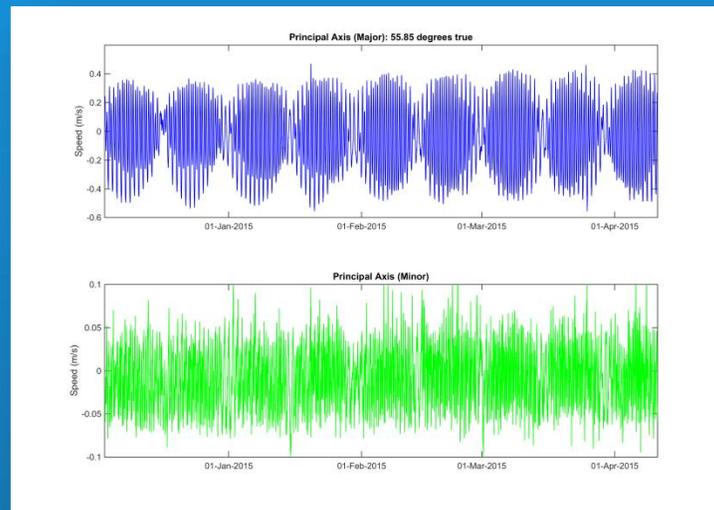


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Oceanographic observations of currents and temperature in the Wallaroo aquaculture zone



John F. Middleton, Charles E. James, Mark J. Doubell
and Paul Malthouse

SARDI Publication No. F2015/000364-1
SARDI Research Report Series No. 842

SARDI Aquatics Sciences
PO Box 120 Henley Beach SA 5022

June 2015

Final Report prepared for Clean Seas Tuna Ltd.

PREMIUM
FOOD AND WINE FROM OUR
CLEAN
ENVIRONMENT



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This publication may be cited as:

Middleton, J. F., James, C. E., Doubell, M. J. and Malthouse, P. (2015). Oceanographic observations of currents and temperature in the Wallaroo aquaculture zone. Final Report prepared for Clean Seas Tuna Ltd. South Australian Research and Development Institute (Aquatic Sciences), Adelaide. SARDI Publication No. F2015/000364-1. SARDI Research Report Series No. 842. 14pp.

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Printed in Adelaide: June 2015

SARDI Publication No. F2015/000364-1

SARDI Research Report Series No. 842

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Date: 22 June 2015

Distribution: Clean Seas Tuna Ltd, PIRSA Fisheries and Aquaculture, SAASC Library, University of Adelaide Library, Parliamentary Library, State Library and National Library

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ACKNOWLEDGEMENTS

We thank the crew of the *R.V. Ngerin* for their assistance in deployment and retrieval of the mooring. This report was formally reviewed by Marty Deveney, Ana Redondo and John Luick of SARDI Aquatic Sciences. We thank the reviewers and editor for their helpful comments that improved the quality of the report.

1. EXECUTIVE SUMMARY

This report presents data on temperature and ocean currents measured over a 4 month period (3rd December 2014 to 10th April 2015) relevant to the sustainable development of Yellowtail Kingfish (YTK) aquaculture proposed for the Wallaroo aquaculture zone (WAZ). The data presented complements the associated modelling study (Doubell *et al.* 2015) that was executed at Clean Seas Tuna's request (hereafter CS), to investigate the identification of possible sites and production strategies for aquaculture of Yellowtail Kingfish (YTK).

At CS's request, an ocean mooring was deployed in the WAZ in a mean water depth of 18.5 m for the period 3rd December 2014 to 10th April 2015. The recovered mooring was heavily bio-fouled but reliable data were obtained for sea level variability, bottom temperature and ocean currents for signals and with periods longer than 1 hour. In the case of ocean currents these were also estimated at 1 m bins in the vertical and at mean water depths between 4 m and 16 m.

Results for sea level indicate a semi-diurnal (12 hr) signal and the associated dodge tide where sea level variability becomes small every 15 days or so: the dodge tide is an extreme neap tide that extends for several days. The maximum tidal displacement was about 2 m.

The raw depth-averaged currents were found to be directed predominantly in the along-isobath direction (the "major axis" with positive values to the N.E.) with magnitudes up to 50 cm/s and also dominated by the semi-diurnal and dodge tides. The cross-isobath ("minor axis") currents were much smaller and around 5 cm/s. The along-isobath currents also exhibit a reduction with depth from 60 cm/s (1.2 knots) at a depth of 4 m (below the surface), to 30-40 cm/s at depths of 16 m. This vertical current shear is expected to arise from frictional effects where bottom currents will be close to zero. The large surface currents and vertical shear may be important to deformation of aquaculture pens.

The tidal currents also indicate a maximum horizontal displacement of 7 km over a 6 hour period and therefore will be important to flushing of the WAZ.

The currents were also filtered to remove variability with periods shorter than three days which includes that due to the 12 hr tides. These filtered currents were also found to be predominantly directed along-isobaths as found for the (tidally dominated) raw data, but with much smaller magnitudes of 7 cm/s or so: the monthly (and December-April) along-isobath time-averaged currents were around 5 cm/s to the S.W. (or 4.3 km/day) and would also be important to flushing of the region.

