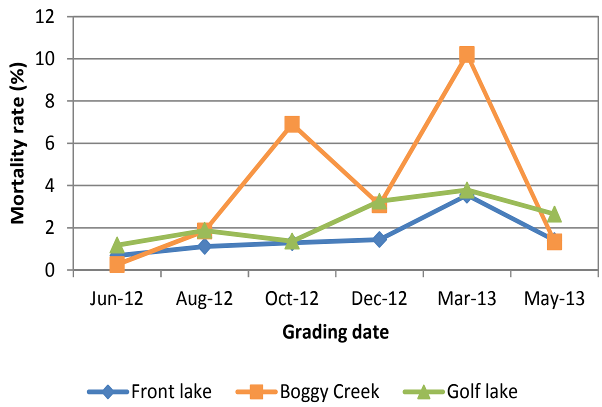


Figure 30: Weighted average shell length for SRO through time at two locations in Merimbula Lake during Program 1 (May 2011 to May 2013) [Data point for Apr12 it is believed to be an outlier]

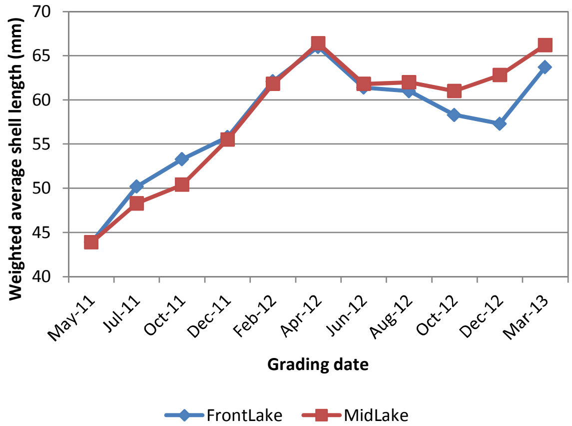
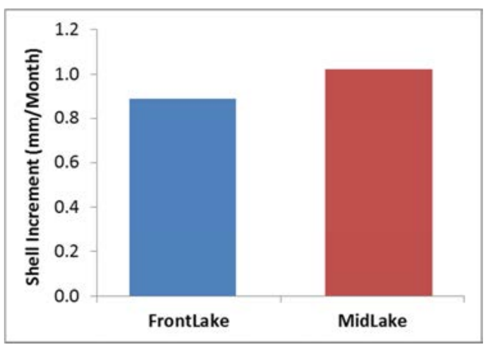


Figure 31: Overall shell length increment for SRO at two locations in Merimbula Lake for Program 1 (May 2011 to May 2013).



During Program 2, there was little growth for all three locations in Merimbula between April and October 2012 (this also corresponded to a period of minimal growth for oysters being monitored as part of Program 1). Greatest growth for Program 2 sites in Merimbula was recorded over October 2012 to February 2013, particularly for Golf lake oysters (Figure 32). Growth differences between locations were not consistent with Front lake oysters growing more during the first half of Program 2 and Golf Lake the least. This pattern reversed in the second half of the program, with Golf lake oysters recording an overall monthly increment of around 1.4mm/month (Figure 33).

Figure 32. Weighted average shell length through time for SRO at three locations in Merimbula Lake during Program 2 (May 2012-May 2013).

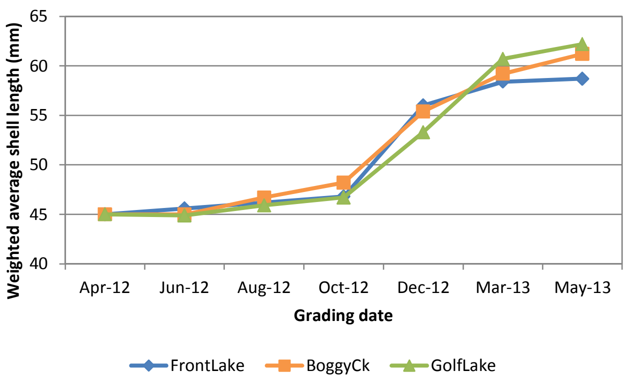
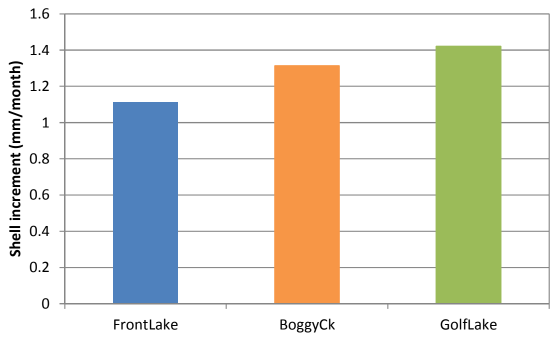


Figure 33. Overall shell length increment for SRO at three locations in Merimbula Lake for Program 2 (May 2012-May 2013).



In Merimbula, SROs were only monitored at the Front lake site during both Programs. While lower mortality was experienced during Program 2 at Front Lake, higher shell growth rates were observe at this location during the first Program (Figure 34 and Figure 35).

Figure 34: Comparison of cumulative mortality after one year for SRO from Merimbula Front Lake site during two monitoring programs

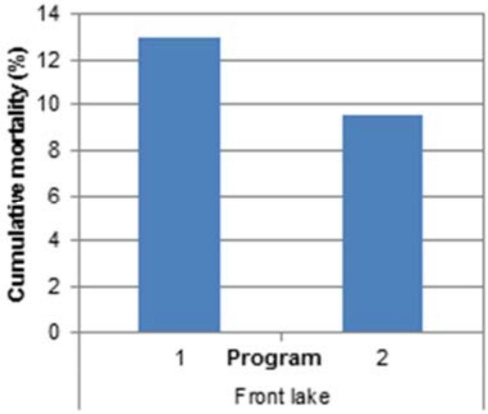
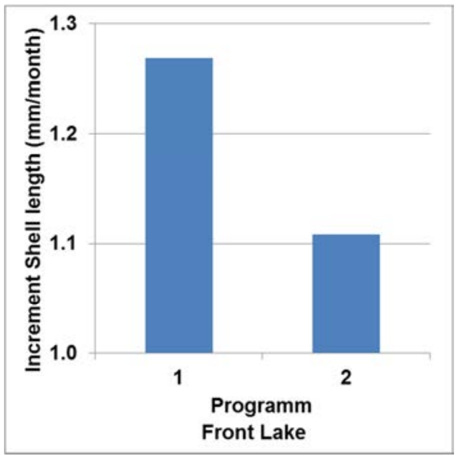


Figure 35: Comparison of overall incremental shell length for SRO at the Merimbula Front lake site during two monitoring programs



4.2.3 Pambula Lake

Throughout the majority of Program 1 (2011/2012), the Mid Lake site at Pambula recorded slightly higher SRO mortality levels than the Front Lake. After an increase in mortality at both sites in the autumn of 2012, mortality levels at both locations decreased significantly over the cooler months of the 2012 winter (Figure 36). Overall, cumulative mortality during Program 1 at Pambula Lake ranged from 20% at the Mid Lake site to 28% at the Front Lake site.

During Program 2, exceptionally low mortality rates were recorded in August 2012 for all locations except the Back Lake site (the low levels at this time were also reflected in little loss for Program 1 oysters, particularly the Mid lake site which recorded no loss at this time). Overall at the conclusion of Program 2 (2012/2013), the highest cumulative loss of 25% was reached at the Back lake site. All other Pambula sites in Program 2, regardless of cultivation method or location, recorded relatively low cumulative mortalities between 13 and 16% (Figure 37).

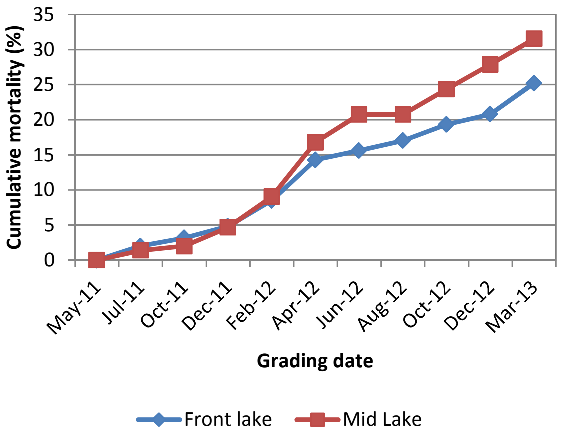
SROs were monitored in Pambula at the Front Lake and Mid Lake sites over both Programs. Over the two years of monitoring there was very little difference in cumulative mortality at the Front Lake, however cumulative loss for the Mid lake site was higher during Program 1 than Program 2 (Figure 38).

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 (Figure 39). 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.

A significant increase in shell length occurred over the first 12 months of monitoring in Program 1, before growth slowed in the second half of this Program. SROs at the Front lake site outgrew oysters at the Mid lake site throughout Program 1 (Figure 42). In Program 2, SROs at the Front lake site again achieved the greatest increase in shell length with an average increment of almost 1.9mm/month (Figure 42).

Figure 36: a) Cumulative mortality and b) mortality rates through time for SRO at two locations in Pambula Lake during Program 1 (May 2011 to May 2013).

a)



b)

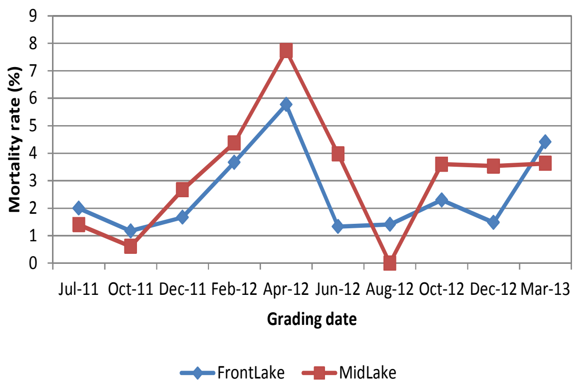
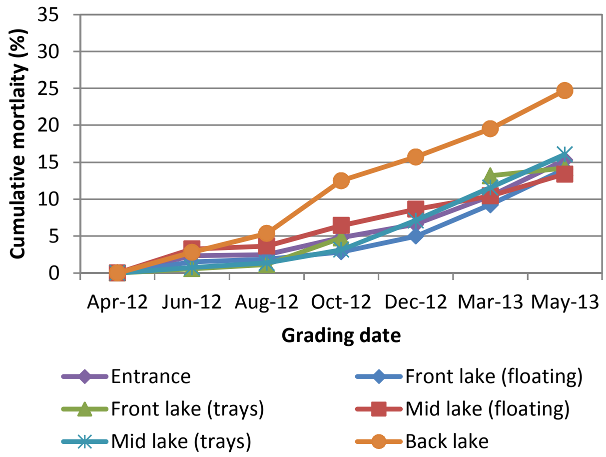


Figure 37. a) Cumulative mortality and b) mortality rates through time for SRO at six locations in Pambula Lake during Program 2 (May 2012 to May 2013).

a)



b)

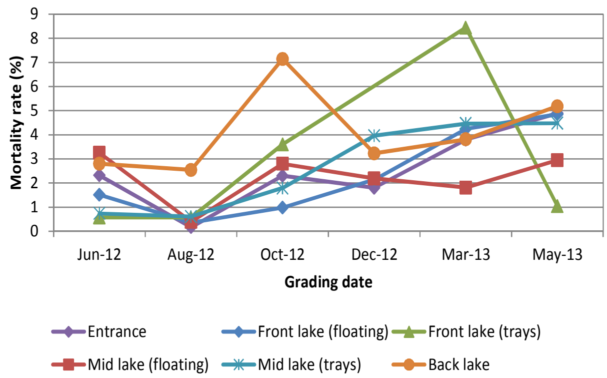


Figure 38: Comparison of average cumulative mortality for SRO (for floating cultivation only) at two sites in Pambula Lake over the duration of two monitoring programs (Program 1: May 2011 to May 2013 and Program 2: May 2012 to May 2013).

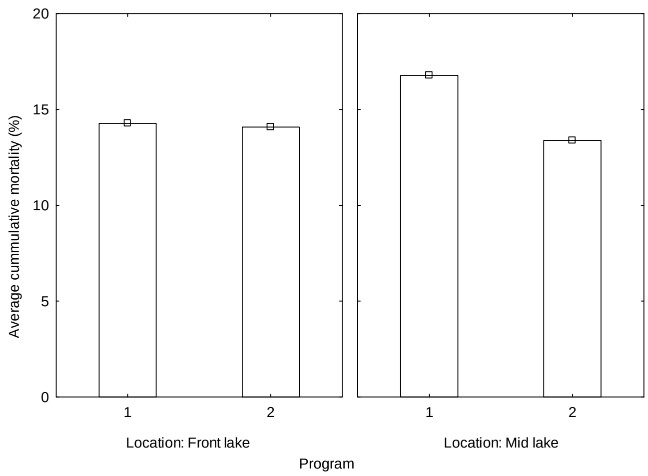


Figure 39. Weighted average shell length through time for SRO in two locations in Pambula Lake over the duration of Program 1 (May 2011 to May 2013).

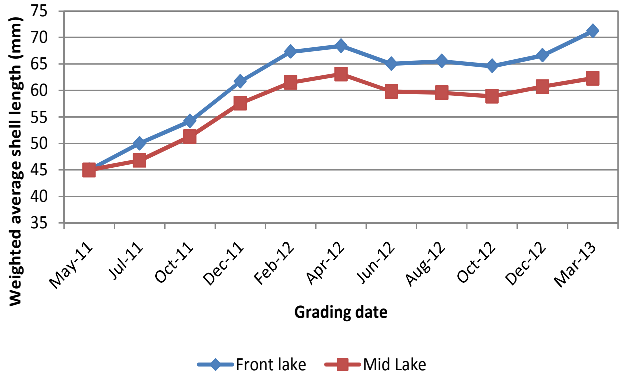


Figure 40. Weighted average shell length for SRO in four locations in Pambula Lake over the duration of Program 2 (May 2012 to May 2013)

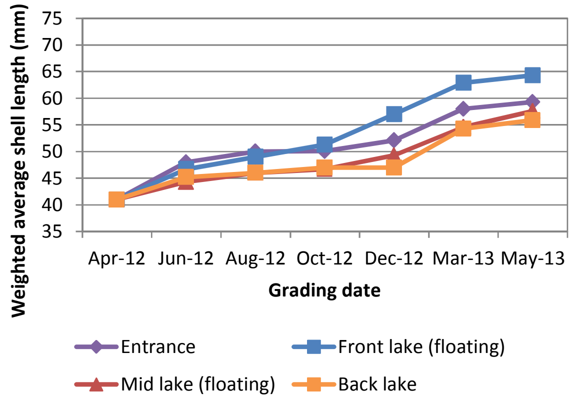


Figure 41: Overall incremental shell length for SRO at two locations in Pambula Lake over the duration of Program 1 (May 2011 to May 2013).

