# Environmental Research in Macquarie Harbour

FRDC 2016/067: Understanding oxygen dynamics and the importance for benthic recovery in Macquarie Harbour

PROGRESS REPORT

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## EXECUTIVE SUMMARY

This report provides an update on the status of dissolved oxygen (DO) and benthic conditions in Macquarie Harbour. It follows on from the results outlined in the IMAS reports released in January, May, September 2017 and January 2018. These reports described a deterioration of benthic and water column conditions in Macquarie Harbour in spring 2016, early signs of faunal recovery observed in May 2017 and a subsequent decline in benthic conditions in spring 2017 when oxygen concentrations in middle and bottom waters returned to very low levels. Oxygen concentrations in the middle and bottom waters have since improved through the summer of 2017/18 due to recharge events that commenced in late spring 2017. This report presents the results and preliminary interpretation of a repeat survey of benthic communities in January 2018 and DO monitoring data up until the beginning of May 2018. This work is part of the research project (FRDC Project 2016-067: Understanding oxygen dynamics and the importance for benthic recovery in Macquarie Harbour to address these needs) funded by the Fisheries Research Development Corporation with the support of both industry and government (EPA and DPIPWE); the scope and funding for the project was recently extended for a further two years (until April 2020).

In mid-October 2017 DO concentrations had returned to the very low levels experienced in spring 2016, albeit for a shorter duration, and we again observed a decline in benthic fauna. This decline was predominately in the deeper central region of the harbour with no concomitant decline evident in the faunal abundance and number of species at the majority of external sites. Oxygen recharge events from late spring 2017 through summer 2018 have led to improved DO levels in middle and bottom waters. These events are most notable in early November 2017, early January 2018 and in mid-March 2018.

The oxygen recharges that commenced in November 2017 and January 2018 again appeared strongly tied to higher salinity at the surface, and hence lower river flow. During these conditions the denser more saline oxygenated oceanic water passes over the sill and enters the bottom waters of the harbour. In late summer and early autumn we have also seen a number of oxygen recharge events that appear more closely linked to the meteorological conditions of extended strong west to north-westerly winds and low atmospheric pressure. These oxygenation events are more evident through the top of the water column as the strong winds effectively mix the water column. This was most notable in mid-March when the mixing extended through much of the water column and the elevated oxygen concentrations have been more sustained.

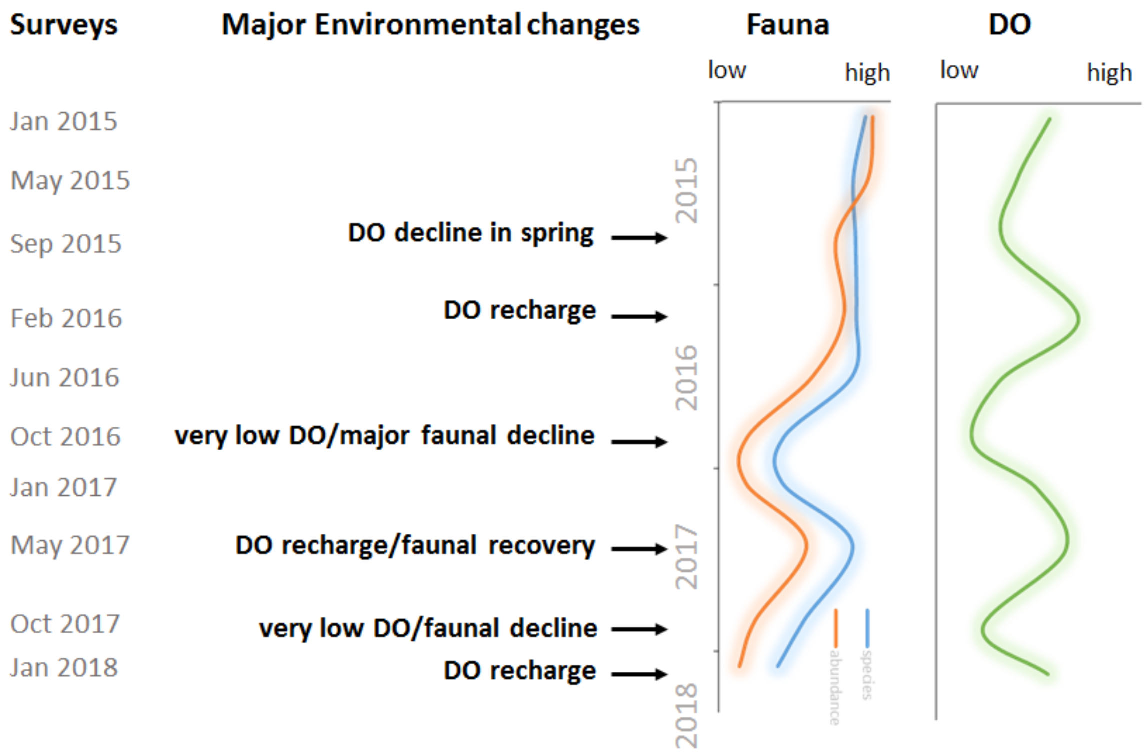
In the October 2017 survey we reported that the early signs of recovery in benthic fauna across lease sites observed in May 2017 had declined, concomitant with the return of very low DO concentrations. Faunal abundances had returned to levels similar to those observed in the October 2016 and January 2017 surveys. The number of species recorded also decreased but not to the same extent. In the January 2018 survey there was little change from October 2017 in faunal abundance and number of species recorded at most of the leases, except at the more southern leases where there had been a further decline. At the majority of external sites (>1km from the leases), the improvements seen in May 2017 remained in October 2017; there has been little further change in January 2018. At the deeper external sites to the south, faunal abundances continue to remain low relative to observations prior to the noted decline in spring 2016 – early 2017, although there has been some improvement at the shallowest of these sites.

The May and October 2017 video surveys indicated a clear reduction in the presence of *Beggiatoa* at both lease and external sites compared to the October 2016 and January 2017 surveys. In the January 2018 video survey there was an increase in the number of dives that *Beggiatoa* was observed on, but this reflected more observations of patches of *Beggiatoa* at lease sites and fewer observations of *Beggiatoa* forming extensive mats relative to the previous two surveys. At the external sites, *Beggiatoa* was observed at the same number (2) of the 28 sites in the January 2018 survey as it was in the September 2017 survey, which is significantly fewer than reported in January 2017 and October 2016. The January 2018 ROV has also seen a reduction in the number of sites where Dorvilleid polychaetes were observed; there also appears to have been a reduction in the

number of sites with very high Dorvilleid scores (>300 abundance categories).

With a sustained period of recharge over summer and early autumn, it will be important to see whether there is again a return of higher faunal abundances and number of species in our next survey scheduled for June. Ultimately though, as we remarked in the previous report, sustained faunal recovery in the deeper central region will most likely depend on the return of more stable and higher DO concentrations in the mid-bottom waters of the harbour throughout the year.

For a timeline of the major environmental events observed over the course of this study, the following schematic highlights changes in benthic faunal communities and bottom water dissolved oxygen (DO).