Near bottom observations of temperature increased from 21 °C at the beginning of December to a maximum of 23.5 °C in late February. Between March and April, the temperature dropped to 19 °C as expected from autumn cooling. The bottom temperatures were typically 2 °C lower than surface values obtained from a hydrodynamic model. The temperature data also indicated variations of up to 0.5 °C that likely result from daily heating and to a lesser extent, transport by the strong semi-diurnal (12 hr) tide.

1.1. Background

The development of aquaculture in Spencer Gulf requires information on the variability and magnitude of ocean variables. Currently, the '*Aquaculture (Eastern Spencer Gulf) Policy 2005*' is under review. Specifically, the Wallaroo sub-tidal aquaculture zone (WAZ) is being investigated for the addition of Yellowtail Kingfish (*i.e.* YTK) aquaculture. Recent results from modelling studies (Doubell *et al.* 2015) provided estimates of current speed, directions, temperature and other oceanographic variables for the WAZ. In regard to the possible expansion of YTK in the WAZ, Clean Seas Tuna (CS) sought direct measures of the *in situ* current and temperature field. The observations in this report will provide for a greater understanding of the variability in the magnitude and vertical structure currents and bottom temperature across the summer months during which production is greatest.

The field measurement provide *in situ* observations of vertical changes (at approximately 1 m resolution) in current speed and direction and near-bottom water temperature at a pre-determined site in the WAZ using an Acoustic Doppler Current Profiler (ADCP) mounted to a frame moored to the ocean floor. Additional conductivity, temperature and depth (CTD) based measurements of near-bottom temperature, fluorescence and turbidity were undertaken by SARDI and made available to CS on request. All raw and processed data were provided to CS. Processed data were provided in a format which is readily useable by CS (e.g. Excel files). This brief written report provided to CS summarises the sea level, current and temperature observations.

1.2. Objectives

- a) Deploy and recover a bottom mooring fitted with oceanographic equipment for a period of 90 days at a site determined by CS in the WAZ. Measured oceanographic variables include; current speed and direction throughout the water column at approximately 1 m intervals and near-bottom temperature. Additional measurements of near-bottom salinity, fluorescence and turbidity will be undertaken by SARDI and made available to CS on request. As agreed with CS, no analyses or reporting of these additional data streams will be provided.
- b) Provide CS with all raw data, as well as processed data in a readily useable format. SARDI will retain the data, and its use, for future purposes (e.g. future model validation).
- c) Provide CS with a brief written report summarising the current and temperature observations.

2. METHODS

A bottom mooring fitted with oceanographic equipment was deployed/recovered for a 4 month period at a pre-determined site in the WAZ (Wallaroo Aquaculture Zone) using the *R.V. Ngerin*. In order to minimise operational costs, the mooring deployment and recovery was conducted 'on the back' of an existing SAIMOS cruise. The deployment date was the 3rd of December 2014 and the mooring was recovered on the 10th April 2015. The deployment co-ordinates were (137.4837E, -33.9502N) or (137° 29.0220' E, -33° 57.0120' N) as shown by the blue circle in Fig. 2.1. The outline of the WAZ is indicated by the green line along with the proposed CS lease site (red circles).