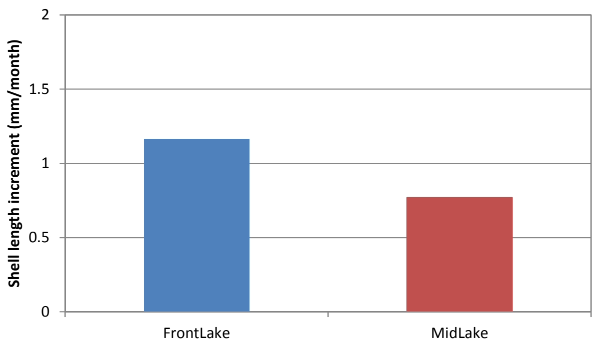
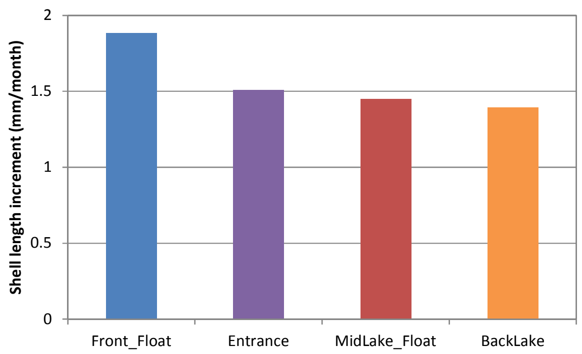
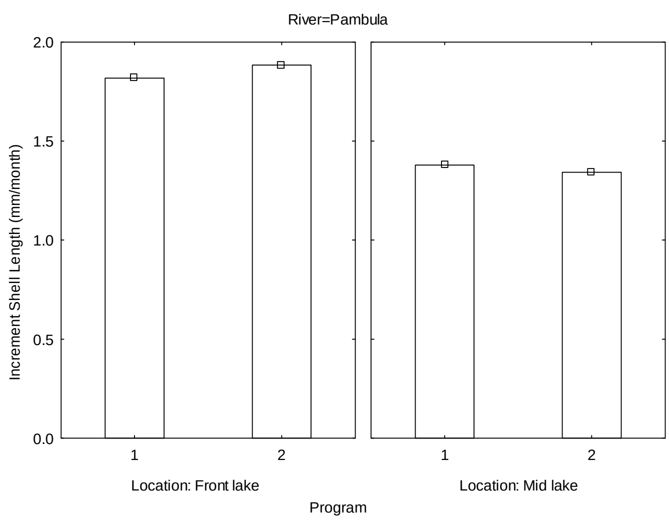


Figure 42. Overall incremental shell length for SRO at four locations in Pambula Lake over the duration of Program 2 (May 2012 to May 2013)



There was almost no difference in growth between the two programs per site (Figure 43) however it was the Front Lake site that again outgrew the Mid Lake oysters with a higher increment/month.

Figure 43: Comparison of incremental shell length for SRO at two locations in Pambula Lake over the duration of two monitoring programs (May 2011 to May 2013 and May 2012 to May 2013).



4.2.4 Clyde River

During Program 2 cumulative mortality across the five monitoring sites in the Clyde River was high, ranging from 20-37% at the conclusion of 20 months monitoring (Figure 44). A spike in mortality rates occurred between late winter and mid spring 2012, although this increase primarily affected the downstream locations of Moonlight and Paddock (Figure 45) potentially as a result of winter mortality. The spike in mortality at Mogo in February 2013 has been attributed to a delay in these oysters being returned to the water after the December 2012 grading.

Figure 44: Cumulative SRO mortality through time at five sites in the Clyde River over the duration of monitoring Program 2 (January 2012 to May 2013).

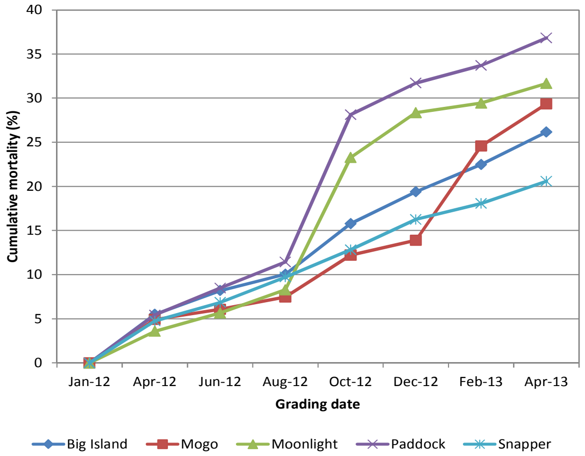
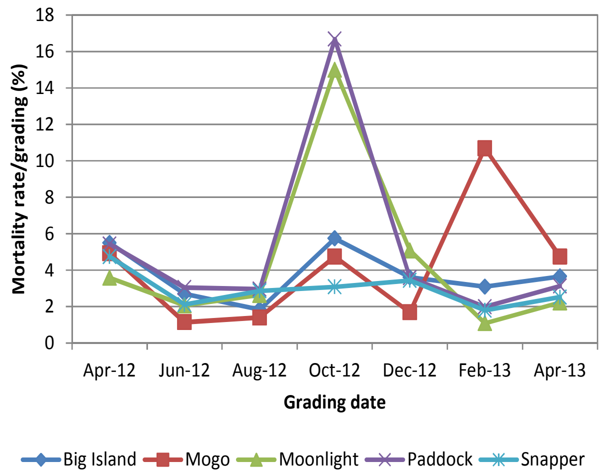


Figure 45. Mortality rates for SRO at five sites in the Clyde River over the duration of monitoring Program 2 (January 2012 to May 2013).



Overall there was low growth across the five Clyde River sites during Program 2. The upstream locations of Mogo and Big Island showed the least amount of growth, achieving around half the growth of oysters further downstream (Figure 46). SROs at the Snapper site recorded the greatest increase in shell length over the 20 months of monitoring, with a monthly increment of just over 0.5mm/month (Figure 47). Snapper was also the site in the Clyde River that recorded the lowest SRO mortality.

Figure 46. Weighted average shell length for SRO at five sites in the Clyde River at the completion of Program 2 (January 2012 to May 2013)

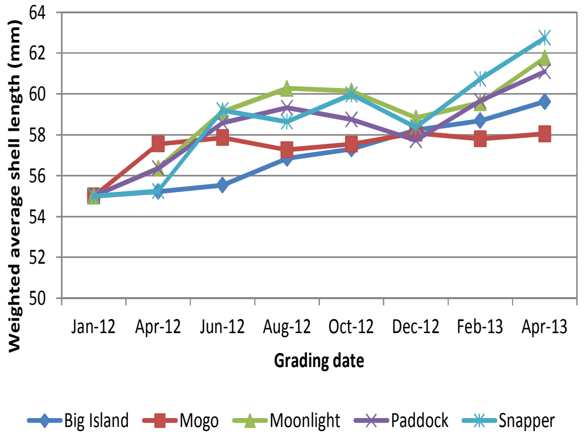
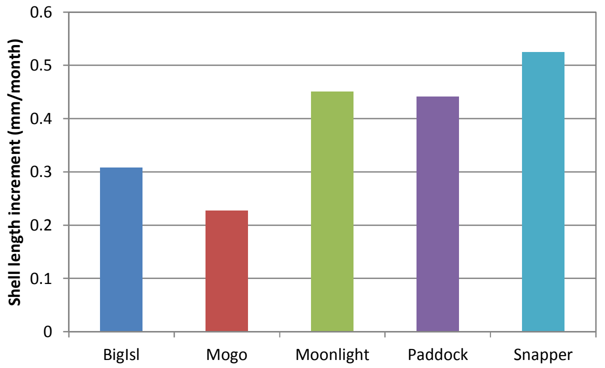


Figure 47. Overall increment in shell length for SRO at five sites in the Clyde River over the duration for Program 2 (January 2012 to May 2013).



4.2.5 Wapengo Lake

With the exception of the very high mortalities that were experienced across all locations at the beginning of the monitoring program, overall cumulative loss from the Wapengo sites would have been quite low with an average of 12% loss (Figure 48).

The exceptionally high rate of loss recorded in March 2012 was likely to be due to the stress the small oysters which were left out the water and exposed to air temperatures after the set-up of the program. (Wapengo also experienced high rainfall over January to March 2012, which may have contributed to the high loss). An increase in mortality at the back lake sites of Spiros and Armstrong was recorded between August and November 2012, otherwise mortality rates in Wapengo were reasonably low and minimal in variation between sites (Figure 49).

Figure 48: Cumulative mortality through time for SRO at five sites in Wapengo over the duration of Program 2 (January 2012 to May 2013).

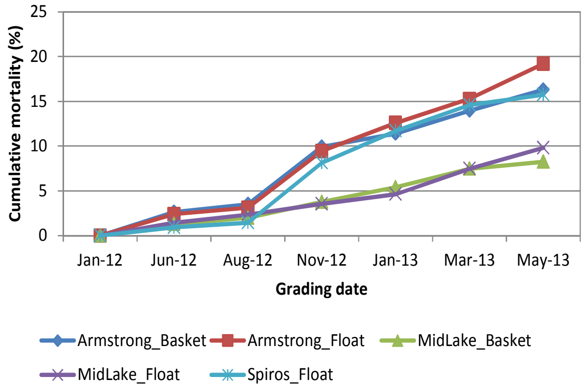
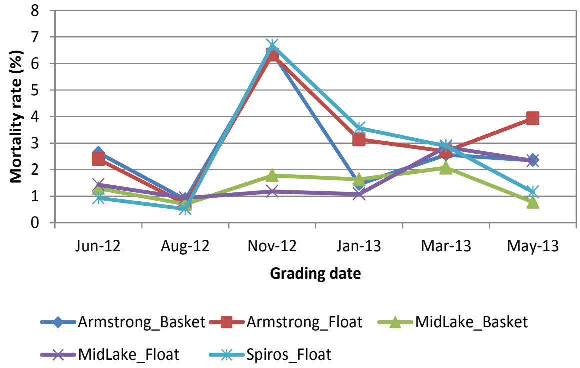


Figure 49: Mortality rates through time for SRO at five sites in Wapengo over the duration of Program 2 (January 2012 to May 2013).



At the same time that the higher mortalities were recorded between August and November 2012, little growth occurred for all sites in Wapengo. Despite this slow growth period, overall growth for each Wapengo site was quite high (Figure 50). Four of the five sites recorded monthly increments in shell length between 1.4 and 1.5mm/month. The greatest overall growth occurred for oysters in floating baskets at the Armstrong site, which had a monthly increment of over 1.7mm/month (Figure 51).

Figure 50: Weighted average shell length through time for SRO at five locations in Wapengo over the duration of Program 2 (January 2012 to May 2013).

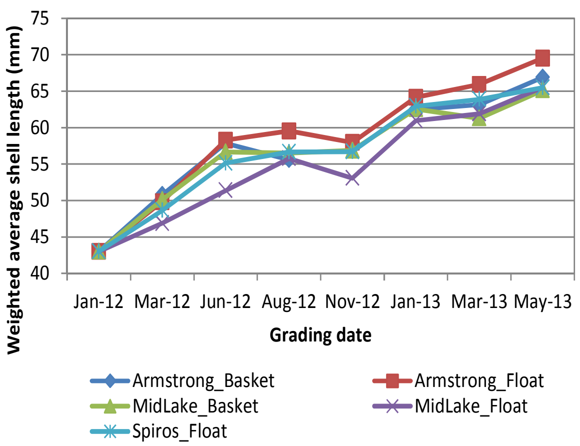
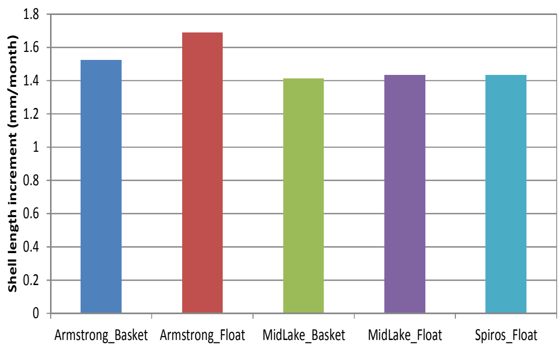


Figure 51. Overall incremental shell length for SRO at five sites in Wapengo over the duration for Program 2 (January 2012 to May 2013).



4.3 Oyster performance by species

In the Shoalhaven River, oyster growers have diversified the number of oyster species being farmed, and for the past three years they have been trialing the cultivation of TPO in some areas of the river. TPO are sourced from Tasmanian commercial hatcheries, while SRO used in the OMP were caught locally in the river.

Throughout Program 1, SRO mortality levels in the Shoalhaven River (averaged across four locations) were significantly higher than for TPO (averaged across two locations, Figure 52). A significant difference in mortality levels was also found during Program 2 but it was not as high as in Program 1 (Figure 53).

This difference was also seen when comparing oyster performance by species at those locations monitored in both years (Figure 54 and Figure 55). Higher variability in mortality levels for TPO in Program 2 during April 2013, especially in April 2013 when SRO overall mortality levels were at their lowest for the year.

Figure 52: Comparison of cumulative mortality for SRO and TPO in the Shoalhaven River over the duration of Program 1 (May 2011 to May 2012).