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## BACKGROUND

In light of deteriorating benthic conditions in Macquarie Harbour, and in particular the very low dissolved oxygen (DO) levels observed in the middle and bottom waters in spring 2016, the Institute for Marine and Antarctic Studies (IMAS) prepared a report for the Environment Protection Authority (EPA) and Department of Primary Industries, Parks, Water and Environment (DPIPWE) on the science and current status of the benthic and water column environments in Macquarie Harbour (Ross & Macleod 2017a). That report summarised the environmental research and observations from Macquarie Harbour and presented the latest observations of the benthic ecology and water column conditions in the context of the collective information.

A key observation from that report was the major decline in the total abundance and number of species collected from the benthic fauna in the spring (October 2016) survey compared to previous surveys. The increase in *Beggiatoa* bacteria mats on the sediments in and around marine farming leases in the spring 2016 ROV compliance surveys provided further evidence of deteriorating sediment conditions. This deterioration in sediment conditions was shown to coincide with very low DO concentrations in bottom and mid waters of the harbour. However, the decline in benthic fauna and DO (bottom and mid water) was not uniform through the harbour. The lowest levels of DO and the greatest changes in fauna occurred at sites in the mid- and southern end of the harbour, with the sites closer to the harbour entrance and the ocean appearing to be less affected; this pattern was observed at both lease and external (harbour-wide) sites.

This review formed part of the information used by the EPA to support their decision to enforce fallowing of multiple cage sites across the harbour. A key challenge facing farmers and regulators is understanding and predicting the length of fallowing required for benthic recovery in this system specifically. This also has major implications for future stocking plans in the harbour. It is clear that DO concentrations have been, and will be, a major determinant of the benthic response over the coming months and years. As such, there is a clear need to better understand the drivers of oxygen dynamics, the influence of DO concentrations on benthic conditions and the effectiveness and duration of fallowing and remediation strategies. With a strong commitment from both industry and government, the Fisheries Research Development Corporation (FRDC) funded project FRDC 2016-067: Understanding oxygen dynamics and the importance for benthic recovery in Macquarie Harbour to address these needs. This information is essential for both operational management of farming activities and the sustainable management of the harbour over the longer term. Recently, the scope (see below) and funding for the project was extended for a further two years (until April 2020).

FRDC 2016-067 comprises three work packages that together will provide a much clearer understanding of both the effectiveness of fallowing and passive remediation for benthic recovery, and the drivers and importance of oxygen dynamics for recovery. Work package 1 (WP1) will assess benthic recovery over time, building on the 6 previous surveys, which documented benthic conditions up until the major decline in faunal abundance and diversity observed in October 2016, with repeat surveys of all lease and external sites every 4[1] months. Work package 2 (WP2) will see the further development of the real time DO observation network in the harbour. This includes deployment of:

i. three vertical strings of acoustic (real-time) DO sensors in the central region of the harbour,
ii. a profiling mooring located at the deepest part of the main basin, and
iii. two additional logger strings (not real-time) to extend the observation network further south (inside the WHA) and north (close to the entrance to the ocean).

The third work package (WP3) involves the further development of the CSIRO Near Real Time (NRT) Hydrodynamic and Oxygen Transport model to better describe the physical drivers of Macquarie Harbour circulation, stratification, mixing and DO drawdown and recharge. In early

[1] In the 2 year extension the benthic surveys will be conducted twice a year

2018 funding for this project was extended for a further two years. This includes all three work packages described above plus the addition of a fourth work package that will see the installation of new river and tide gauges and mapping of nutrient and microbial dynamics in the harbour; information that will allow for the biogeochemical implementation of CSIRO's model to further resolve and quantify the biological and chemical contribution to oxygen dynamics in the harbour.

This report provides an update on environmental conditions in Macquarie Harbour based on the most recent benthic surveys conducted in summer 2018 and water column observations up until early May 2018.

## WATER COLUMN CONDITION

In Ross & MacLeod (2017a) we provided an overview of DO observations in the harbour since the early 1990s and outlined the steady decline observed in bottom and mid-waters since 2009 (Figure 1). In spring 2016 DO concentrations were extremely low throughout the harbour; in fact the lowest on record. Whilst a range of independent data sets confirmed this observation the Sense-T environmental strings provided the most detail on the evolution of these DO levels through the centre of the harbour. These strings provided real time data on DO and temperature changes throughout the water column at three farm sites along the centre of the harbour; Table Head Central closest to the influence of the ocean, Franklin near the boundary of the World Heritage Area (WHA), and Strahan, a site midway between the two (Figure 2). These three strings were refurbished and updated with the latest technology in early June 2017 and the observation network extended further south and north, with additional delayed mode data loggers deployed on a string inside the WHA to the south and on a string in the King River Basin in the north (see Figure 2). These additional strings provide important insight into the influence of boundary conditions (e.g. Gordon River and the ocean).

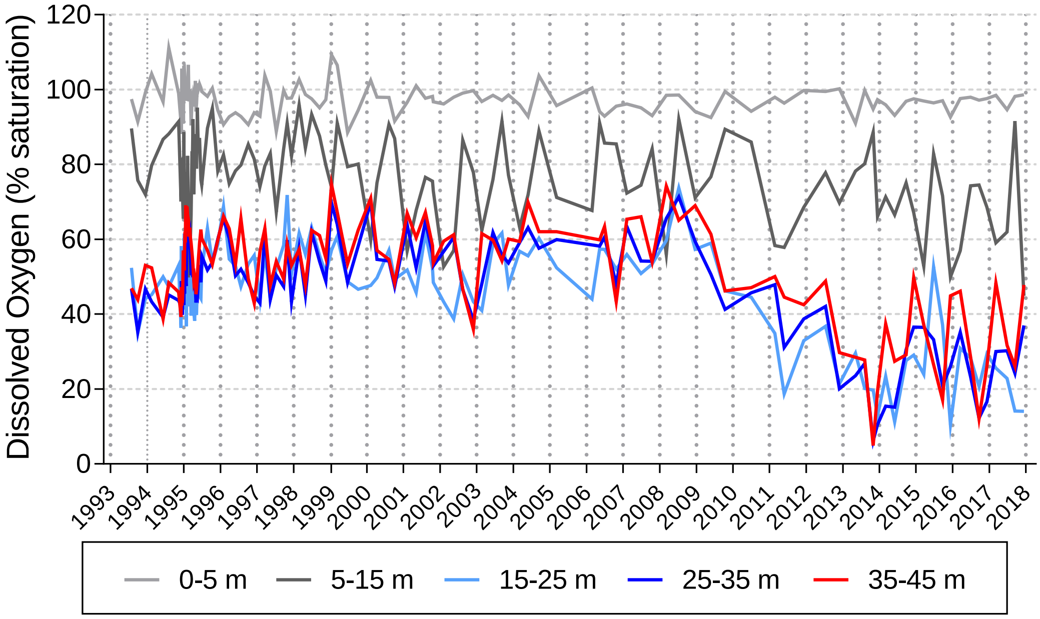


Figure 1 Long term trend in DO within a number of depth ranges at EPA site 12 (updated from MHDOWG 2014).

The contour plots produced from the three real time strings have been updated to include data up until early May 2018 (Figure 3-5). These figures demonstrated the decline in bottom water DO concentrations in spring 2017 to the very low levels experienced in spring 2016, and subsequent recharge and replenishment of bottom waters from early November 2017. The replenishment of bottom water oxygen levels coincided with low river flows, as evidenced by increased surface water salinities, and the incursion of oxygenated oceanic water over the shallow sill at the entrance to the harbour (Figure 6 & 7). Oceanic recharge of the bottom waters appears to have continued through the rest of summer as river flows remained relatively low.