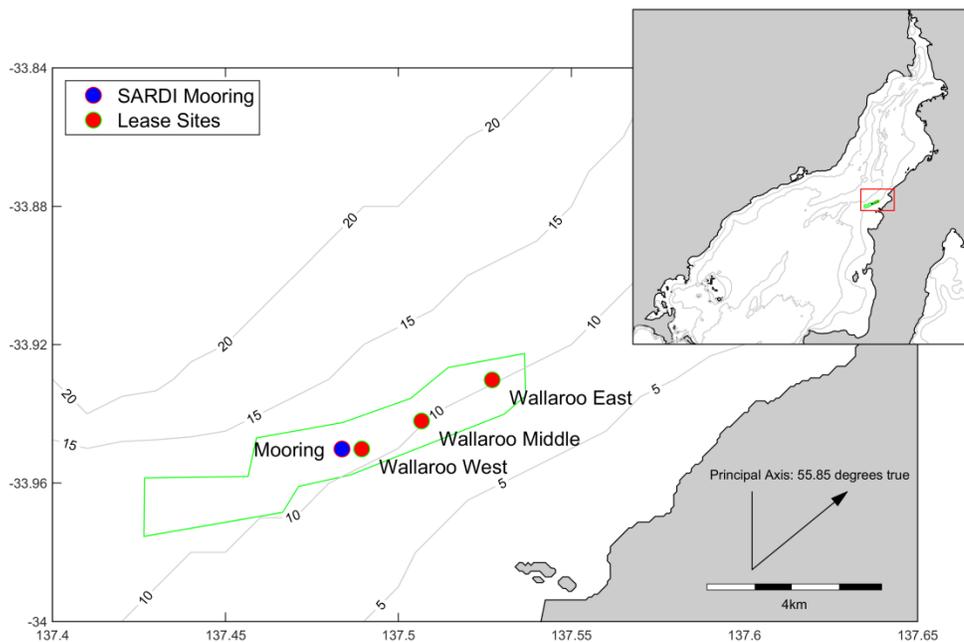


Figure 2.1 The deployment co-ordinates of the SARDI mooring were (137.4837E, -33.9502N) or (137° 29.0220' E, -33° 57.0120' N) as shown by the blue circle. The outline of the WAZ is indicated by the green line along with the proposed CS lease sites (red circles). The black lines correspond to isobaths depths in meters. The principal axis of current flow is indicated in the lower right of the panel by the black arrow: direction 55.85 ° clockwise from true north. The location within Spencer Gulf of the WAZ region is indicated by the upper right inset plot.

The oceanographic equipment on the SARDI mooring included; (i) a RDI Workhorse Sentinel 600 KHz ADCP to measure ocean currents (and their depth-dependence) and near bottom temperature, (ii) a Teledyne Citadel CTD for measurement of near-bottom temperature, salinity, chlorophyll fluorescence and turbidity and (iii) an ORE acoustic pop-up release/cart, SABLE satellite tracker and a Novatech strobe beacon for deployment and recovery purposes.

The ADCP was configured to sample 1 m vertical bins every 20 minutes with a series of 50 acoustic pings from four beams to form profiles of the current field, The CTD was configured to

burst sample for 15 seconds at 2 Hz every 30 minutes; the burst samples were then averaged to produce two observations per hour.

The mooring was heavily bio-fouled after the 4 month deployment as indicated in Fig. 2.2. However, the ADCP and associated measured currents along with temperature are little affected by such bio-fouling. Salinity measured by the CTD was strongly affected by bio-fouling and was of no value. Fluorescence and oxygen concentrations measured by the CTD provide a calibrated estimate of phytoplankton biomass concentrations ($\mu\text{g/l}$) dissolved oxygen saturation (%) levels, respectively. The acoustic release failed to open due to the bio-fouling and the mooring was retrieved by trawling.



Figure 2.2 The recovered SARDI mooring in April after 5 months deployment. The bio-fouling is extensive.

The deployment depth of the mooring was in about 18.5 m of water. This is about 50% larger than indicated by the topographic contours shown in Fig. 2.1 where the model topography would suggest a depth of around 12 m.

3. RESULTS

3.1. Sea Level

A plot of sea level height relative to the mean water depth of about 18.5 m and for the observation period is shown in Fig. 3.1. The height variability was measured from the base of the CTD and about 0.5 m from the sea floor; results from the pressure sensor on the ADCP were almost identical. The semi-diurnal variability is notable along with the dodge tide (period 29 days); the latter results from the semi-diurnal M_2 and S_2 (~12 hr period) tides that are of equal magnitude and “beat” together to produce the “dodge” tide where sea level (and currents) become relatively small every 15 days or so. The maximum tidal displacements are up to 2 m.

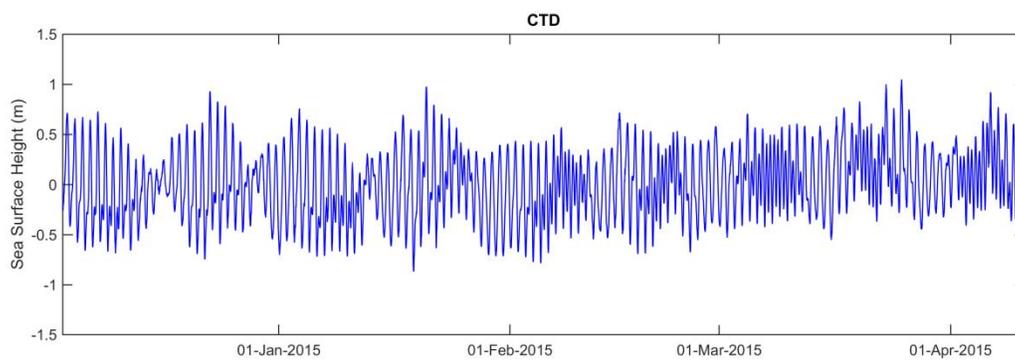


Figure 3.1 The raw depth-averaged sea level (meters) measured by the pressure sensor at the base of the CTD (about 0.5 m from the sea floor).