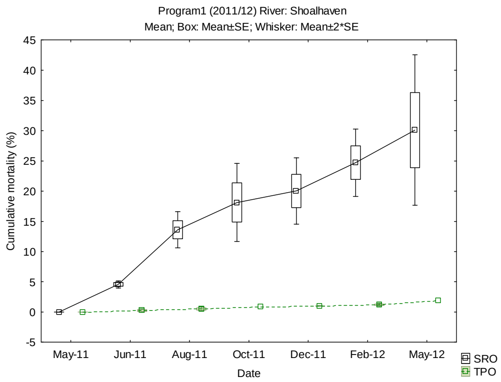


Figure 53: Comparison of cumulative mortality for SRO and TPO in the Shoalhaven River over the duration of Program 2 (May 2012 to May 2013).

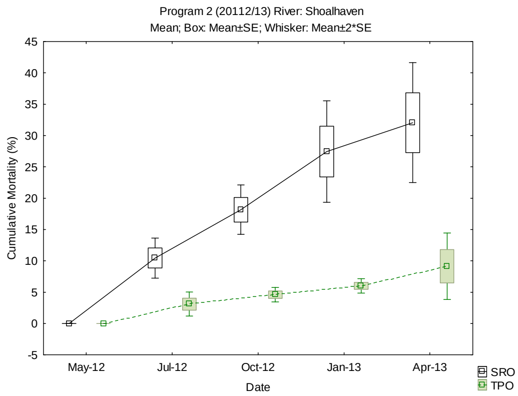


Figure 54: Comparison of mortality rates for SRO and TPO in the Shoalhaven River over the duration of Program 1 (May 2011 to May 2012).

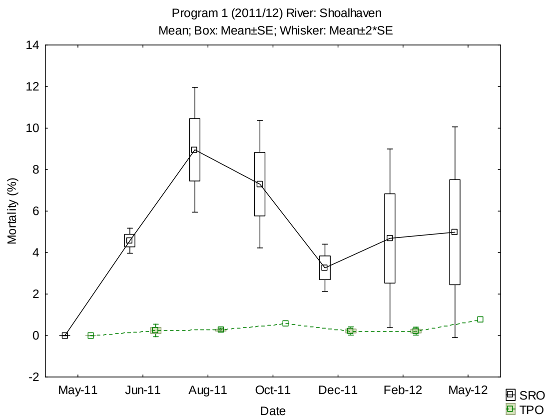
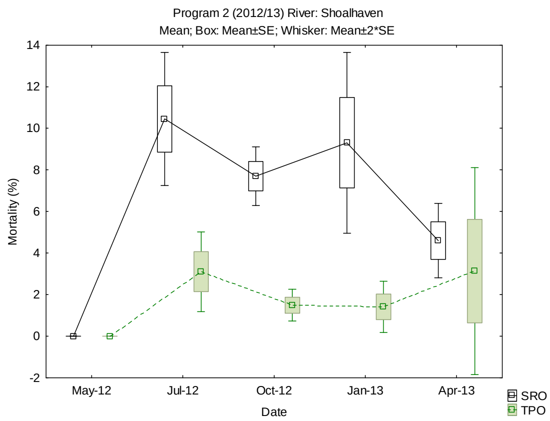


Figure 55: Comparison of mortality rates for SRO and TPO in the Shoalhaven River over the duration of Program 2 (May 2012 to May 2013).



As part of the Shoalhaven programs SRO and TPO were monitored side-by side in the oyster lease of Comerong across two years, and for 12 months at the growing area at Goodnight Island. In Program 1, significantly higher growth was recorded for TPO than SRO, especially from December 2011 onwards at Comerong (Figure 56). In Program 2, noticeable growth over the October to January period was significant for TPO (Figure 57).

Figure 56: Comparison of weighted average shell length for SRO and TPO at one location in the Shoalhaven River over the duration of Program 1 (May 2011 to May 2012)

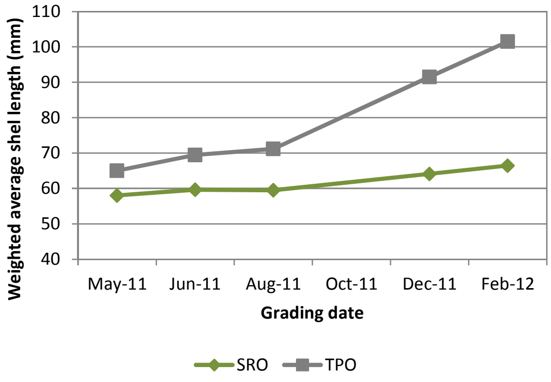
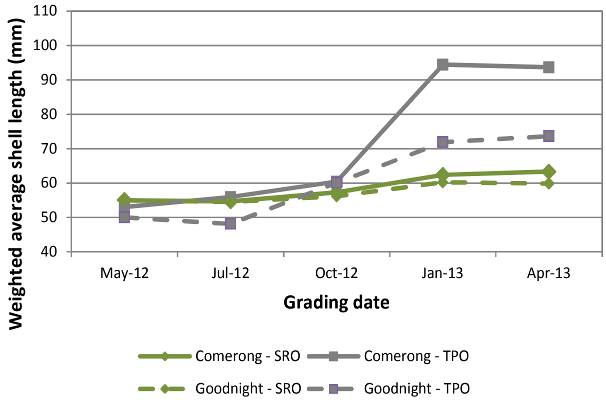


Figure 57: Comparison of weighted average shell length for SRO and TPO at one location in the Shoalhaven River over the duration of Program 2 (May 2012 to May 2013)



4.4 Effect of cultivation method on oyster performance

As an extension to the scope of Program 1, growers were interested in quantifying oyster performance across different cultivation units at certain growing areas in order to consider options for maximising productivity. As such, during Program 2 the effect of different cultivation methods on oyster performance was monitored in two estuaries. In Pambula floating baskets and trays were compared, while in Wapengo floating baskets were compared with static intertidal baskets at a number of locations. The cultivation methods chosen are typically used at these estuaries (Figure 2).

In Pambula a difference was observed in the cumulative mortality levels for the different infrastructure. During the first half of year of the program higher rates of loss were recorded for oysters in floating bags, however this patterned reversed during the second half of monitoring resulting in slightly higher cumulative mortality from trays than floating baskets (Figure 58). On the other hand there was noticeably higher growth for SROs in floating baskets than in trays. With a monthly increment of almost 1.7mm/month oysters in floating bags outperformed oysters in trays where an increment of 1.1mm/month was reached (Figure 60). This difference was observed at both the Mid lake and Front lake locations in Pambula.

The effect of infrastructure in Wapengo differed slightly from the one described for Pambula above. At the conclusion of the monitoring program, higher cumulative SRO mortality was observed in Wapengo for SROs in floating baskets than those in static intertidal baskets (Figure 59). Minimum difference was observed in overall shell growth increment between the two different cultivation units with SROs in floating baskets recording higher growth than oysters grown in the static baskets (Figure 61). This difference in growth was only observed at the Armstrong location as there was no difference on the effect of cultivation gear on oysters at the Mid Lake in Wapengo.

Figure 58: Comparson of cumulative mortality between two different cultivation methods in Pambula during Program 2 (May 2012 to May 2013)

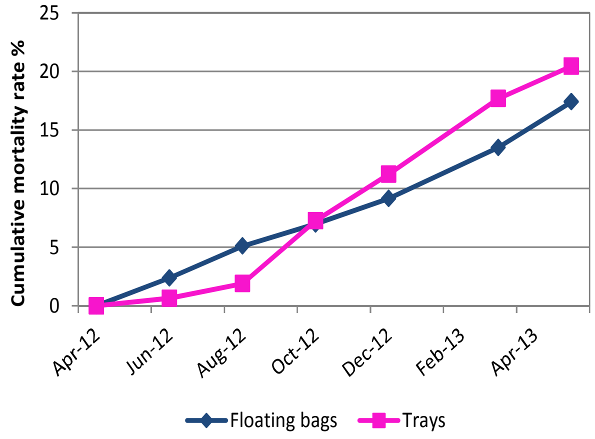


Figure 59: Comparison of cumulative mortality between two different cultivation methods in Wapengo during Program 2 (January 2012 to May 2013)

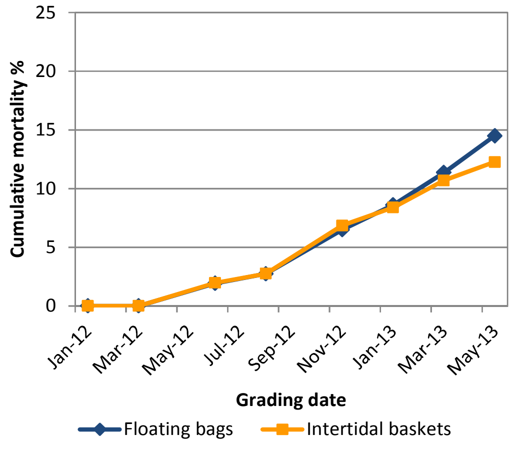


Figure 60: Comparison of incremental shell length between two different cultivation methods in Pambula during Program 2 (May 2012 to May 2013)

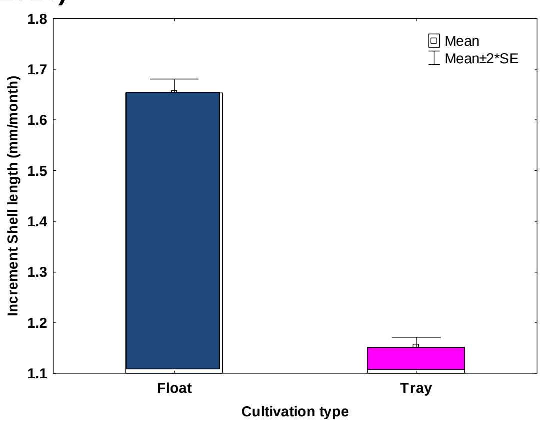
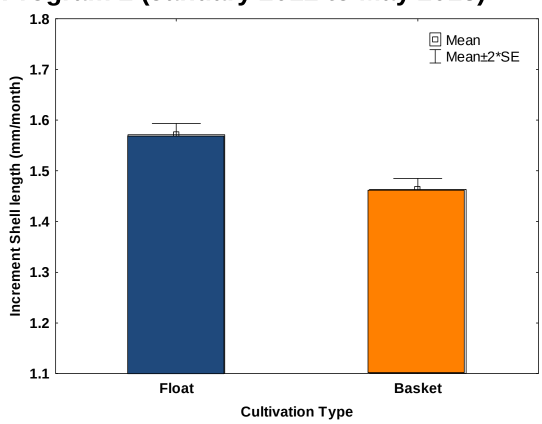


Figure 61: Comparison of incremental shell length between two different cultivation methods in Wapengo during Program 2 (January 2012 to May 2013)



4.5 Effect of stocking density on oyster performance

In Merimbula and Pambula Lakes a third monitoring program began in June 2012 to investigate the effect of different stocking densities on the performance of oysters cultivated in floating bags at one location in the lake. This program was set-up to test whether the design of the OMP could assist industry in quantifying the effect of stocking densities in overall oyster productivity. Two replicates of 70 oysters per bag and two of 110 oysters per bag were monitored between June 2012 and May 2013 at the Mid lake location in Merimbula and at the Mid lake location in Pambula.

In Merimbula the lower density of 70 oysters per bag ended with the highest cumulative loss at the end of the program. However this pattern was not seen through the program and was impacted by higher than usual mortality levels at the March 2013 grading (Figure 62). There was minimal difference in the growth and weight between the two densities at the conclusion of the program, with the greatest increase in shell length occurring over the warmer months October 2012 to March 2013 (Figure 64 and Figure 64).

In Pambula there was no difference in cumulative mortality between the two different stocking densities at the end of monitoring (Figure 63). There was, however, some difference in weighted average shell length and average weight per oyster detected. A slightly higher increase in length and weight occurred for oysters in the lower density towards the end of the monitoring period during the warm months (Figure 65 and Figure 67).

Figure 62: Comparison of cumulative SRO mortality across different stocking densities in Merimbula

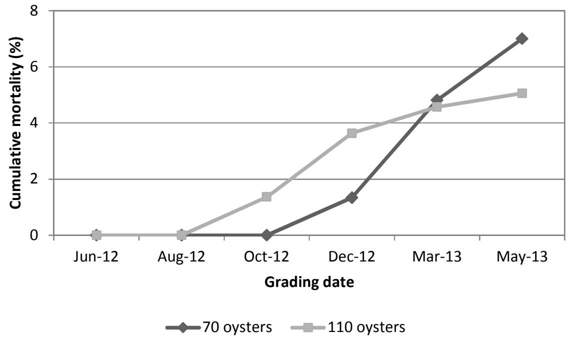


Figure 63: Comparison of cumulative SRO mortality across different stocking densities in Pambula

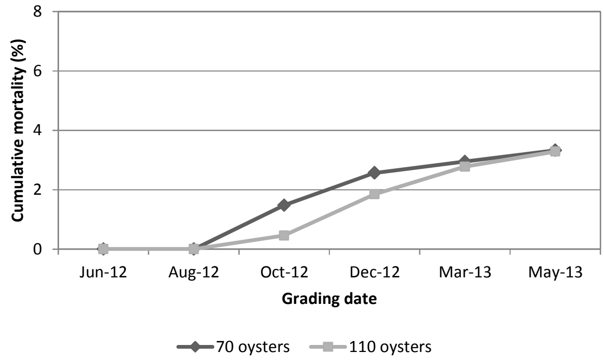


Figure 64: Comparison of average weighted shell length of SRO across different stocking densities in Merimbula

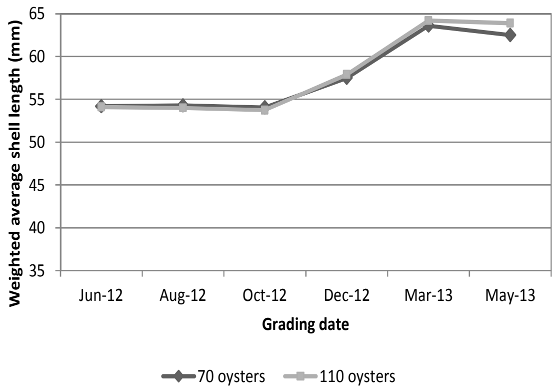


Figure 65: Comparison of average weighted shell length of SRO across different stocking densities in Pambula