In late summer/early autumn 2018, there were a number of notable wind driven oxygenation events of the water column. In mid-February (~14$^{th}$), mixing of the water column was observed concomitant with a period of strong west to north-westerly winds and low atmospheric pressure (Figure 8). The top down wind driven nature is evident at all three strings with DO concentrations increasing in the top 10m (Figure 4 & 5). At the Table Head Central site, the mixing event caused a momentary (~2-3 hours) drop of DO to less than 50% saturation throughout the entire water column before the halocline quickly re-established (Figure 9). In mid-March (~18-20$^{th}$), there was a far more significant wind driven event that saw the mixing and oxygenation of the entire water column (Figure 9). This is clearly evident in all of the oxygen figures below, and notably in Figures 6 & 7 where it is evident that surface salinities momentarily reach 25 ppt.


Figure 2 Map of Macquarie harbour showing location of the environmental strings. The yellow sites provide data in near real time and the red sites use delayed mode data loggers. The CSIRO profiling mooring is directly adjacent to the Strahan environmental string.

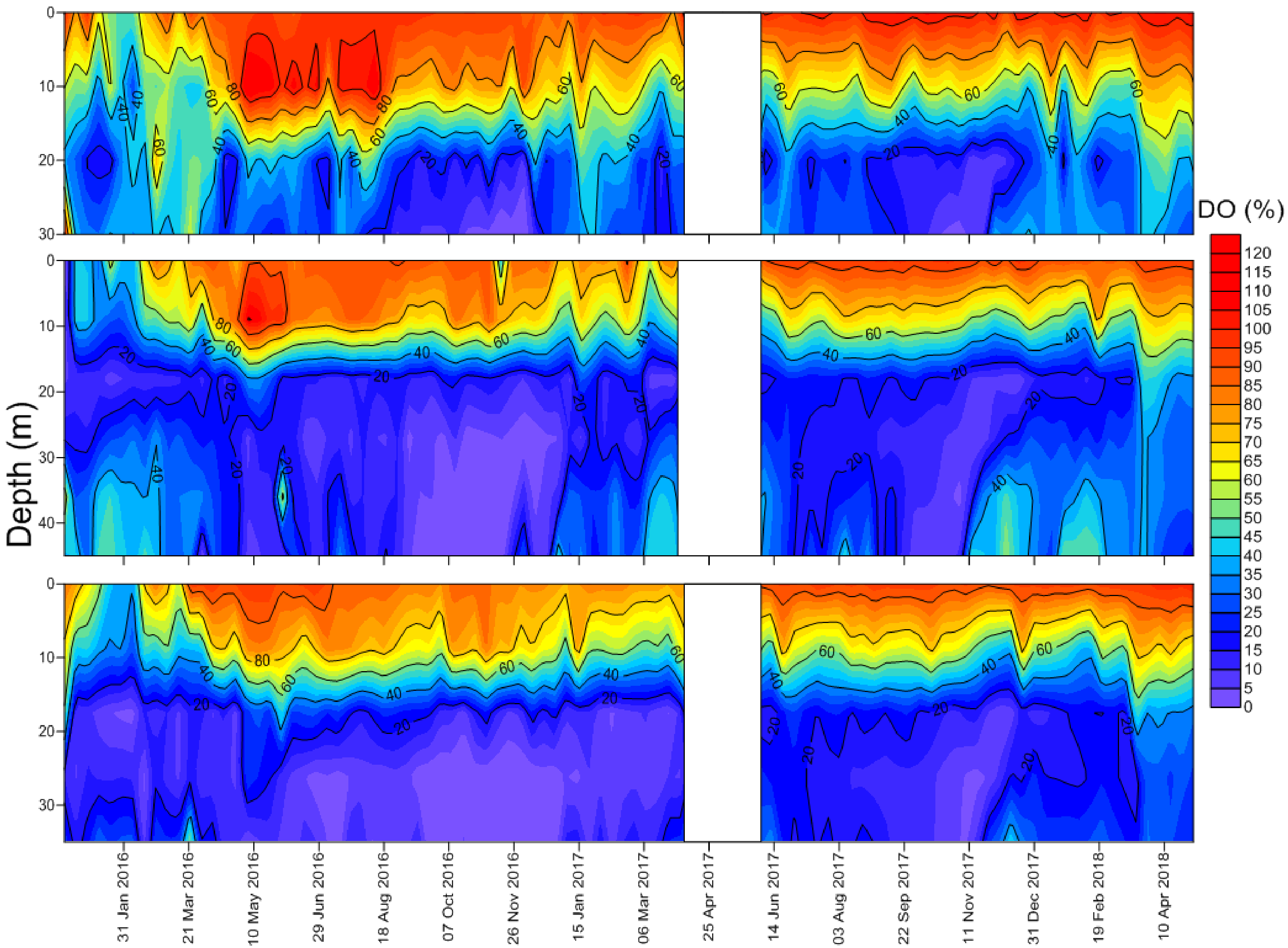


Figure 3 Contour plots showing DO profiles through the water column from the environmental strings at Table Head Central (top panel), Strahan (middle panel) and Franklin (bottom panel) over the period from December 2015 to late April 2018. Note, the data that underpins these plots for the period Dec 2015 to April 2017 is from the environmental sensors deployed under the Sense-T project. The sensors and associated infrastructure were replaced and updated in June 2017 as part FRDC project (FRDC 2016-067).