3.2. Currents

Currents for the region are, in order of importance, driven by a) tides and b) winds and the thermohaline circulation; the latter arises from changes to sea water temperature and salinity that are respectively affected by atmospheric heating/cooling and evaporation (less precipitation which is relatively small). This relative importance is borne out by the plot in Fig. 3.2 of the raw depth-averaged currents that have been resolved along the major and minor axes of the raw data. The major axis is that in which the largest time-varying variability is found and the minor axis the smallest. For this site and data, the major axis (positive values) is directed towards 55.8° clockwise from magnetic north. This direction approximately corresponds to the along-isobath direction shown in Fig. 2.1 and to the N.E. The minor axis is directed at right angles to the major axis and approximately to the S.E. The current variability shown in Fig. 3.2 (top panel) is predominantly along isobaths and also dominated by both the semi-diurnal M_2 and S_2 (~12 hr period) tides. As noted above for sea level, evidence for the dominance of both semi-diurnal tides (and that they are of equal magnitude), is that they “beat” together to produce the “dodge” tide where currents become relatively small every 15 days or so. Note 1 m/s is equal to 1.944 knots or 86.4 km/day. A tidal current amplitude of 0.5 m/s indicates a maximum displacement of a water parcel of 6.9 km over a 6 hour period. This result is derived by assuming a simple

sinusoidal model for the net displacement dX of water over the spring tide equal to $u_T T_T / \pi$ where we take the $u_T = 0.5$ m/s as a typical tidal amplitude (Fig. 3.2), $T_T = 12$ hrs as the tidal period, so that $dX = 6.9$ km. This distance is comparable to the length of the WAZ so that tides are important to flushing of the region.

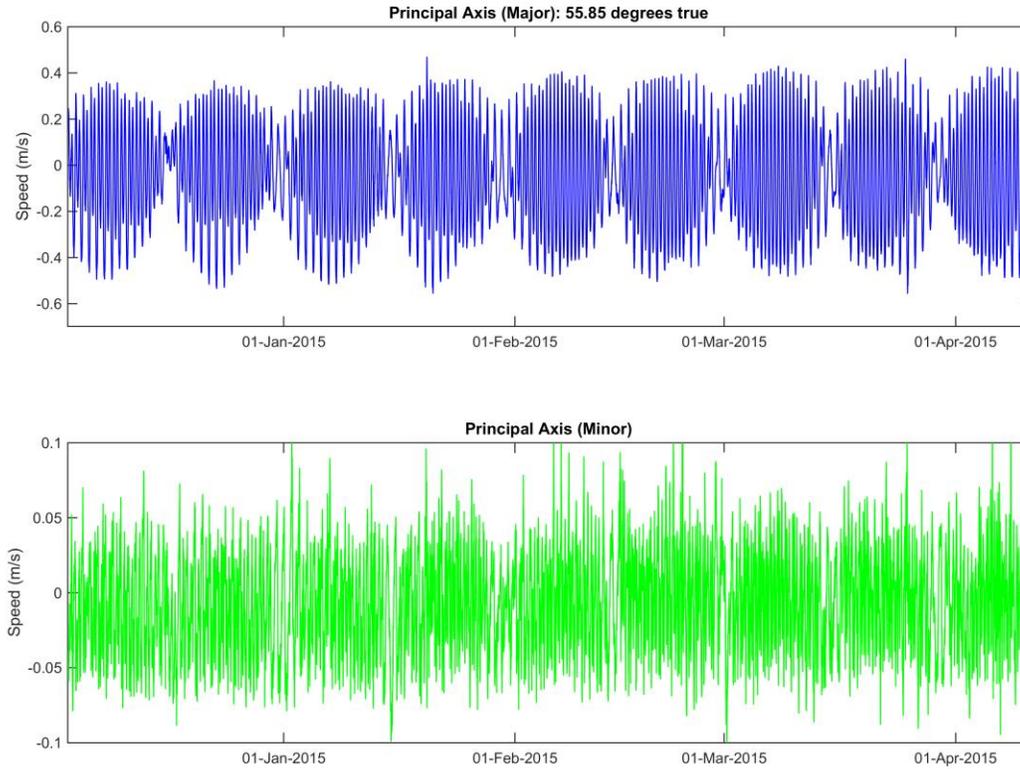


Figure 3.2 The raw depth-averaged ocean currents from the SARDI mooring as resolved along the major and minor principal axes and for the December 2014 to April 2015 period. Note the difference in the scale of the vertical axes for the major (0.6 m/s) and minor axis (0.1 m/s).

The observational results are also in reasonable agreement with those modelled using the “IS2” hydrodynamic model shown in Fig. 3.3. These model results were obtained at the Wallaroo West site (Fig 2.1) and the major axis is also directed in the along-isobath direction as illustrated in Fig. 2.1. For this model site, the major axis (positive values) is directed towards 51.6° clockwise from true north.