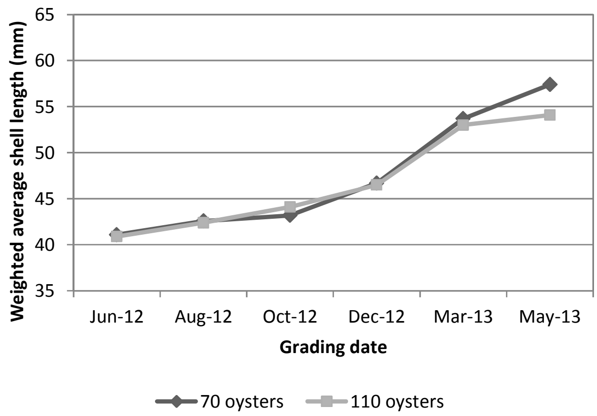


Figure 66: Comparison of average weight of SRO across different stocking densities in Merimbula

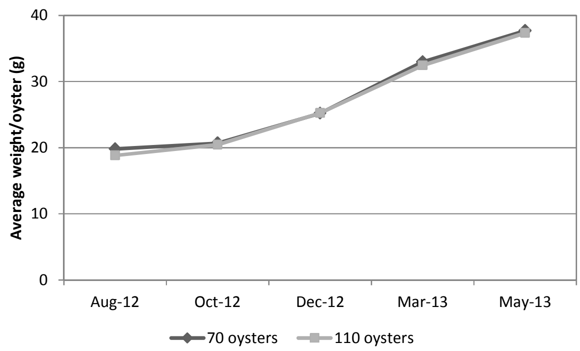
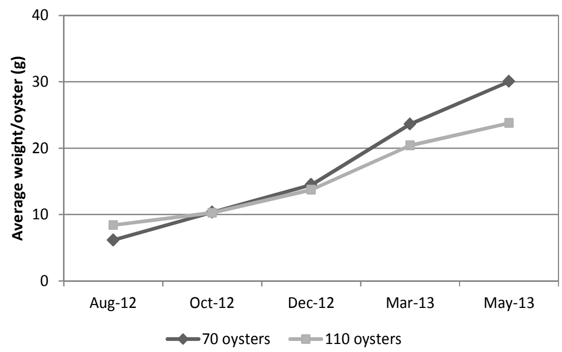


Figure 67: Comparison of average weight of SRO across different stocking densities in Pambula



4.6 Relationships between oyster performance and environmental parameters

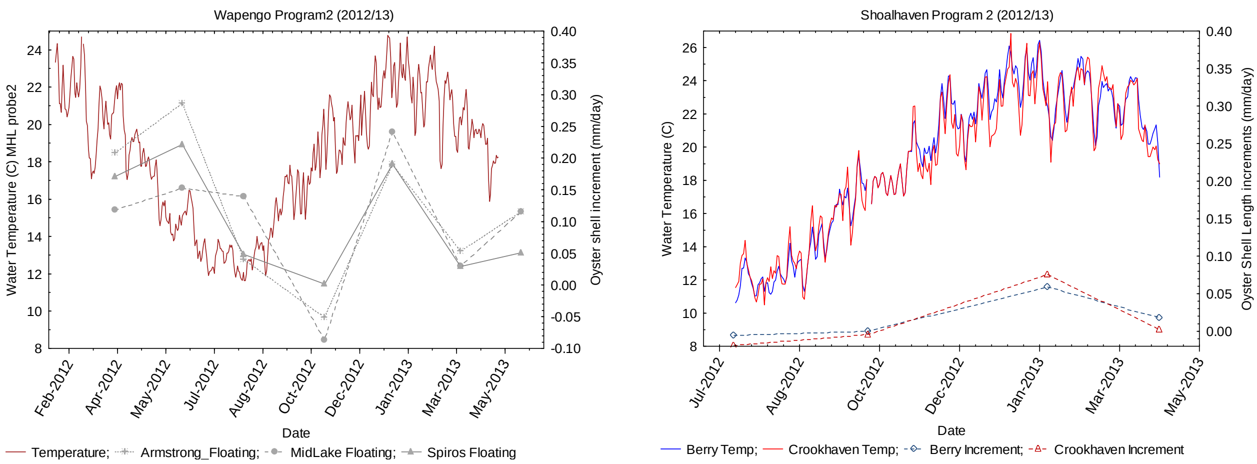
Environmental parameters like temperature and salinity levels are known to influence the maximum feeding rates of suspension-feeders like oysters (see references in Shumway 2011). With access to 12 months data, these parameters along with phytoplankton composition and abundance have been explored as part of the OMP. 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 also been suggested to influence oyster performance but were not included in this project.

4.6.1 Salinity and water temperature

In this study an overall increase in growth rates during the warmer months was observed across all the estuaries involved in the OMP and for both oyster species. A lag of approximately two months on oyster growth was seen in most estuaries with water temperature increasing from the end of August but shell growth not increasing until the end of October (Figure 68). Oyster shell increments were minimal during the winter months with none to negative growth during temperatures of 12-14°C.

Figure 68. Relationship between water temperature and shell length increment in various monitoring locations in Wapengo Lake (a) and Shoalhaven River (b).

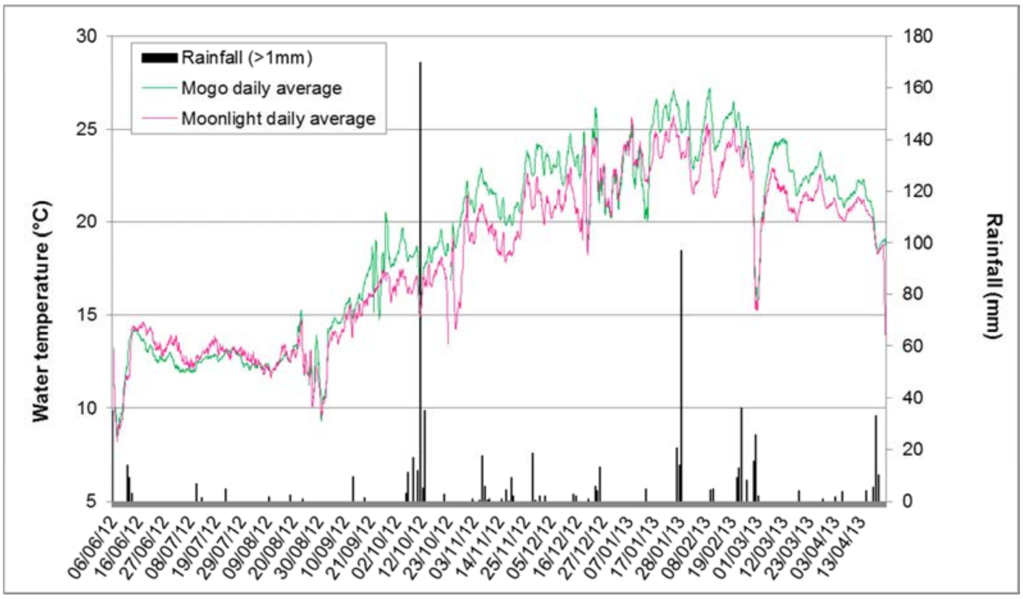
a) b)



In all the rivers and lakes used in this monitoring program it was observed that during winter, water temperature in the locations at the entrance of the river or front of the lake were slightly warmer (by 1-2ºC) than in the middle of the lake. Average monthly water temperature in winter ranged from 11 ºC in upstream locations to 13.9 ºC in downstream locations. Water temperature of 11ºC is considered to be an extreme low threshold for SRO growth potentially slowing oyster growth. As the surrounding air temperature warms up towards spring, water temperature increases in the upstream locations, becoming a few degrees warmer than water towards the front of the lake (Figure 69).

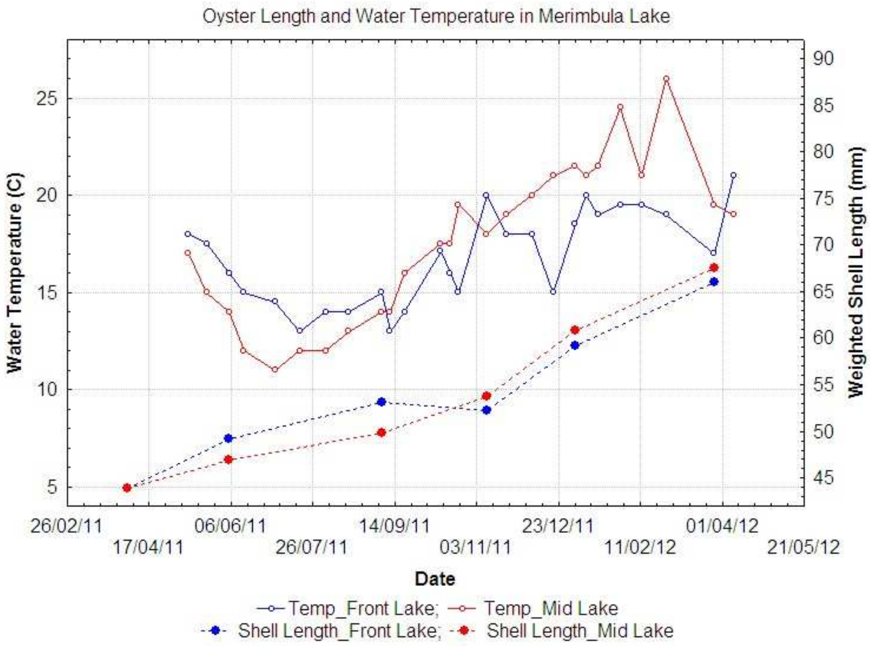
A slight relationship was found between oyster growth patterns and water temperature at the lease location with slightly higher SRO growth at the locations closer to the entrance compared to the oysters cultivated further inside the lake/ upstream the estuary during winter and the opposite during summer. This pattern is shown in Figure 70, which represents conditions in Merimbula Lake during Program 1 (2012/13, Figure 70). Further data is needed to confirm these patterns but should they be consistently found 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 69: Time series of water temperature at two locations in the Clyde River also showing rainfall events. Moonlight is the downstream location closer to the entrance of the estuary and Mogo is a creek off the main channel approximately 8kms upstream from Moonlight.



Available salinity data used in this study is limited to that collected by growers through the SQAP, which has a low and inconsistent sampling frequency. It is highly likely that rainfall would have influenced oyster performance over the duration of the OMP, however no significant relationship was found between salinity and oyster growth or mortality. Higher frequency and more consistent salinity data is needed in order to confirm any links between salinity and oyster performance. In order to address this issue, protocols in the collection of fortnight harmful algae sampling through SQAP, now integrates the recording of both water temperature and salinity levels. In addition, the grading of oysters every two months may restrict the ability to identify growth limitations as a result of low salinities, unless these conditions are maintained for the entire two months.

Figure 70: Relationship between water temperature and weighted average shell length for SRO in the two locations in Merimbula Lake during Program 1 (May 2011/12).



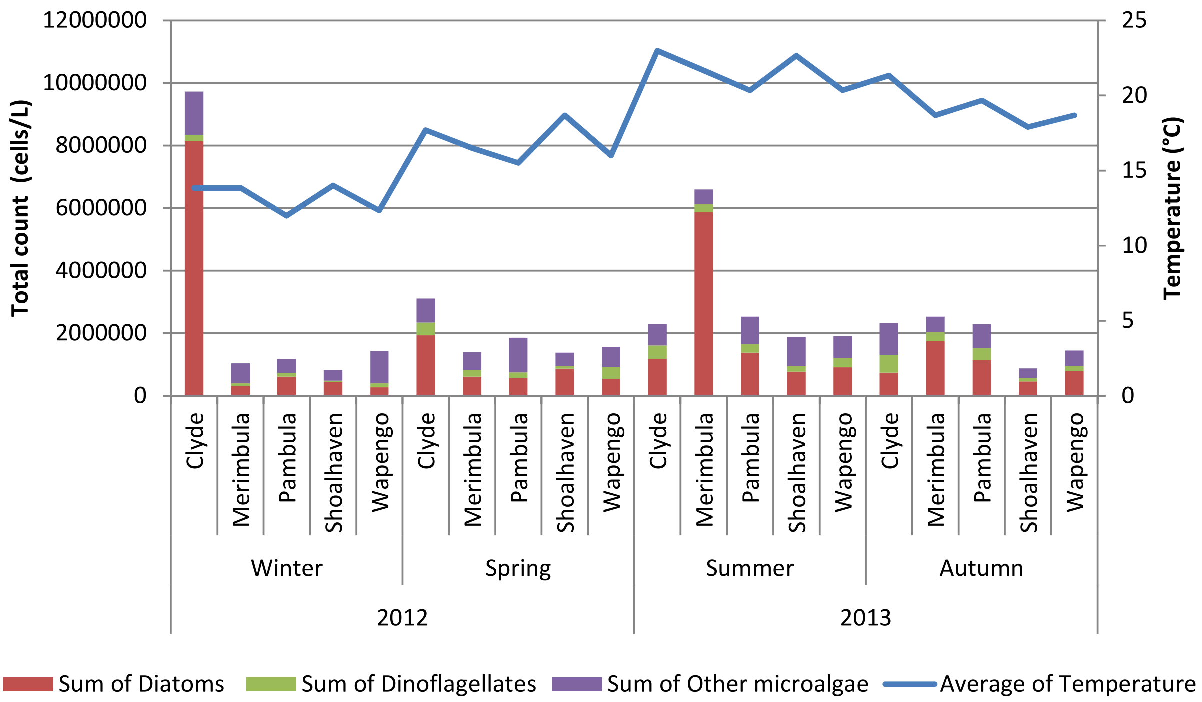
Existing literature reports that higher growth rates as a result of high filtration rates are expected for oysters growing at warmer temperatures and optimal salinity levels (Shumway 2011). However in most cases this relationship is not linear, with defined temperature and salinity thresholds influencing 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 availability (see references in Gosling 2003). While performance data appears to be linked to seasonality, extreme values (high and low) in water temperature and salinity can severely affect oyster growth and survival rates. In previous SRO research in the Clyde River was found that that sustained water temperatures of 13ºC or less during the winter period resulted in minimal activity in terms of oyster weight (Rubio 2008). This research also found that growth in SRO was minimised when salinities were lower than 15ppt for the order of a month.