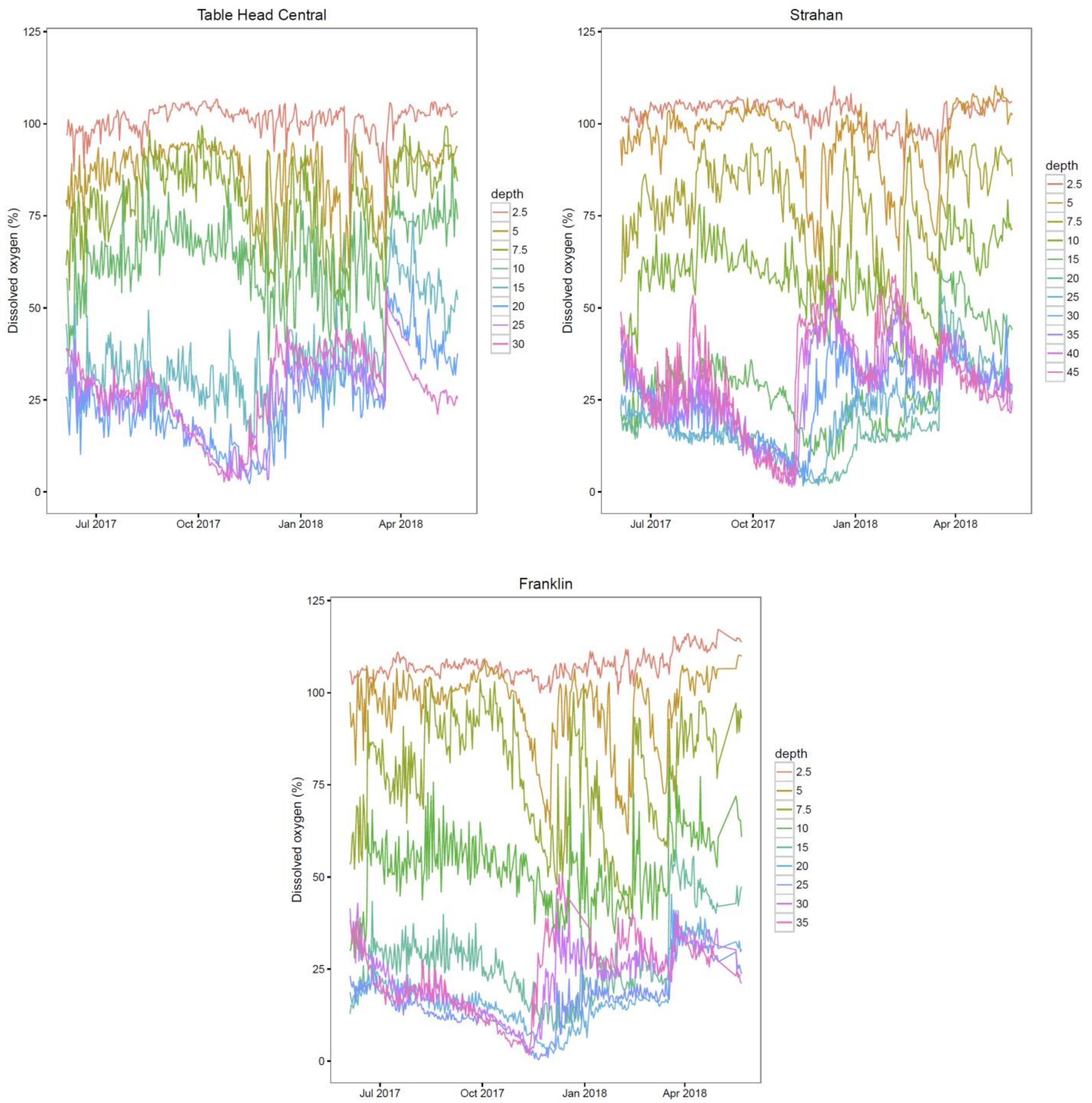


Figure 4 Daily mean DO (% saturation) levels at sensor depths from strings at Table Head Central, Franklin and the World Heritage Area over the period from the beginning of June 2017 to early May 2018.

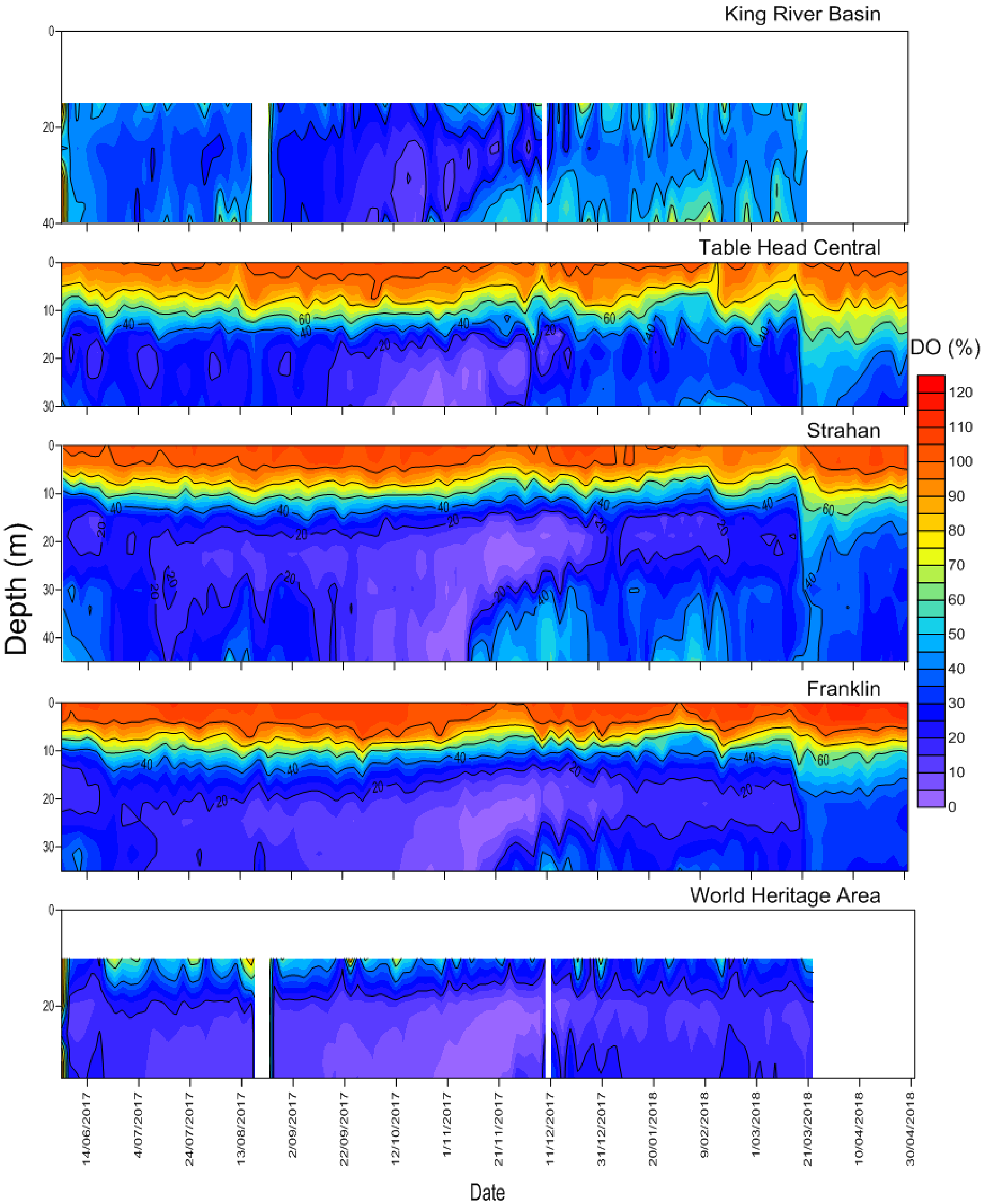


Figure 5 Contour plots showing DO profiles through the water column from the environmental strings at King River Basin, Table Head Central, Strahan, Franklin and the World Heritage Area over the period from the beginning of June 2017 to the early January 2018. This represents the data from the upgrade to the three near real time strings and the two additional strings deployed as of part FRDC project (FRDC 2016-067). Note, the two additional strings don't measure to the surface because they are in high traffic waters.