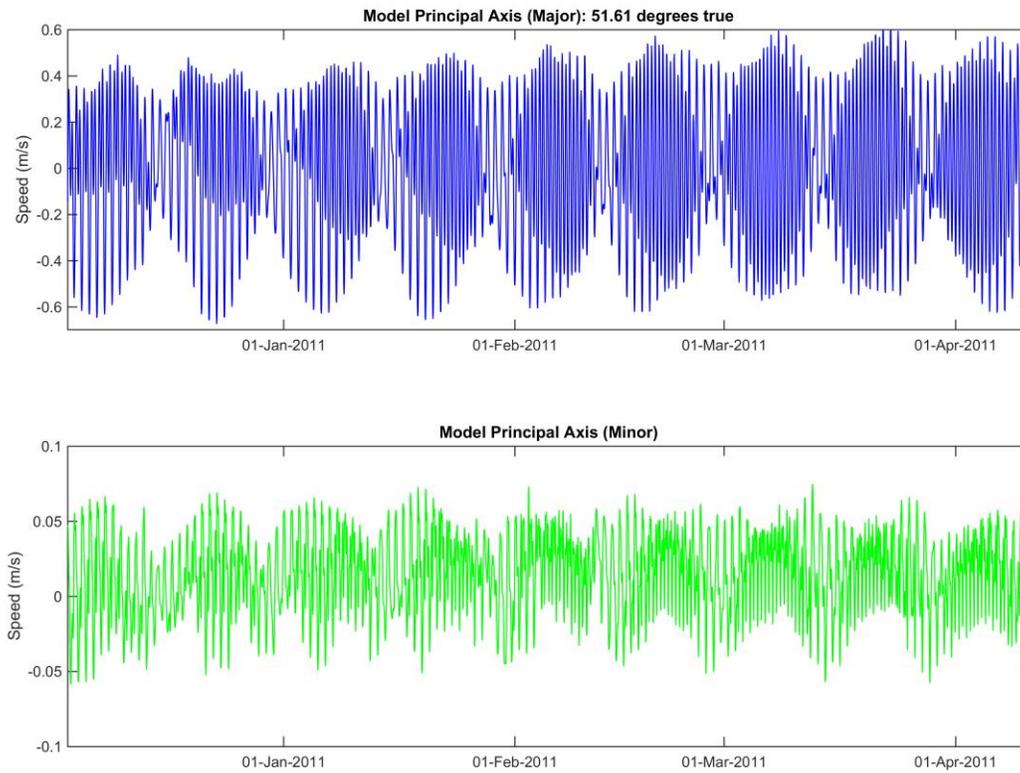


Figure 3.3 The modeled depth-averaged ocean currents from the IS2 Spencer Gulf model obtained for the Wallaroo West proposed lease site (Fig. 2.1). The currents were resolved along the major and minor principal axes and for the December 2010 to April 2011 period. Note the difference in the scale of the vertical axes for the major (0.6 m/s) and minor axis (0.1 m/s).

The vertical change or shear in the raw currents is indicated in Fig. 3.4 where plots of a selection of maximum currents along the major axis are presented as a function of depth and for each 1 m deep “bin”. The top 4 m of ADCP current data are excluded as these data are distorted by surface waves and changes in sea level. To avoid spurious acoustic returns, the first bin starts 2.1 m above the top face of the ADCP so no data are available between this bin and the sea floor (~ 18.5 m).

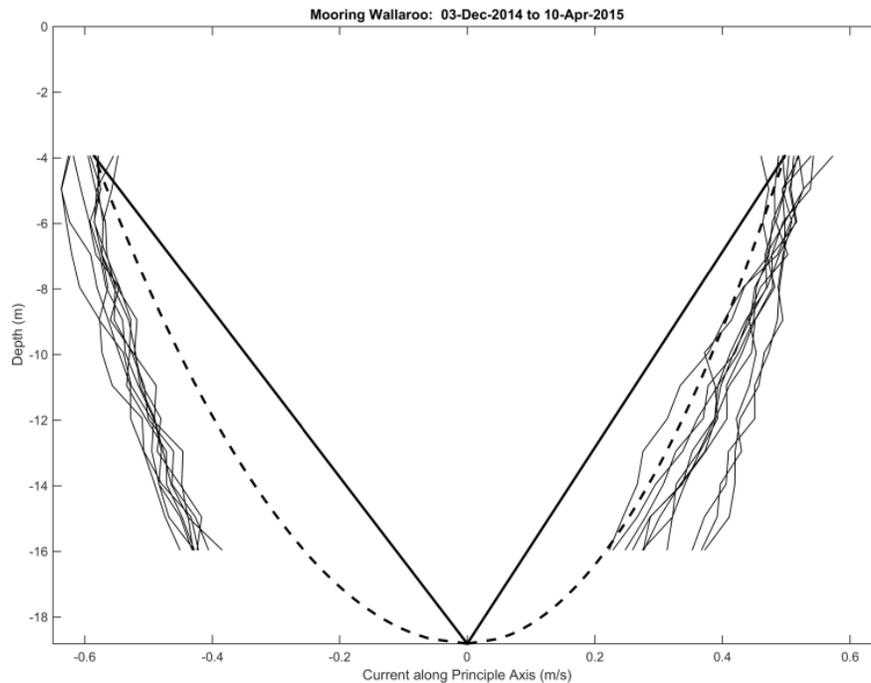


Figure 3.4 The vertical shear of selected maximum currents at 1 m bins as estimated from the ADCP (black thin lines). The bold solid and dashed lines indicate linear and parabolic models for vertical shear where friction is expected to bring currents to near zero at the sea floor.