4.6.2 Phytoplankton

The composition and abundance of total phytoplankton counts in each estuary varied with overall higher counts recorded in the warmer months in particular for Diatoms and Dinoflagellates (Figure 71). An exception to this was found in the Clyde River where extremely high levels of Diatoms were recorded in the middle of winter (July 2012) during Program 2.

A mix of planktonic diatoms (*Pseudo-Nitzschia, Chaetoceros*) and benthic diatoms (*Ceratoneis, Navicula*) were found on this occasion but it is unclear the conditions that led to this bloom apart from the high abundance of chain-forming diatoms species *Fragilariopsis*, potentially contributing to the high counts. Overall diatoms tended to make up the majority of the total phytoplankton counts in the samples (Figure 71). Dinoflagellates tend to follow the same distribution as Diatoms but at lower counts.

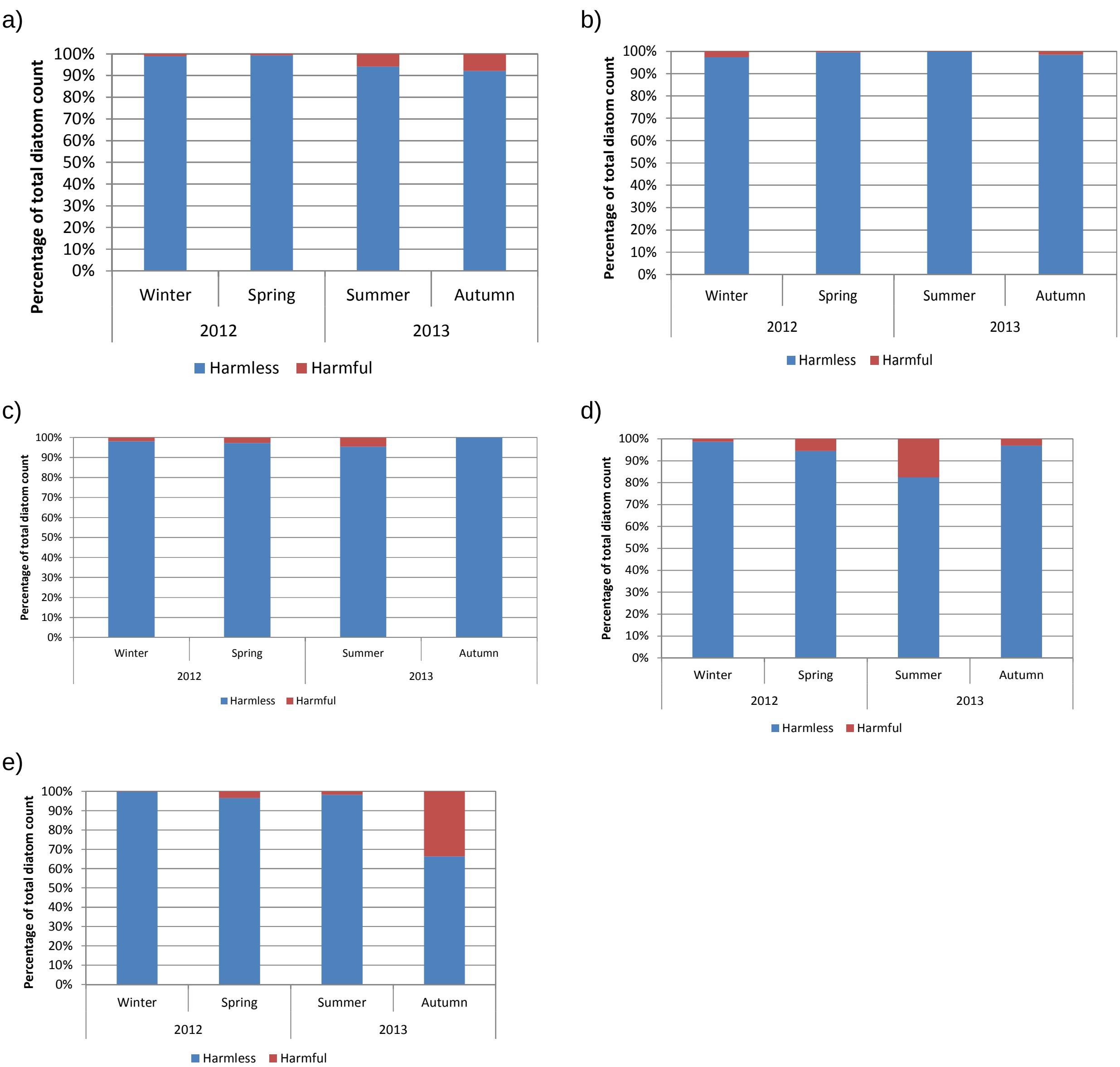
Figure 71: Seasonal phytoplankton counts split by major microalgae groups at each of the five estuaries part of the OMP.



As filter feeders, oysters filter microscopic particles from the water in order to find food. If harmful substances (eg biotoxins and microorganisms) are present in the water, shellfish such as oysters can accumulate them to dangerous levels for human consumption. Biotoxins are harmful substances produced by some types of algae. They can cause illnesses ranging from diarrhoea to severe respiratory and neurological problems. Harmful microorganisms, such as viruses and bacteria, may enter waterways, especially after heavy rainfall, causing illnesses such as hepatitis and diarrhoea.

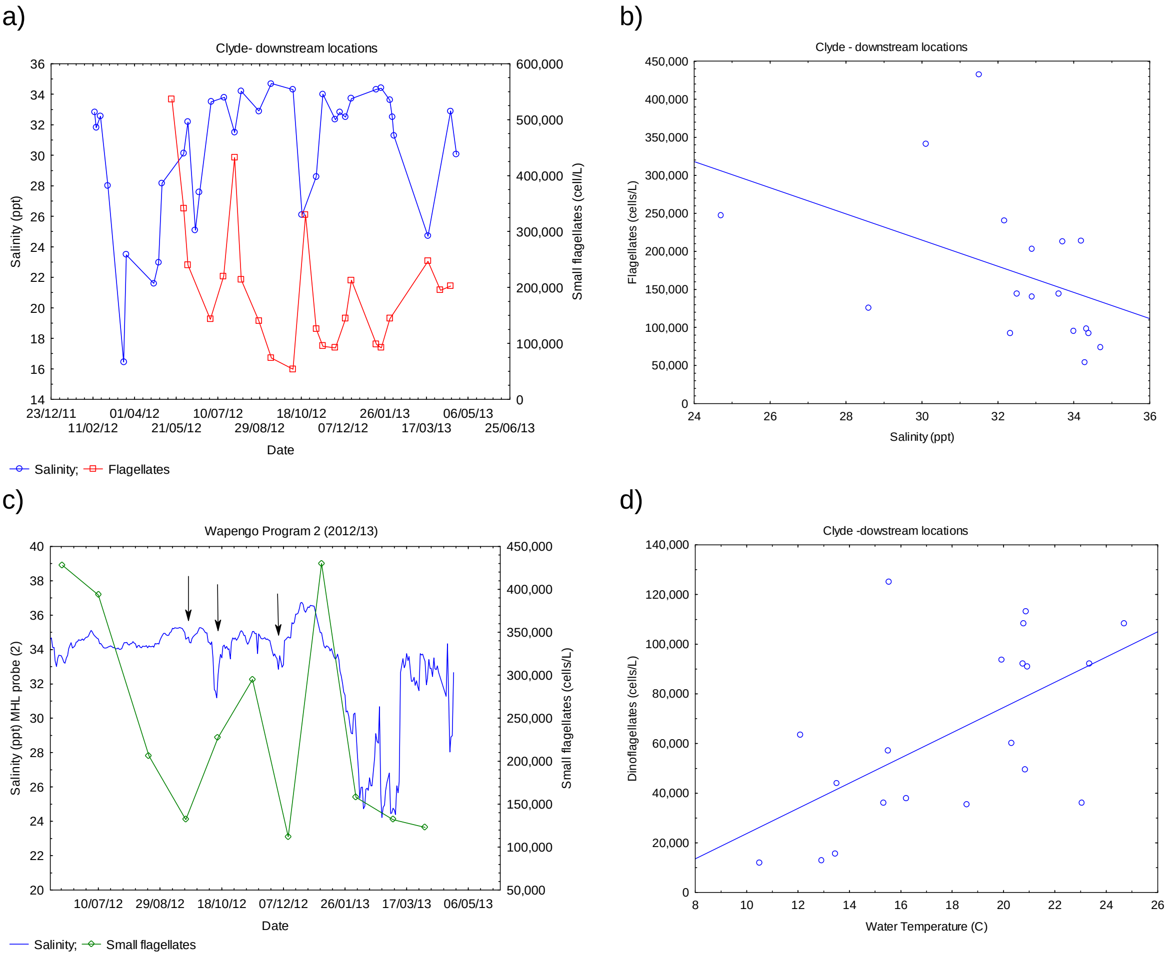
During monitoring of phytoplankton abundance and composition, the proportion of harmless algae was always much larger than the level of harmful algae detected from the samples at all estuaries (Figure 72). The majority of harmful algae belonged to the diatoms group (ie Pseudo-nitzchia spp). The detection of higher levels of harmful diatoms did not correspond to a particular time of year but they are more prevalent during summer, with the exception of Wapengo in Autumn of 2013 where the highest concentration of harmful algae was recorded (Figure 72e).

Figure 72: Proportion of harmful versus harmless diatoms detected in monthly samples from June 2012 to May 2013 at a) Pambula; b) Merimbula; c) Shoalhaven; d) Clyde and e) Wapengo



The total amount of phytoplankton was also independent of environmental conditions. However, when analysing the data by splitting the overall counts into major algae groups, small flagellates were found to be negatively correlated with salinity and temperature (Figure 73). Small flagellates tended to bloom during lower than normal salinity levels (i.e. after small rainfall events). This pattern was found at Wapengo where following a slight drop in salinity the abundance of small flagellates increased (refer to arrows Figure 73c). During these conditions, overall oyster shell growth increments appear to be higher and mortality results lower. On the other hand, dinoflagellates appear to increase in numbers with increasing water temperature but no relationship was found with salinity.

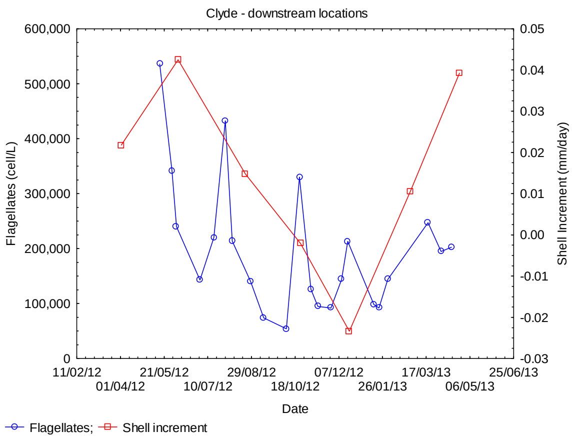
Figure 73: Relationship of environmental parameters with major phytoplankton groups: a) and b) Salinity and small flagellates in downstream locations at Clyde River; c) salinity and flagellates at Wapengo at the middle of the lake; d) temperature and dinoflagellates at Clyde River.

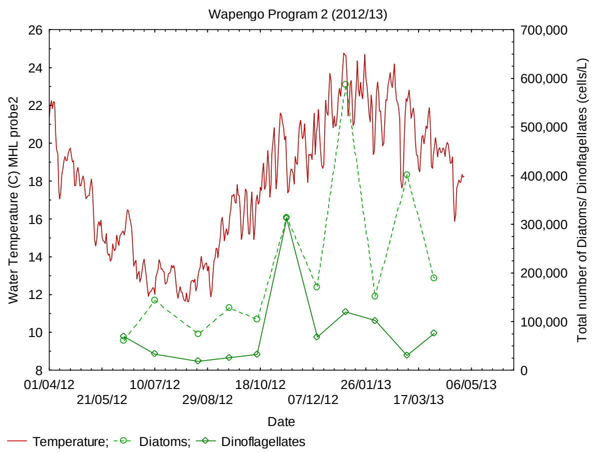


Overall phytoplankton counts increased from winter to summer corresponding with the patterns observed in oyster shell growth (Figure 74). Consequently it appears that oyster growth is supported by increasing water temperatures and food availability based on correlation data analysis. However, this was not supported by the data collected from the Clyde River, probably as a result of the poor growth during Program 2. Oyster growth in Wapengo was found to be positive related to high counts of all main groups of algae: diatoms, dinoflagellates and small flagellates. On the other hand, Merimbula oyster growth in Boggy Creek and Golf lake sites appeared to be positively correlated to the presence of high counts of small flagellates, while oyster growth at the front of Pambula appeared to be driven by the high counts of diatoms. In the Shoalhaven oyster growth at Comerong and Goodnight Island appear to be influenced by blooms of small flagellates that result from small rain events.

Phytoplankton dynamics are hard to quantify especially with low frequency monthly sampling. Higher frequency and larger geographical coverage can assist in the better understanding of the relationship between phytoplankton and oyster performance. Therefore, there is a need for long-term intensive monitoring in order to determine baseline conditions, and relationships between changes in food source abundance/compositions and oyster performance.

Figure 74: Relationships of phytoplankton with a) oyster shell growth and b) environmental parameters like water temperature.