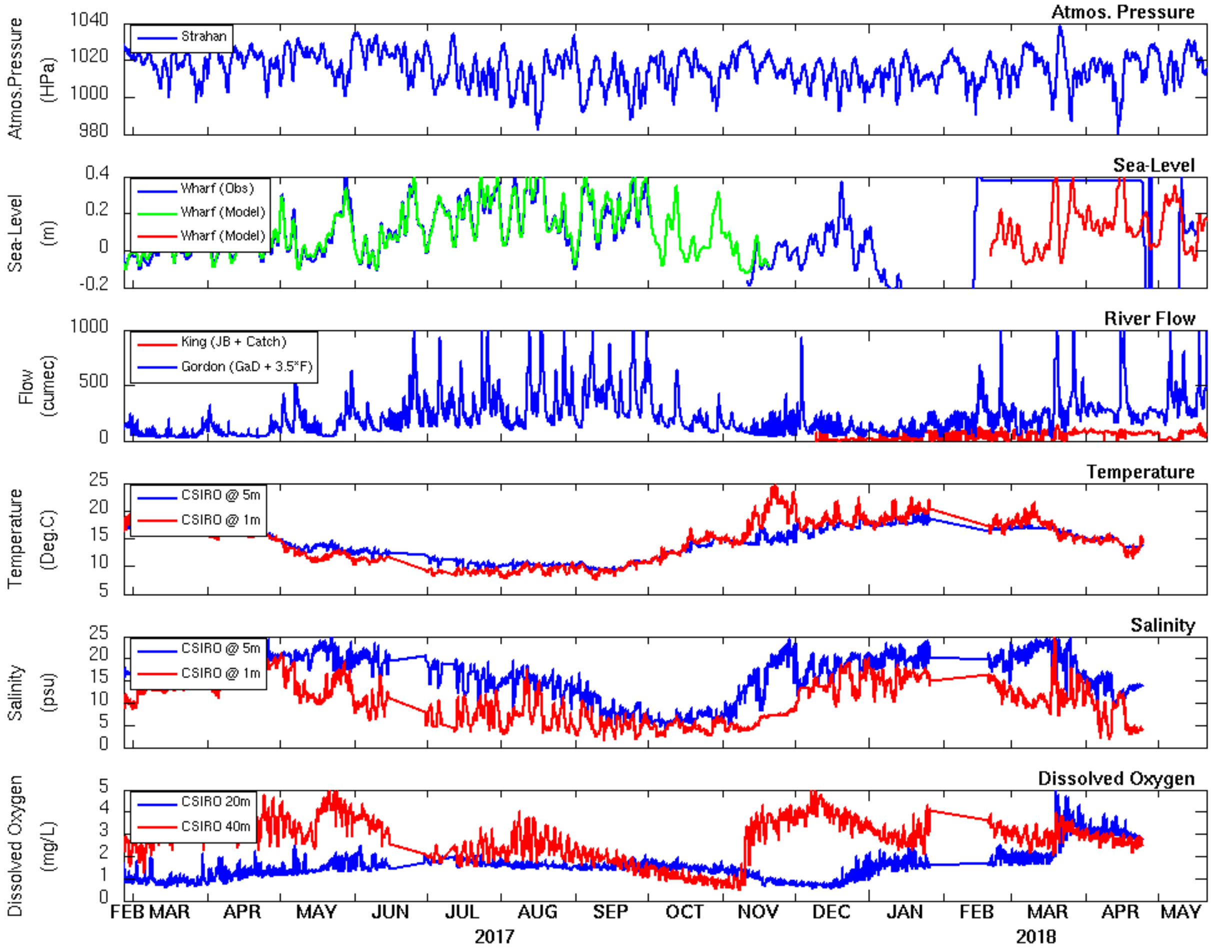


Figure 6 Time-series of concurrent environmental phenomena which may suggest favourable conditions for oxygen recharge.

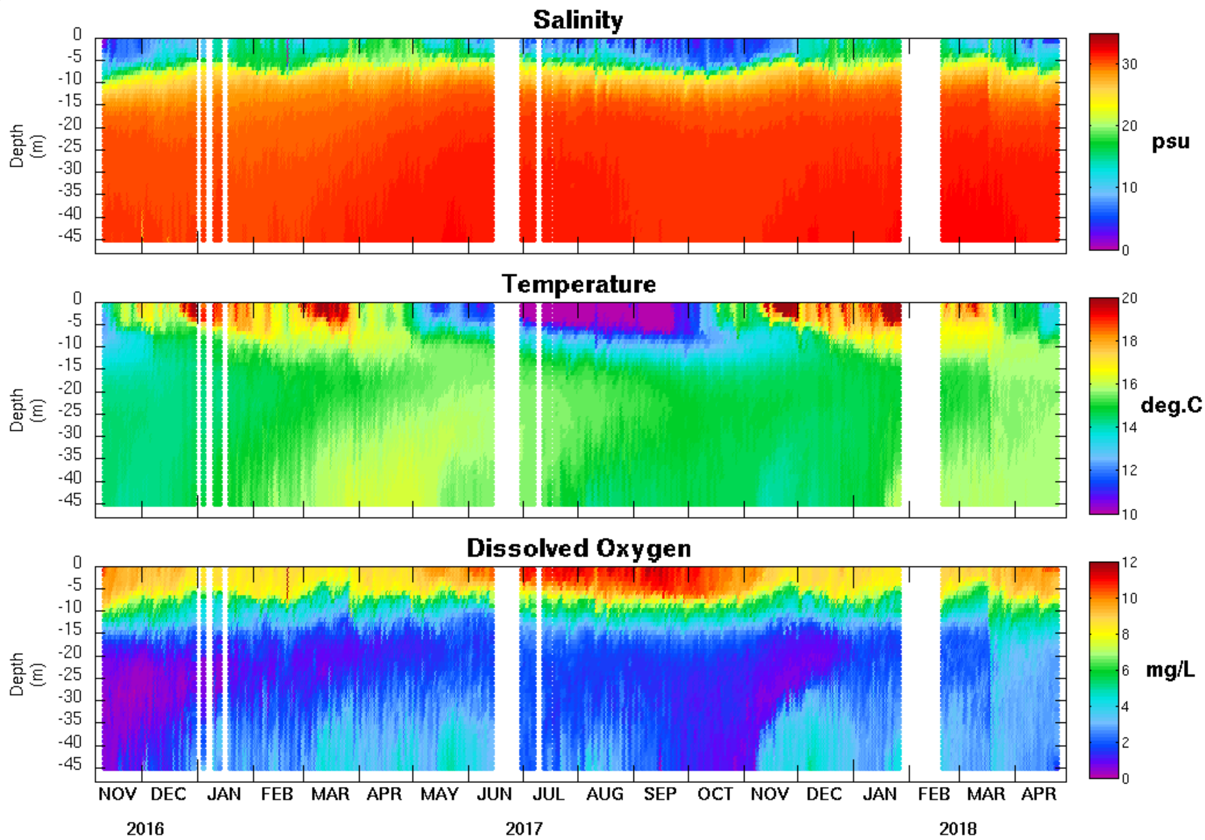


Figure 7 Observations from the CSIRO profile mooring showing the temporal change of water column salinity, temperature and dissolved oxygen concentration for the full deployment. Profiling operations were suspended (i.e. the gaps in the figure) during very rough weather to avoid entanglement, and on a few occasions to enable platform maintenance.