The thin black line of current show maximum current speeds of 60 cm/s which drop to 30-40 cm/s at depths of 16 m. Below this depth, currents will be smaller and very small at the sea floor due to frictional effects. The solid and dashed lines represent simple linear and parabolic models for ocean current depth dependence and the latter (parabolic) gives a better representation of the data as also found by Middleton *et al.* (2013, 2014).

The vertical shear described above may be important in the deformation of aquaculture pens during periods of maximum current. It is also important in enhancing the horizontal diffusion of nutrients as shown by Middleton *et al.* (2013, 2014).

While the tidal currents are important, the longer period currents are also important to the flushing of nutrients for the region. A low pass filter that removes periodic signals of 3 days or less was applied to the raw current data in Fig. 3.2 and the results are presented in Fig. 3.5.

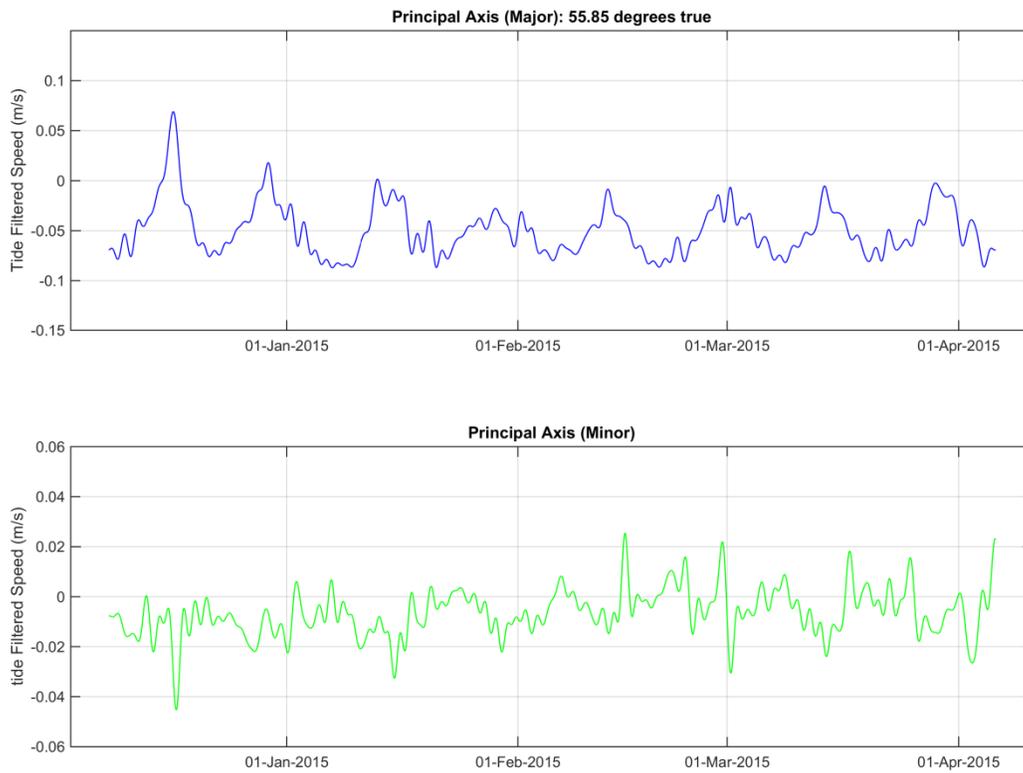


Figure 3.5 The (low-pass) filtered data illustrating signals of periods three days or more. The major axis (positive values) is directed towards 55.8° clockwise from true north. This direction approximately corresponds to the along-isobath direction shown in Fig. 2.1 and to the N.E. The minor axis is directed at right angle to the major axis and approximately to the S.E.

The 29 day period signal due to the dodge tide is still evident in the filtered major axis data along with other signals that are likely related to wind forcing and the thermohaline circulation. However, the filtered current magnitude is a factor of 10 smaller than the raw data (Fig 3.1; upper panel). The filtered minor axis data are smaller again compared with the major axis data. A summary of the mean and standard deviations of the raw and filtered major and minor axis data are presented in Table 1. Notably, the mean currents of both the raw and filtered major axis data are almost identical (5 cm/s).

Table 1 Statistics of the raw and filtered velocities (m/s) from the SARDI mooring and resolved along the major and minor axes. A positive major (minor) value corresponds to that directed approximately towards the north-east (south-east).

Velocity	Mean (m/s)	Standard Dev. (m/s)
Raw Major Axis	-0.050	0.230
Raw Minor Axis	-0.007	0.033
Filtered Major Axis	-0.049	0.026
Filtered Minor Axis	-0.007	0.009

Monthly averages of the major filtered currents were also obtained (not shown) and each indicates mean speeds of about 5 cm/s. This result is consistent with the clockwise circulation found elsewhere for the Gulf from observations and hydrodynamic models (Middleton *et al.* 2013). In addition, the correspondence between the direction of the major axis of the (slowly varying) filtered currents and the along-isobath direction shown in Fig. 2.1 is expected on dynamical grounds (e.g., Gill, 1982). This provides evidence that the direction of the isobaths is locally correct even though the depths are too shallow compared to that measured at the SARDI mooring site (18.5 m rather than 12 m).