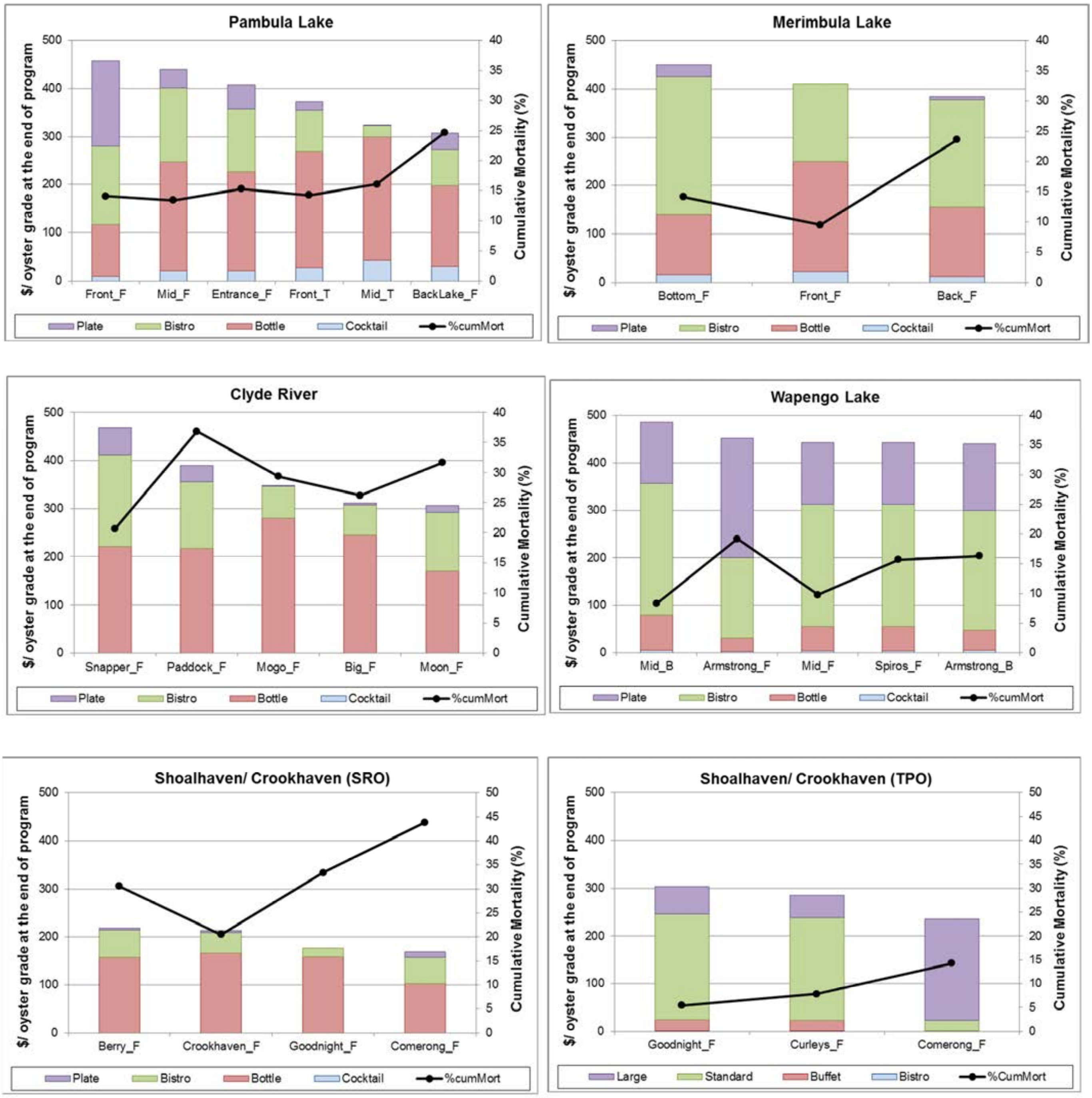
5. Oyster lease profitability

In this report results from Program 2 are presented (i.e. data from 2012/13). Corresponding results for Program 1 (2011/12) of the OMP were discussed in a previous report by Nash & Rubio (2012). The profitability results presented here do not take into account the capital cost of the various infrastructure used, or the operating costs for maintenance (cleaning, drying, fixing) or spat cost. It has been assumed that the production of oysters using various infrastructure methods and oyster batches used in the OMP cost the same. Therefore, the profitability assessment only considers the overall value of oysters based on final number of oysters per grade and location or cultivation infrastructure.

Figure 75 shows the annual return at each location within the five estuaries involved in the monitoring program. The overall value of the SRO batches at the end of Program 2 did not appear to vary greatly across locations in Wapengo, followed by Merimbula and Shoalhaven, however the relative proportion of oysters of certain size grades and the mortality levels did. On the other hand, the different locations in Pambula Lake, some of which used multiple cultivation techniques show important differences. Based on the results for Pambula, oysters at the Front lake site showed greatest oyster performance in regards to a higher proportion of oysters reaching the larger sized grades. This site, using floating units showed substantially more high-value plate oysters than any of the other location/technique contributing towards the high overall value ($) of this SRO batch.

In Pambula Lake, based on the two locations in which both floating units and trays were used, floating units resulted in a 20-25% increase in profitability. This improved profitability was not seen in Wapengo, with minimal difference found in overall value ($) between oyster infrastructure. At the Armstrong site, a much larger number of plate oysters were found in the floating units compared to other sites within this lake. However this site/infrastructure combination also had higher mortality levels bringing down overall profitability.

Figure 75: Profitability ($ value, bar plot) and cumulative mortality (%, black line) of oyster batches by oyster grade size per location and cultivation methods in five NSW south coast estuaries. Sydney rock oysters were used in all rivers and Triploid Pacific oysters only in the Shoalhaven. Results are presented in descending order for overall profitability values within each estuary. Profitability levels cannot be compared across rivers as initial total number of oysters per location was different. The following farm gate prices were used based on industry's feedback: SRO cocktail (40-50mm) $4/dz; SRO bottle (50-60mm) $5/dz; SRO bistro (60-70mm) $6.5; SRO plate (70-80mm) $8.5/dz; TPO bistro (50-60mm) $5.5/dz; TPO buffet (60-70mm) $6.5/dz; TPO standard (70-85mm) $7.5dz; TPO large (85-100mm) $9/dz.



A significant difference in the annual return was obtained across lease areas with SROs in the Shoalhaven River. Oysters at Berry and Crookhaven resulted in similar level of profitability. Despite mortality levels in Berry being 30% higher than in the Crookhaven, oysters at Berry grew more (i.e. higher proportion of Bistro oysters than in the Crookhaven). Profitability in the Clyde River was kept down across all sites as a result of higher than normal mortalities (based on comments from Clyde River growers') experienced during Program 2.

Figure 75 also shows the profitability values for leases where TPO were cultivated in the Shoalhaven River. Since mortality rates for TPO are lower than for SRO, TPO grown in an area of high production can achieve higher returns in 1.5-2 years in comparison to SRO, which grow slower and appear to have significantly higher mortality. TPOs grew the fastest in Comerong, however the largest mortality levels were also found at this site, reducing the overall profitability of this location. The overall mortality levels for TPO found at this site during Program 2 differed significantly from the levels monitored during Program 1. Consequently long-term monitoring is required in order to more accurately characterise TPO growing sites in the Shoalhaven.

6. Discussion

The following section discusses some of the main results and patterns that have been observed over the duration of the Southern Rivers OMP. For more detailed descriptions on the results of individual programs please refer to the reports available from the monitoring tab of the Oyster Information Portal (www.oysterinformationportal.net.au/monitoring).

6.1 Oyster performance and mortality

Distinctive patterns in overall cumulative mortality levels were found across the five estuaries involved in the OMP. SROs in the Shoalhaven had the highest mortalities (average 30.5%±9) over both years of monitoring, with high levels occurring across all sites within this estuary. During Program 2, the Clyde River also had higher mortalities (29%±6) compared to the other three estuaries of Wapengo, Merimbula and Pambula.

Higher 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 anthropogenic factors. 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.

Of all the estuaries, the Shoalhaven catchment has more activities potentially affecting the oysters in this waterway (e.g. flood gates, paper mills, old sewage drainage) than in the other estuaries, possibly resulting in oysters in this estuary being more stressed than in others. However, this reasoning does not hold true for TPO, which performed well in terms of growth and mortality in the Shoalhaven over the same period of monitoring. The difference in mortality between SRO and TPO may also 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 Department of Primary Industries 2012).

The differences in mortality levels could also be attributed to the difference in oyster origin and size at the start of the monitoring program (refer to Table 1). While experiencing much more acceptable rates of loss in Merimbula and Pambula, there was an increase in the variability of loss as oysters aged. This occurred at the same time as oyster growth slowed down. However mortality differences were expected to be more influenced by season than age. Mortality rates tended to be the lowest during autumn independent of estuary or season. But with mortality levels at Shoalhaven River consistently high through all seasons and over time, seasonality (i.e. water temperature) did not seem to be the driving factor influencing mortality levels within this estuary.

It is also known that common oyster diseases like winter mortality will impact oysters during both the cold months and once water temperature starts to warm up. This was suggested as the likely cause for the high mortality rates recorded in the Clyde River in the spring of 2012, with rates of loss possibly also influenced by the high rainfall experienced in October 2012.
The high levels of mortality during Program 1 in the Crookhaven location at the Shoalhaven, may have been influenced by the extremely low salinities as a result of wetter conditions that were sustained for prolonged periods in some parts of the river, potentially affecting the oyster's filtering capacity and therefore, overall health. Mortality levels in the Crookhaven during Program 2, with drier conditions, were significantly lower. In Wapengo an increase in mortality at the back lake sites of Spiros and Armstrong in spring 2012, may also have been influenced by the high rainfall recorded at Wapengo in October 2012.

Despite these likely drivers of SRO loss, 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. With such high rates of loss at some of the key growing areas, the need to better understand the average rate of production versus loss is evident, and can only be achieved through monitoring like this.

6.2 Oyster performance and growth

Growth rates for each monitoring program also showed distinct patterns across estuaries. As well as experiencing more acceptable levels of mortality, the estuaries of Wapengo, Merimbula and Pambula, also recorded steady growth over time. Wapengo had the highest overall increment in shell length per month for all locations. In Merimbula SROs grew on average more than 1.2mm/month and despite quite high mortality on two occasions at Boggy Creek, overall growth at this site was not severely affected by the loss, with averaged growth rates still reached.

Although there were lower mortalities recorded at the upstream sites of the Clyde River, there was also lower growth recorded at these sites. Similarly, the Wapengo mid lake sites recorded slightly lower mortalities but also lagged in growth, this may have been a result of oysters being exposed to greater wash or current which could have been knocking off soft shell frill. However, in Merimbula and Pambula lakes the front lake sites tended to outgrow those further upstream suggesting that growing conditions upstream and downstream will vary depending on the estuary.

Overall, all sites in the Clyde River had low monthly shell increments for SRO (0.4±0.12 mm/month) this rate was followed closely by the SROs in the Shoalhaven River (0.55±0.15 mm/month). The slower SRO growth in the Shoalhaven and Clyde rivers could be a consequence of the larger starting size of these oysters but may also as a potential result from catchment/waterways activities. However, with only one year of data, in particular for the Clyde River, it is hard to conclude if this pattern of poor oyster performance is the norm for this estuary or if it is a result of abnormal occurrences and/or particular environmental influences present at this time.

6.3 Oyster performance by species, cultivation method and stocking density

The Shoalhaven OMP monitoring program involved the comparison of SRO performance with that of TPO. Although overall SRO growth in the Shoalhaven was minimal making it hard to characterise each experimental site from a growth performance point of view, overall TPOs in the Shoalhaven had significantly lower mortality levels and 25-30% higher shell growth increments than the SROs grown in this estuary.

The higher SRO mortality rates occurred at two sites in the Shoalhaven where TPO and SRO were being monitored (Comerong and Goodnight Island). At these two monitoring sites environmental and water quality conditions influencing both species were expected to be the same allowing for direct comparison of performance. With TPO outperforming SRO at both sites, 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). A higher growth rate was expected for TPO than for SRO as Pacific oysters tend to have the highest filtration rates (Bayne 1999). In addition TPOs 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.

The effect of type of cultivation on oyster performance varied per estuary resulting, for instance, in higher oyster shell growth in floating cultivation units than in intertidal trays in Pambula Lake. However, the use of different types of cultivation units had minimal effect on SRO performance at Wapengo Lake where floating cultivation did not significantly outperform static intertidal baskets used by some growers. These results should be re-evaluated under an overall wetter year as higher mortality levels would be expected from the floating cultivation, therefore impacting on overall oyster production.

Stocking densities used in this project did not result in overall significant differences except in Pambula Lake where the lower density of 70 oysters per floating unit resulted in a higher overall oyster batch weight. However, low replication was used in this monitoring program, so that further monitoring is needed. In addition, a wider range of stocking densities should be trialled using different oyster sizes so that oyster productivity can be maximised.

6.4 Oyster performance and environmental conditions

Over the duration of the OMP, oyster shell length at most locations increased the greatest over the warmer months of November to January, probably as a consequence of increased water temperatures and food availability. In most of the estuaries water temperature tended to follow the same seasonal pattern, whereby water temperatures upstream or in the mid/back areas of estuaries were colder in winter than at the entrance/front lake locations where sites had greater exposure to oceanic waters at this time. In summer this pattern reversed and water in the upstream locations of the estuary tended to be warmer than at the downstream sites closer to the entrance. Oyster growth was minimal during the winter months once water temperatures reached on averaged 12°C. Therefore by trying to grow oysters in warmers areas, over the low temperature threshold, could result in significant advantage in oyster growth during winter.

Phytoplankton are the key source of micronutrients, vitamins, oils and trace elements for aquatic communities like oysters. They are rich sources of macronutrients, protein, carbohydrates and especially specific essential fatty acids. The nutritional value of phytoplankton is species-specific which can also vary according to nutrient and light availability, and other physical and chemical conditions experienced during growth. Consequently, a wide range of phytoplankton species is needed to support healthy oyster populations. In the wild oysters generally have access to a wide range of phytoplankton species.
In recent investigations, it has been found that oysters in the wild feed largely on benthic microalgae, mainly benthic diatoms, that might be available from adjacent mudflats or resting on seagrass fronds, both of which become available to the oyster through resuspension (Rubio 2008). Overall diatoms and dinoflagellates were found to increase with temperature while small flagellates were found to increase with slight decreases in salinity, in most cases as a result of medium to small rain events. As a result larger shell growth increments were found in locations where

frequent small rainfall events took place (i.e. when the presence of small flagellates was higher) in comparison with estuaries with drier conditions.