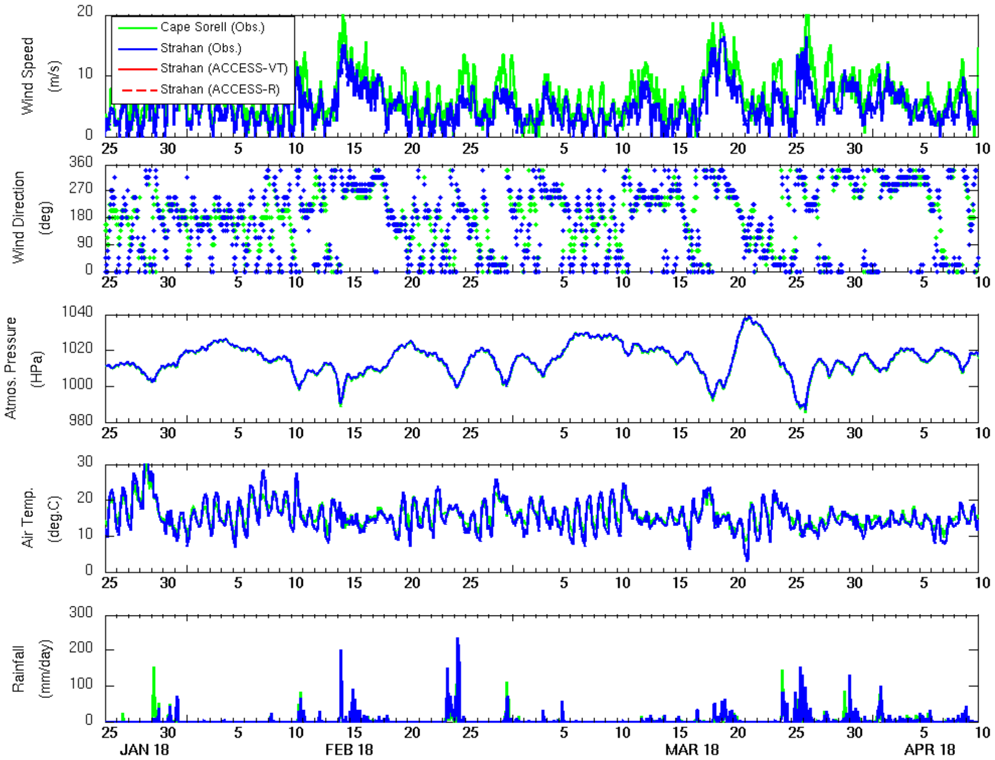


Figure 8 Time-series of Macquarie Harbour meteorological data in early 2018.

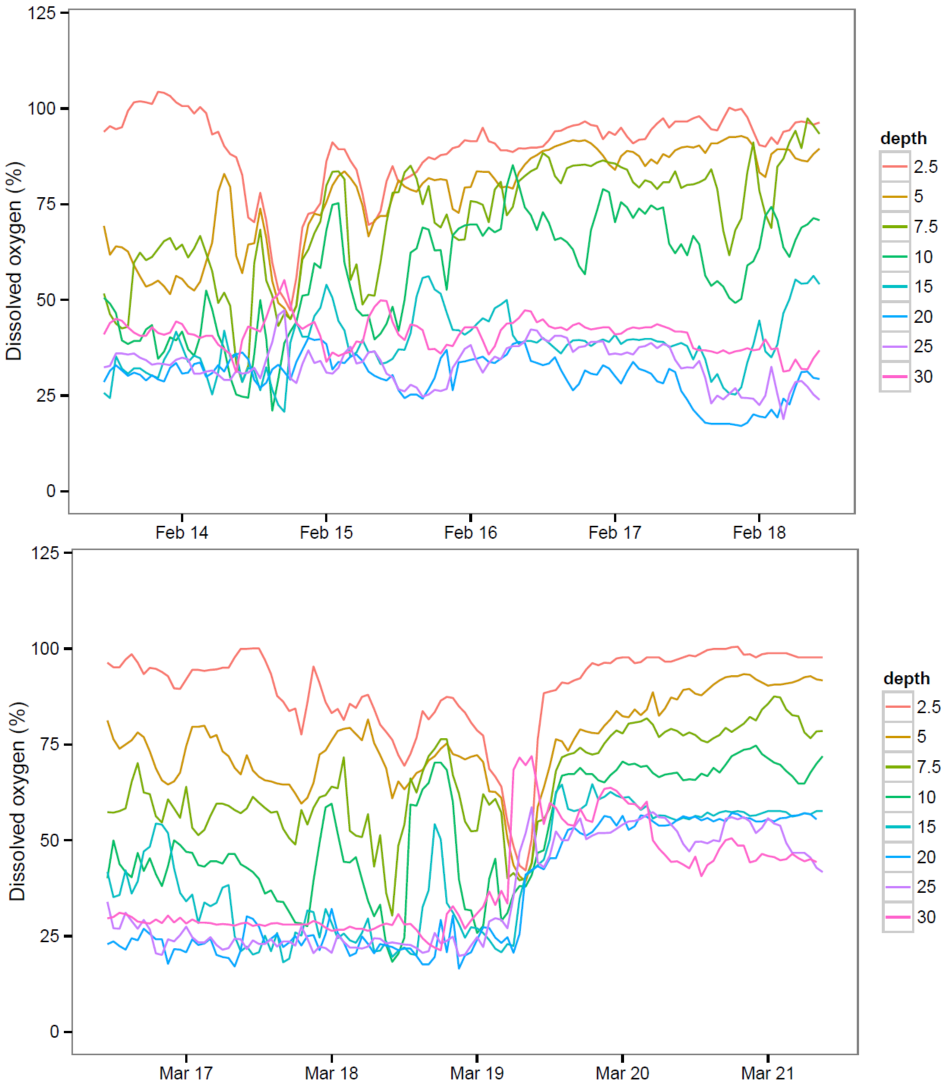


Figure 9 Dissolved oxygen concentrations (% saturation) at sensor depths on the Table Head string during mid-February and mid-March wind driven mixing events.

## BENTHIC CONDITION

In January 2018, IMAS conducted a benthic survey of five leases and 24 external sites as part of FRDC 2016-067 (Figure 10, Table 1). This represents the 10th benthic survey conducted under consecutive FRDC projects (FRDC 2014-038, FRDC 2015-024, FRDC 2016-067) since the beginning of 2015. The work was initiated (via. FRDC 2014-038) when video footage identified an increase in abundance of Dorvilleid polychaetes. In addition, it was noted that there were two Dorvilleid species in the video footage and given that these species were used as indicators of enrichment it was felt that it was important to understand the distinction between these two species and whether their environmental responses were comparable. FRDC 2014-038 identified four sites (leases) for assessment. FRDC 2015-024 was commissioned to review the effectiveness of current monitoring protocols in new farming areas (i.e. Macquarie Harbour and Storm Bay in Southern Tasmania), and undertook a broader suite of sampling at the same sites (leases) employed in project 2014-038. The major decline in the abundance and number of species of benthic fauna observed in October 2016 was the final survey of the Macquarie Harbour component of FRDC 2015-024 but it was felt that it was important to extend the research to assess benthic recovery and the effectiveness of fallowing, and as such FRDC 2016-067 was initiated. FRDC 2016-067 extended the benthic sampling to include an additional lease (lease 5) and more external sites[2].