3.3. Temperature

Observations of near bottom temperature were made from the ADCP and CTD and are almost identical as shown by the statistics in Table 2.

The plot of temperature in Fig. 3.6 shows the highest values (~ 23 °C) during the summer months (December to February), followed by a rapid cooling of 4 °C during autumn (March to April) to a value of 19 °C. A visual comparison with the filtered major current velocities (Fig. 3.4) does not indicate any strong correlation during weak (dodge) or strong mixing events associated with the tidal current maxima. Careful examination of the data in Fig. 3.6 shows the existence of predominantly diurnal (24 hr) signals (e.g., February 7th) of up to 0.5 °C, as well as mixed diurnal and semi-diurnal (12 hr) signals (e.g., around February 4th).

Table 2 Statistics of the raw and filtered near bottom temperatures ($^{\circ}$ C) from the SARDI mooring.

Bottom Temperature	Mean ($^{\circ}$ C)	Standard Dev. ($^{\circ}$ C)
Raw CTD	22.00	0.87
Filtered CTD	22.14	0.69
Raw ADCP	22.02	0.87
Filtered ADCP	22.16	0.69

The explanation of the diurnal signals is possibly due to daily summertime heating in conjunction with northerly winds: these winds will act to drive warmed surface waters towards the eastern coast where it may be downwelled and flow as a dense (salty) bottom current towards the site of the SARDI mooring. A more definitive explanation is beyond the scope of this data report.

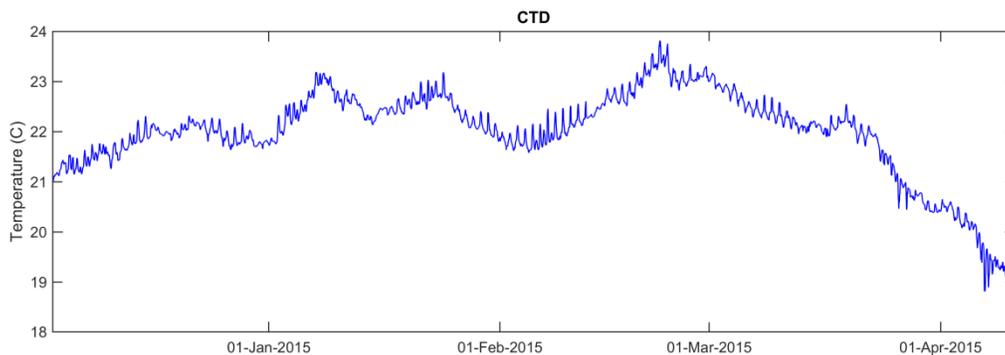


Figure 3.6 The raw near-bottom temperature as measured by the CTD on the SARDI mooring.

Finally, it is worth comparing the gross features of the bottom observed temperatures for 2014-2015 with the modelled surface temperatures for 2010-2011 (Doubell *et al.*, 2015). The latter are presented in Figure 3.7. At the beginning of December, the surface temperature from 2010 are around 22.5 $^{\circ}$ C and warmer than those at the bottom in 2014 by 1.5 $^{\circ}$ C. In the later summer months, the modelled surface temperatures are generally warmer than the 2015 observations, In both cases, the temperatures drop during the autumn period although the modelled temperature are still warmer than the 2015 observations by about 2 $^{\circ}$ C.

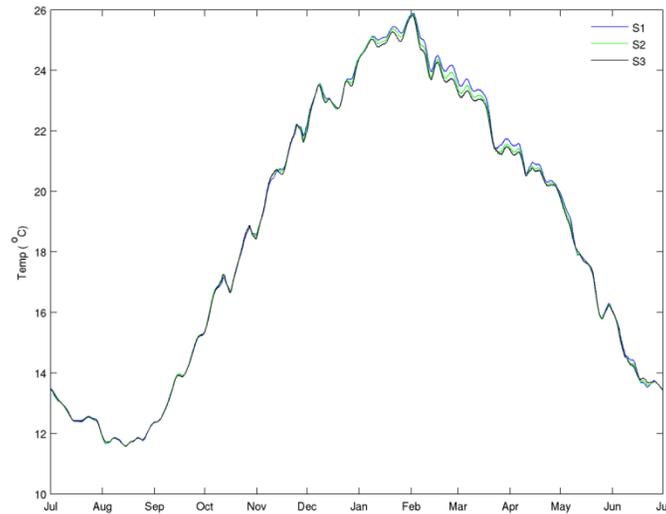


Figure 3.7 Simulated sea-surface temperature (°C) at the three sites proposed for YTK aquaculture in Wallaroo. See Figure 2.1 for site locations.