6.5 Oyster performance and profitability

Ideally to maximise profitability in an area, oyster growth must be maximised while mortality levels minimised. Data collected through the OMP can assist industry in improving profitability by understanding oyster productivity across different growing areas and cultivation methods. This improvement can be achieved by taking advantage of localised environmental conditions favourable to stronger oyster performance (higher growth and lower mortality). With more information on the expected profitability over the three-year life cycle of SRO, greater benefit can be derived by growers, who can maximize returns and achieve sustainable production. This type of information can also be further analysed by economists and contribute towards current oyster research projects like the Seafood CRC benchmarking project or the Queensland University of Technology's research project on the economic analysis of the Sydney rock oyster industry.

7. Outcomes and implementation

Monitoring the growth and mortality of the same cohort of oysters across different growing areas along the Southern Rivers region, has assisted in the characterisation of different estuaries and cultivation sites. The collation of environmental factors such as salinity, water temperature and phytoplankton with growth and mortality results has identified preliminary relationships and their potential influence on overall oyster production. While not necessarily revealing profoundly new issues, the formality of collecting data and exploring this information provides growers with the confidence to make operational decisions based not only on an observational/anecdotal basis, but also on identified characteristics documented over time.

An example of the application of the results from Program 1 was observed in the Shoalhaven River. During Program 1 mortality rates for TPO in Curleys Bay were higher and growth slower than those TPO being grown at Comerong. Realising that differences in the performance of the same species was occurring in different parts of the river, the grower responsible for TPO at Curleys opted to try an alternative management option that would see oysters in this part of the Shoalhaven River match the growth of other areas. By adjusting the height at which floating baskets were hung, the grower intended to reduce the risk of exposure to mudworm, hence reducing stress on the oysters, ultimately improving mortality and growth rates. Improvements in the performance of TPO at Curleys were noticeable during Program 2 with a reduction in mortality and an increase in monthly incremental shell length.

Another example of the influence the OMP data collection and sharing has had on changing behaviour and management practices, involves growers in Pambula. Lease areas at the entrance of Pambula have in recent times largely been used for catching spat, and not as a primary growing area. After good growth results, and mortality rates similar to other areas of the lake, recorded during Program 2, Pambula growers expressed interest in making better use of this area of the Lake.

Although the external coordination of the OMP contributed to its success, some dedicated growers involved in the OMP have stated their commitment to continue using their time and access to automated graders for tracking growth despite the conclusion of the funded OMP. With simple protocols established that mimic everyday practices, industry can observe and record data on growth over time with little disruption to their current practices.

As quoted by one of the industry participants involved in the Shoalhaven OMP, the benefits of the program from a growers perspective can be summarised as: *"The main benefit from the program is having long-term monitoring of the health of our growing areas and being able to match qualitative* *observations with quantitative data. It also allows for sharing of information of different growing areas."*

Additional benefits of the OMP also include the generation of industry interest in pursuing the collection of environmental data to further explore relationships with water quality. For example, Clyde growers have shown specific interest in better understanding the influence of the abundance and composition of phytoplankton on the growth (and therefore production) of oysters in this estuary. The oyster industry has also displayed support to continue with the deployment of temperature loggers despite the conclusion of the official OMP. Having been exposed to this low cost/effort method for collecting water temperature the industry now know there are options available for collecting data relevant to their practices with minimal output.

The application of the OMP for managers lends itself to focusing resources towards priority issues. With the evident performance differences between and within estuarine systems, the essential need for on-going monitoring of oyster performance in order to determine and distinguish between baseline information and unusual events is emphasised. For example, the high unexplained mortalities experienced in the Shoalhaven have to an extent been accepted as the norm within industry members. As a result of the overall low profitability gained from growing SRO at the Shoalhaven, industry in this estuary opted to diversify in species by focusing effort on the production of TPO. However, through the OMP industry members now know that other close by estuaries in the Southern Region of NSW have much lower levels of SRO mortality suggesting that there must be something affecting oysters in the Shoalhaven that is not present or as dominating in other systems such as Merimbula and Pambula. The information gained from the OMP should be used to address and prioritise research on this unusual oyster performance.

8. The future of oyster monitoring programs

Here a prototype oyster monitoring program has been trialled with the aim of building baseline information on oyster performance across and within key oyster producing estuaries of the Southern Rivers region of NSW. Information generated by the OMP has been well-received by the oyster industry (O'Sullivan 2012), with the original scope of the program expanded by more than 200% in 2012, resulting in more locations and cultivation methods being added to existing programs. In addition, two new oyster producing estuaries established programs during 2012/13.

By establishing oyster monitoring programs a two-fold benefit ensues. The first benefit enables the oyster industry to quantify current production at the lease levels and to modify its husbandry practices to maximise production across higher performing and more profitable areas, while the second benefit arms catchment managers with an improved ability to understand and manage catchment processes, in turn, supporting a viable oyster industry.

Baseline performance and environmental data is required to assess unusual conditions and the associated effects on the surrounding aquatic ecosystems. Estuarine systems are subjected to a variety of stressors, both natural and anthropogenic. These systems are recognized as critically important habitats and thus the monitoring of their ecological status is essential (Cajaraville et al. 2000). Through greater understanding of the drivers influencing oyster performance, industry and managers will be in a better position to respond to unexpected events and be equipped with management options for responding to environmental change.

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

As a pre-cursor for a potential Australian-wide oyster monitoring program, the OMP can also support a key role of managers in their requirement to report on the state of our catchments. For example, the goals of the OMP align with key objectives of the NSW Monitoring, Evaluation and Reporting (MER) Strategy (2010-2015). The NSW MER guides the efforts of natural resource and land management agencies, including CMAs (the central agency involved in the OMP), to better understand whether the overall health of the natural resources of NSW are changing and to assess the effectiveness of remedial action in reversing observed trends. Like the MER strategy the OMP aims to contribute to the monitoring and evaluation of the condition of, and pressure, on the oyster industry. The OMP strives to improve data collection addressing knowledge gaps and improving the sharing of information across stakeholder groups. The OMP is also aimed at developing and enhancing partnerships between industries, catchment users and managers.

8.1 Improvements and recommendations

To add value to the current investment on this OMP and in order to expand on the information already collected on oyster performance and environmental data, there is a need to maintain this type of monitoring program into the future. The two years of monitoring by this project have demonstrated the need for, and value of, the data collected in setting the base from which to build an Australia-wide oyster monitoring program.

The following points provides a summary of suggested changes that could improve the overall strength of the data collected and further improve the outcomes generated from monitoring the canaries of our catchments.

8.1.1 Environmental data collection

In order to achieve a better understanding of the relationship between food availability and oyster performance, there is a need to collect phytoplankton data more frequently to a minimum of two weeks and to monitor additional sites within an estuary (i.e. upstream and downstream sites) so that the data gives a better representation of the dynamics taking place in the waterways.

An increase in the frequency of salinity data collection and ongoing water temperature recording at multiple sites across each estuary will provide a better understanding of short-term changes in salinity and temperature on oyster performance, and how it affects abundance and composition of phytoplankton.

8.1.2 Monitoring design

While the process involving the use of automated graders to recorded information about oyster growth has been proven as an efficient method for capturing relevant oyster performance data, improvements could be made in the design and set-up of future programs.

In order to be able to make direct comparisons of oyster performance across estuaries, there is a need to establish new monitoring programs using the same batch of oysters so that monitoring oysters have same age and size at start and have same origin and spat/juvenile husbandry. With additional oyster growing estuaries in NSW having been granted access to trial TPOs in conjunction with SROs, there is room to increase our knowledge on the performance differences within an estuary between SRO and TPO.

Future monitoring of optimal stocking density levels should incorporate a larger range of densities and replications per site and cultivation type. There is also the need to further investigate the effect of stocking densities in different cultivation methods and at different points during the SRO life cycle.

8.1.3 Stakeholder engagement

Any future OMP should also involve greater integration and incorporation into existing data collection programs and processes, such as the SQAP and MER programs. Stronger links should be formed between oyster monitoring data and other data collection processes regardless of differing organisations and jurisdictions. The storage of this data in an accessible common place like the online Oyster Information Portal means many stakeholders can utilise the data for multiple outcomes.

Further consideration should also be given to preferred methods for presenting data to industry, and options for building on industry interest to form a strong support platform of growers involved in the program across all estuaries. The success of a monitoring program is greatly enhanced when implementation and delivery of the program has industry involvement.

9. Conclusion

As end-users of the catchment, the oyster industry is coping with all the activities undertaken upstream and is highly vulnerable not only to water quality changes but also to changes in landuse, in particular as a result of increased coastal development. Acknowledging that the oyster industry plays a key ecological role, helping to remediate potential negative local effects in bays and the downstream areas of estuaries, there is still a lack of information on the potential drivers influencing oyster aquaculture production. The need to continue monitoring and collecting data on oyster performance and water quality is crucial in order to improve production levels and achieve inclusive catchment management.

Information on oyster performance and relationships with environmental conditions can be used to improve husbandry operations leading to efficiencies in management techniques, increasing the industry’s viability into the future. Just as important this information can be used by other stakeholders and managers interested in understanding the factors and relationships influencing estuarine systems.

Recognising the benefit of using oysters as the canaries of our catchments, local councils, CMAs and other government agencies, have shown support for this cost effective monitoring approach, which sees oysters acting as bioindicators for the productivity and health of estuaries. Options for securing funding for an ongoing OMP are necessary, as long term monitoring of oysters for production purposes will always hold the added benefit of monitoring the overall health of our catchments.

10. Related documents

This document collates information included in the bimonthly reports delivered to industry after every grading event. For more detail on month to month observations and results please refer to the documents listed below, which can be accessed from the Oyster Information Portal www.oysterinformationportal.net.au

- Nash, C and Rubio, A (2012) Monitoring the canaries of our catchments. Conference paper for NSW Coastal Conference 2012, Kiama, NSW, Australia
- Rubio, A., Winberg, P. and Kirkendale, L. (2012). Oyster Information Portal: a user-group focused 'Coastal Google' for the future. Conference paper for NSW Coastal Conference 2012, Kiama, NSW, Australia
- O'Sullivan, D. (2012). Assessing long term lease performance using automatic oyster graders.Austasia Aquaculture. 26 (2): 33-38
- Final report – Shoalhaven River oyster monitoring program - Program 1 2011/12
- Final report – Shoalhaven River oyster monitoring program - Program 2 2012/13
- Final report – Merimbula Lake oyster monitoring program - Program 1 2011/12
- Final report – Merimbula Lake oyster monitoring program - Program 2 2012/13
- Final report – Merimbula Lake oyster monitoring program - Program 3 2012/13
- Final report – Pambula Lake oyster monitoring program - Program 1 2011/12
- Final report – Pambula Lake oyster monitoring program - Program 2 2012/13
- Final report – Pambula Lake oyster monitoring program - Program 3 2012/13
- Final report – Wapengo oyster monitoring program 2012/2013
- Final report – Clyde River oyster monitoring program 2012/2013