Table 1 Benthic survey details

| Survey | Survey period | Reference in report | Study |
|---|---|---|---|
| 1 | 6/1/2015 - 30/01/2015 | January 2015 | FRDC 2014-038 |
| 2 | 25/5/2016 - 4/06/2016 | May 2015 | FRDC 2015-024 |
| 3 | 8/9/15 - 18/9/2015 | September 2015 | FRDC 2015-024 |
| 4 | 9/2/2016 - 18-2-2016 | February 2016 | FRDC 2015-024 |
| 5 | 31/5/2016 - 21/06/2016 | June 2016 | FRDC 2015-024 |
| 6 | 11/10/2016 - 3/11/2016 | October 2016 | FRDC 2015-024 |
| 7 | 17/1/2017 - 16/2/2017 | January 2017 | FRDC 2016-067 |
| 8 | 16/5/2017 - 7/6/2017 | May 2017 | FRDC 2016-067 |
| 9 | 10/10/2017-25/10/2017 | October 2017 | FRDC 2016-067 |
| 10 | 16/01/2017-25/01/2017 | January 2017 | FRDC 2016-067 |

In the May 2017 survey we observed signs of benthic faunal recovery in both abundance and number of species collected relative to the previous two surveys (Figure 11-14). However, the magnitude of recovery varied between leases; the faunal abundance at study leases 2 and 4 were consistent with levels observed prior to the faunal decline observed in October 2016, whilst the abundances at leases 1 and 3 appeared to have recovered to some extent, but not yet to levels equivalent to those prior to the faunal decline (October 2016). At the external sites (> 1km from leases) we have previously noted that the greatest area of faunal decline in October 2016 was in the deeper central region of the harbour, with relatively little change occurring in the shallower regions around the margins of the harbour. In the May 2017 survey we found that faunal abundance and species number had increased at many of the sites and/or was within the range recorded historically; albeit the increase was smaller at the deeper southern sites.

The results of the October (spring) 2017 survey showed that there had been a subsequent decline in both the abundance and number of species of benthic fauna at lease sites following the recovery

[2] All external sites are at least 1km from active leases and allow comparison of benthic changes in the harbour as a whole alongside changes associated with farming, and provide a means to assess temporal changes in benthic ecology.

observed in May 2017. This coincided with the return of very low DO concentrations in bottom waters throughout the harbour in spring 2017. In the January 2018 survey, DO concentrations in bottom waters had returned to much higher levels at all of the leases, but there was little change observed in the benthic fauna from that seen in October 2017. It is important to note that at the same time last year, there had also been little change in fauna following the decline in the preceding spring, and it wasn't until the May 2017 survey that signs of recovery were observed.

At lease 4, the northern most of the study leases, total abundance and number of species remained relatively unchanged from that observed in October 2017 (Figure 11). This was the site which had the smallest faunal decline in both spring 2016 and 2017. A similar pattern was observed at lease 3 with little change evident in either total abundance or number of species from that observed in October 2017 (Figure 12Figure 11). At lease 2, there was a marked decline in total abundance and number of species recovered from samples at all distances from the cage between October 2017 and January 2018, with the levels in January 2018 lower than those observed during the faunal decline in spring (October 2016) (Figure 13). Lease 1 – which is the most southern lease has also seen a further decline in the total abundance and number of species since the October 2017 survey (Figure 14). However, in this case the decline was not to the level observed in the previous spring (October 2016). This lease was completely fallowed just prior to the May 2017 survey, consequently it would seem likely that the return to very low DO concentrations in spring 2017 has played a significant role in the observed faunal decline at this lease. Although bottom DO levels at this lease weren't as low in October 2017 as they were in the October 2016 survey (Figure 14), the continuous data from the Franklin string shows that there would have been sustained periods of very low DO at this lease (Figure 3 and 4).

At lease 5, the distinct differences between the two transects for this lease were again evident (Figure 15) with a general trend of higher abundances and more species on the shallower SE transect as compared to the deeper NW transect. The deeper NW transect tending to reflect the more enriched conditions known to occur on that side of the lease. In the January 2018 survey the total abundance and number of species remained relatively unchanged on the NW transect, but had declined at the intermediate distances (i.e. 50-250m) from the cage on the SE transect compared with the October 2017 survey.

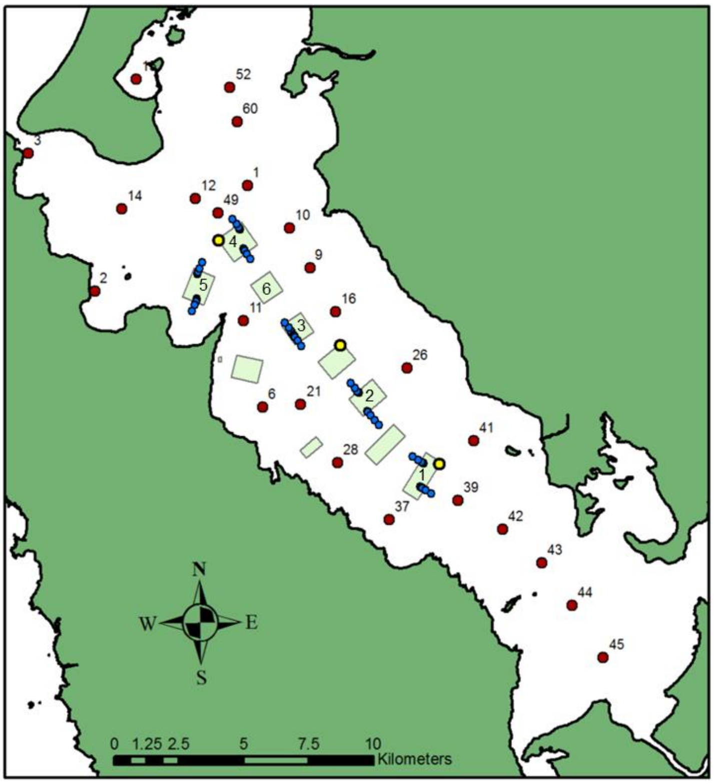


Figure 10 Maps showing external (red), lease (blue) and environmental string (yellow) sites. There are 2 transects from each of the study leases with five sites (at 0, 50, 100, 250 and 500m) on each transect.