3.4. Fluorescence and Oxygen

Observations of near bottom fluorescence and dissolved oxygen concentrations were made from the moored CTD and are plotted in Fig. 3.8.

Fluorescence observations give a calibrated estimate of chlorophyll *a* concentration (chl *a*) which provides an indicator of the phytoplankton biomass ($\mu\text{g/l}$). Fluorescence values ranged from a maximum of $0.91 \mu\text{g/l}$ in the summer months (January to February) to a minimum of $0.22 \mu\text{g/l}$ during autumn (March to April) with a mean and standard deviation of $0.49 \pm 0.15 \mu\text{g/l}$ measured across the deployment period. Observed values compared well with reported model predictions for the corresponding time period under the control scenario (Doubell *et al.* 2015) with maximum, minimum and mean and standard deviation values of 0.73 , 0.42 and $0.51 \pm 0.07 \mu\text{g/l}$, respectively.

Dissolved oxygen concentrations measured as percentage saturation values (Fig. 3.8) decreased from a maximum of 99% during early summer (December) to a minimum of 61% in late March. Mean and standard deviation values of $81 \pm 9\%$ were measured across the deployment period with variability largely driven by diurnal temperature fluctuations and the tides. The high saturation values ($>85\%$) measured during December and January suggest a well-mixed and aerated water column. Decreased saturation levels ($<75\%$) measured across February to April indicates limited aeration of bottom waters due to water column stratification.

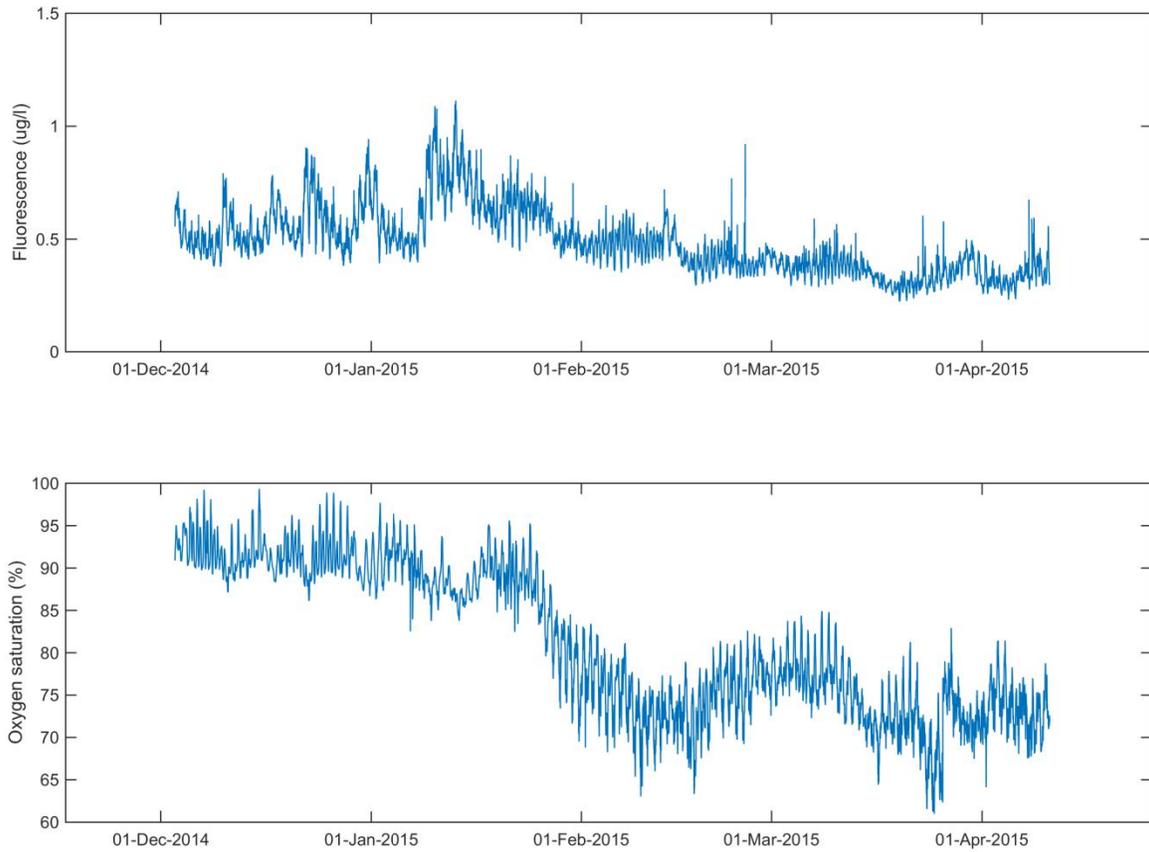


Figure 3.8 The raw near-bottom (top) fluorescence ($\mu\text{g/l}$) and (bottom) dissolved oxygen saturation (%) concentrations as measured by the CTD on the SARDI mooring.

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