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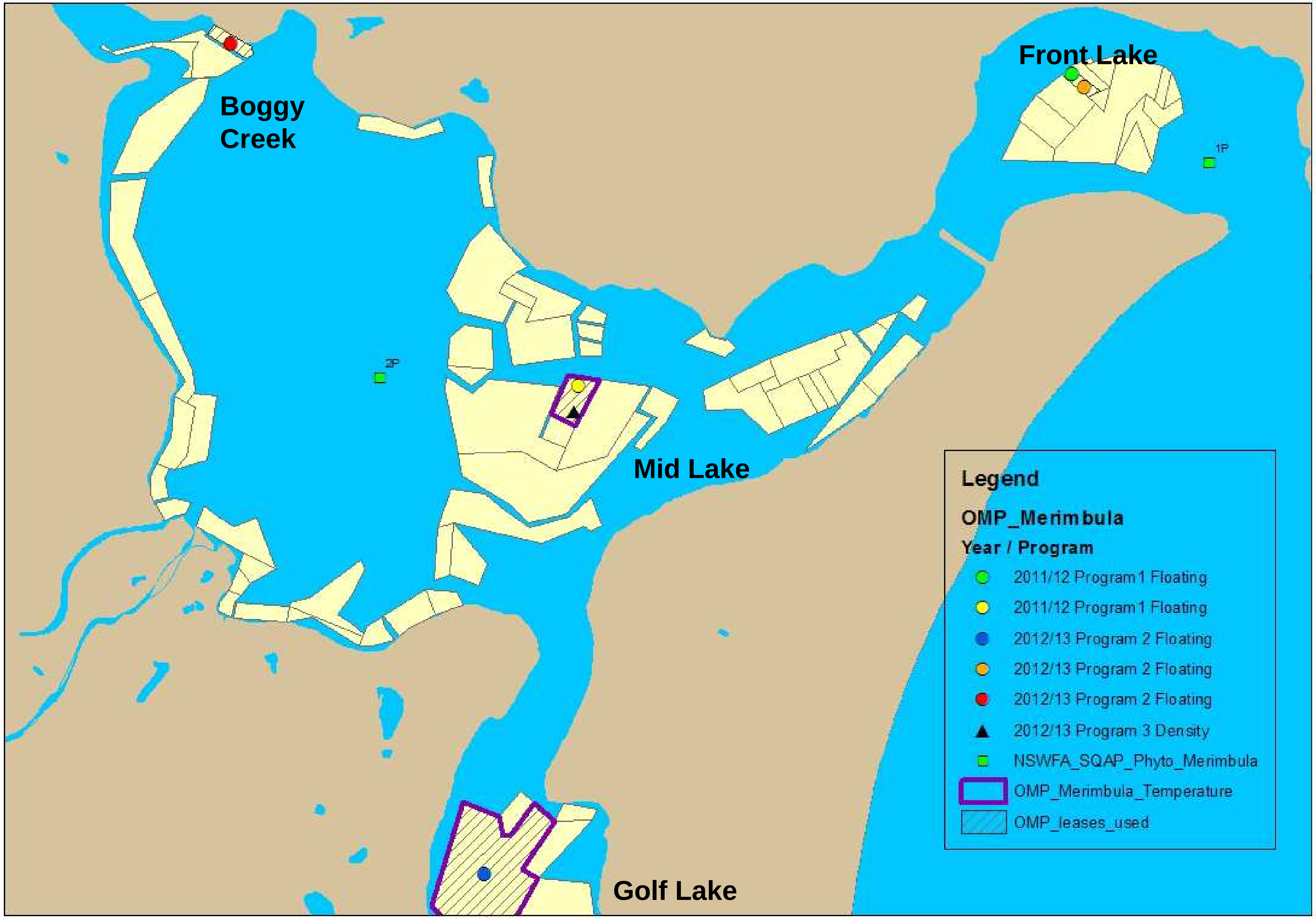
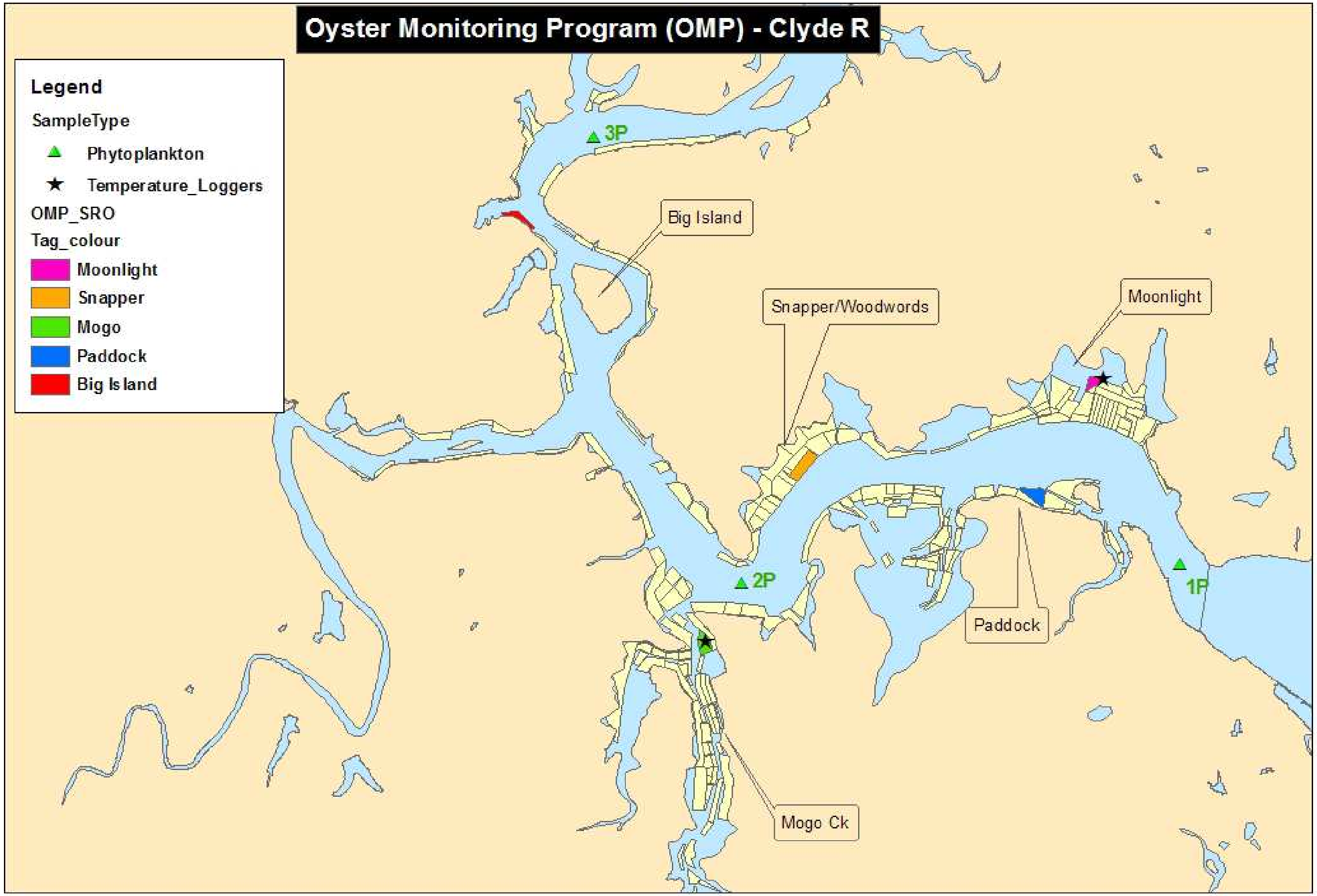
Appendix 1. Location of Oyster Monitoring sites, phytoplankton collection points, and temperature logger recording sites

1.1 Pambula Oyster Monitoring Program

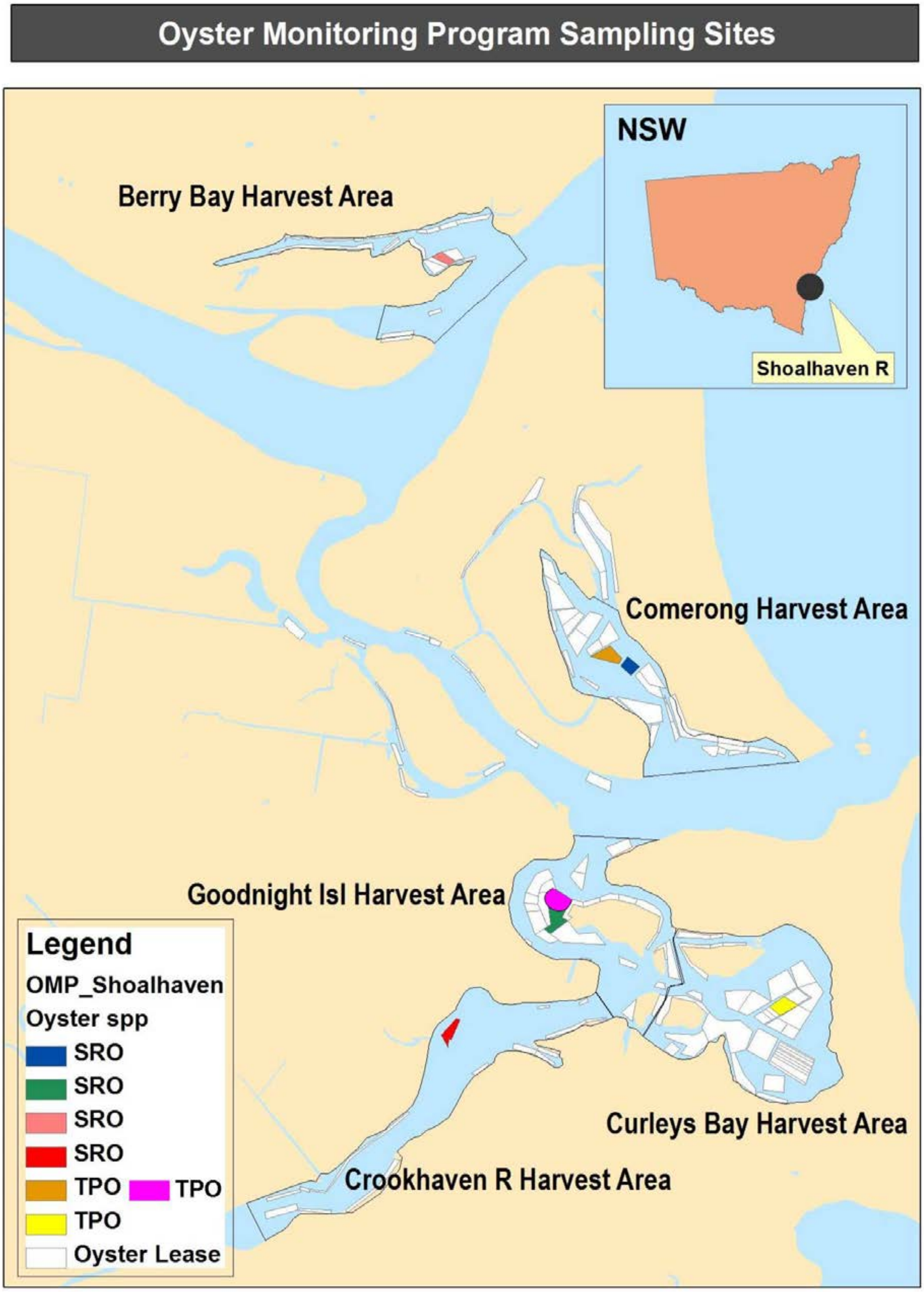
1.2 Merimbula Oyster Monitoring Program



1.3 Clyde River Oyster Monitoring Program



1.4 Shoalhaven Oyster Monitoring Program



1.5 Wapengo Oyster Monitoring Program

Appendix 2. Oyster Monitoring Program grading process

1. Retrieve oysters from the different locations (engage as many oyster growers as possible)
2. Separate oyster groups by locations and grade oysters from one location at a time
3. For location 1: Empty oysters from the cultivation method used into the grader bins
4. Allocate a bucket for dead oysters – Please count dead oysters and record them
5. Start grader:
    a. Remember to wet the belt and calibrate the grader
    b. Upload the grader recipe (i.e. Pambula/Merimbula monitoring program)
    c. Make sure that oyster densities are set as agreed in the program (i.e 100 oysters/grade 1, 100 oysters/ grade 2 etc)
    d. Re-start the run so counts are re-set to ‘0’
    e. Set speed of grader to a medium/slow speed
    f. Place a bucket at the end of grader to collect ‘rejects’- count & record them
6. Inspect oysters while the oysters travel on the inspection belt. Dead oysters are thrown into the bucket and doubles are set aside. At the end doubles will be chipped and put back through the machine and dead oysters need to be counted and recorded.
7. Once all oysters have been graded put the rejects through the grader again and grade the doubles you have already chipped. Look for oysters that might have fallen through the singulator and try to grade them again
8. Once grading has finished, switch window view to statistics and write down the average sizes of the oysters for each grade
9. Write down the number of oysters graded in each grade (this is a back-up in case the electronic report does not get saved)
10. Stop grader and save report – use a good name for the file (e.g. Date_Lease name_Pambula.txt)
11. Make sure you have recorded: mortalities (number of dead oysters), rejects that have not been graded, number of oysters per grade
12. If at the end of the grade a cultivation unit is not complete (based on the densities of the recipe) make a decision whether you leave the cultivation unit as it is (i.e. if it is close to the total density) or combined ‘left-over’ oysters with oysters from different grades
13. Make sure that the different cultivation methods have the right colour tags (per location)
14. Take a sample of 10 oysters representing all grades. Store them in a zip lock bag and label bag with Date / Lease name / Pambula. Freeze them until Ana picks them up.
15. Repeat the above steps for the rest of the locations
16. Save recipe and Report files in a USB drive- you can find the files in c:/Batchfiles

Appendix 3. Southern Rivers Oyster Monitoring Program grading events

Estuary	Program	Grading No.	Grading event	Date
Merimbula	1	1	Set-up	4/05/2011
		2	First grading	21/07/2011
		3	Second grading	7/10/2011
		4	Third grading	1/12/2011
		5	Fourth grading	7/02/2012
		6	Fifth grading	26/04/2012
		7	Sixth grading	21/06/2012
		8	Seventh grading	23/08/2012
		9	Eighth grading	25/10/2012
		10	Ninth grading	20/12/2012
		11	Final grading	7/03/2013
	2	1	Set-up	26/04/2012
		2	First grading	21/06/2012
		3	Second grading	23/08/2012
		4	Third grading	25/10/2012
		5	Fourth grading	20/12/2012
		6	Fifth grading	7/03/2013
		7	Final grading	2/05/2013
	3	1	Set-up	21/06/2012
		2	1st grading	23/08/2012
		3	2nd grading	25/10/2012
		4	3rd grading	20/12/2012
		5	4th grading	7/03/2013
		6	Final grading	2/05/2013
Shoalhaven	1	1	Set-up	5/05/2011
		2	First grading	15/06/2011
		3	Second grading	17/08/2011
		4	Third grading	20/10/2011
		5	Fourth grading	14/12/2011
		6	Fifth grading	15/02/2012
		7	Final grading	3/05/2012
	2	1	Set-up	3/05/2012
		2	First grading	19/07/2012
		3	Second grading	11/10/2012
		4	Third grading	31/01/2013
		5	Final grading	11/04/2013
Clyde	2	1	Set-up	30/01/2012
		2	First grading	2/04/2012
		3	Second grading	6/06/2012
		4	Third grading	22/08/2012
		5	Fourth grading	24/10/2012
		6	Fifth grading	19/12/2012
		7	Sixth grading	27/02/2013
		8	Final grading	24/04/2013

Estuary	Program	Grading No.	Grading event	Date
Wapengo	2	1	Set-up	31/01/2012
		2	First grading	30/03/2012
		3	Second grading	7/06/2012
		4	Third grading	9/08/2012
		5	Fourth grading	1/11/2012
		6	Fifth grading	10/01/2013
		7	Sixth grading	21/03/2013
		8	Final grading	23/05/2013
Pambula	1	1	Set-up	4/05/2011
		2	First grading	21/07/2011
		3	Second grading	7/10/2011
		4	Third grading	1/12/2011
		5	Fourth grading	7/02/2012
		6	Fifth grading	26/04/2012
		7	Sixth grading	21/06/2012
		8	Seventh grading	23/08/2012
		9	Eighth grading	25/10/2012
		10	Ninth grading	20/12/2012
		11	Final grading	7/03/2013
	2	1	Set-up	26/04/2012
		2	First grading	21/06/2012
		3	Second grading	23/08/2012
		4	Third grading	25/10/2012
		5	Fourth grading	20/12/2012
		6	Fifth grading	7/03/2013
		7	Final grading	2/05/2013
	3	1	Set-up	21/06/2012
		2	1st grading	23/08/2012
		3	2nd grading	25/10/2012
		4	3rd grading	20/12/2012
		5	4th grading	7/03/2013
		6	Final grading	2/05/2013