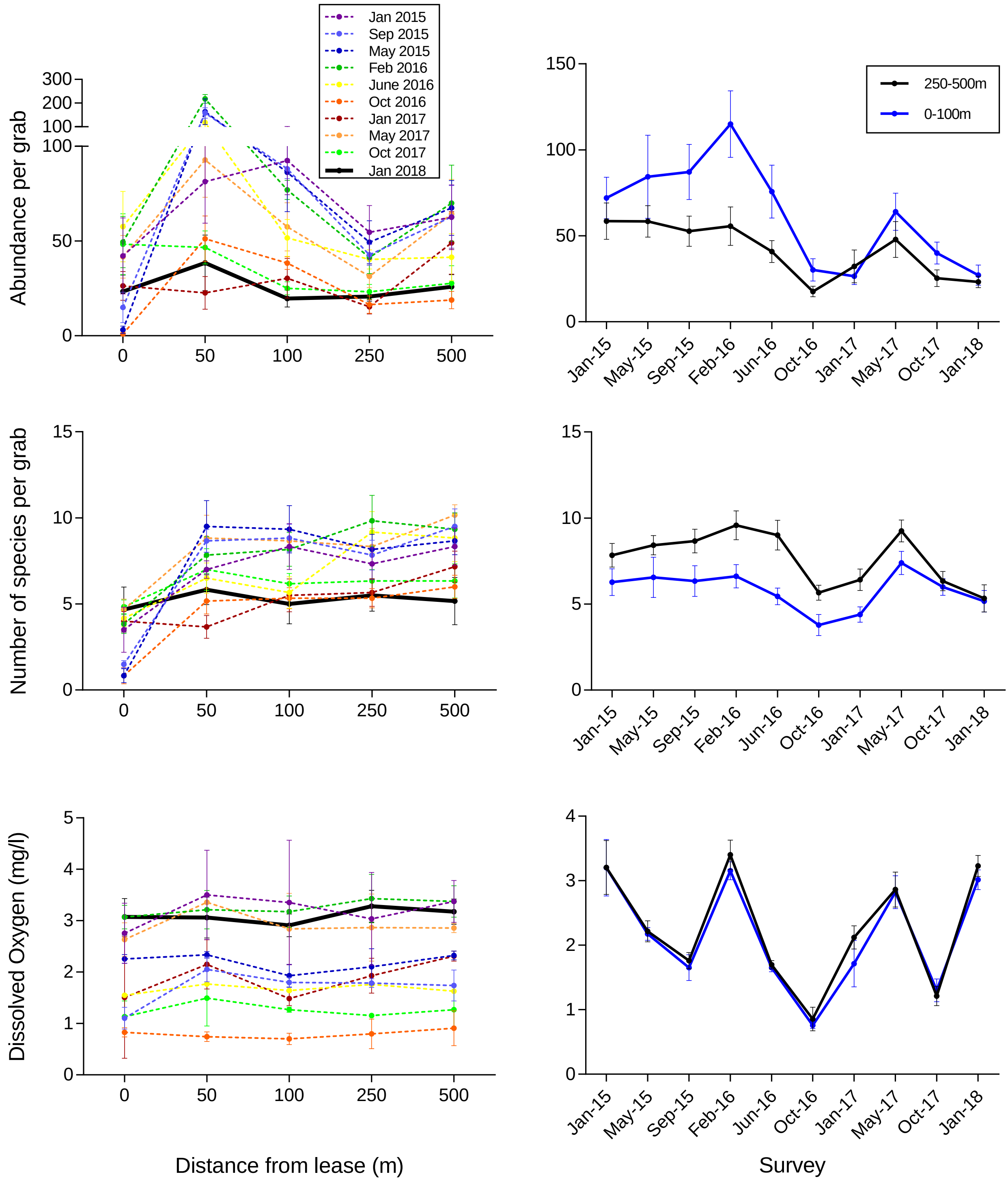


Figure 11 Lease 4 plots of total infaunal (>1mm) abundance (per grab = ~ 0.0675m²; top panel), number of species collected in grabs (n=3; middle panel) and the dissolved oxygen (mg/L) overlying the bottom (bottom panel) in relation to 1 (left panels): distance from the cage (0, 50, 100, 250 and 500m from cages) for each survey, and 2 (right panels) survey date with data pooled into 2 distance categories (i.e. those closest: 0, 50 and 100m sites pooled and more distant: 250 and 500m sites pooled). In the left hand panels the data represents the mean (±SE) from two transects that radiate out from cages on opposite sides of the lease, and in the right hand panels the data represents the mean (±SE) from the two transects for each distance category. In the left hand panels the last survey (Jan 2018) has been highlighted with a solid black line.

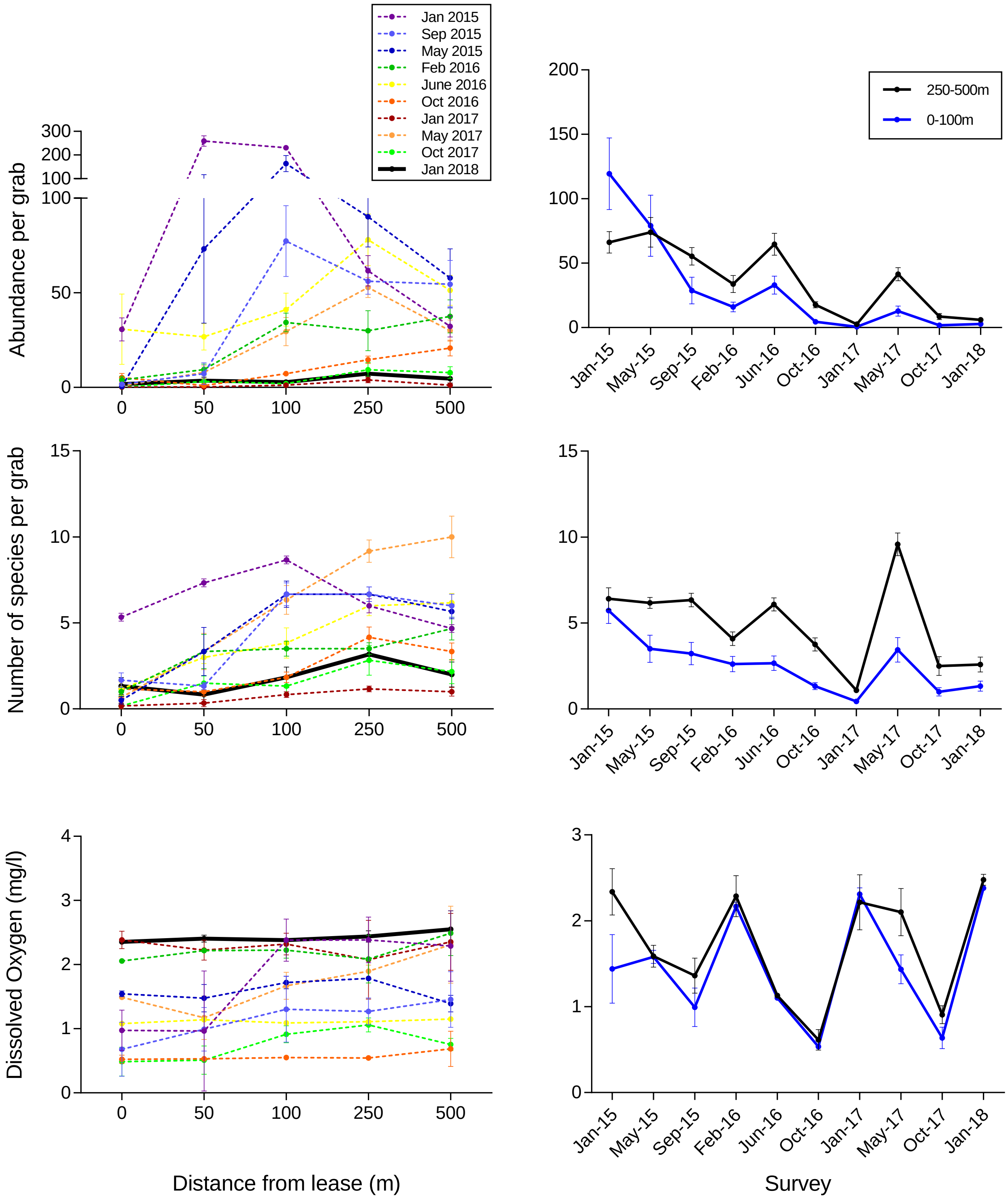


Figure 12 Lease 3 plots of total infaunal (>1mm) abundance (per grab = ~ 0.0675m²; top panel), number of species collected in grabs (n=3; middle panel) and the dissolved oxygen (mg/L) overlying the bottom (bottom panel) in relation to 1 (left panels): distance from the cage (0, 50, 100, 250 and 500m from cages) for each survey, and 2 (right panels) survey date with data pooled into 2 distance categories (i.e. those closest: 0, 50 and 100m sites pooled and more distant: 250 and 500m sites pooled). In the left hand panels the data represents the mean (±SE) from two transects that radiate out from cages on opposite sides of the lease, and in the right hand panels the data represents the mean (±SE) from the two transects for each distance category. In the left hand panels the last 3 surveys have been emphasised to show the change since the decline in fauna and low oxygen levels observed in the October 2016 survey.

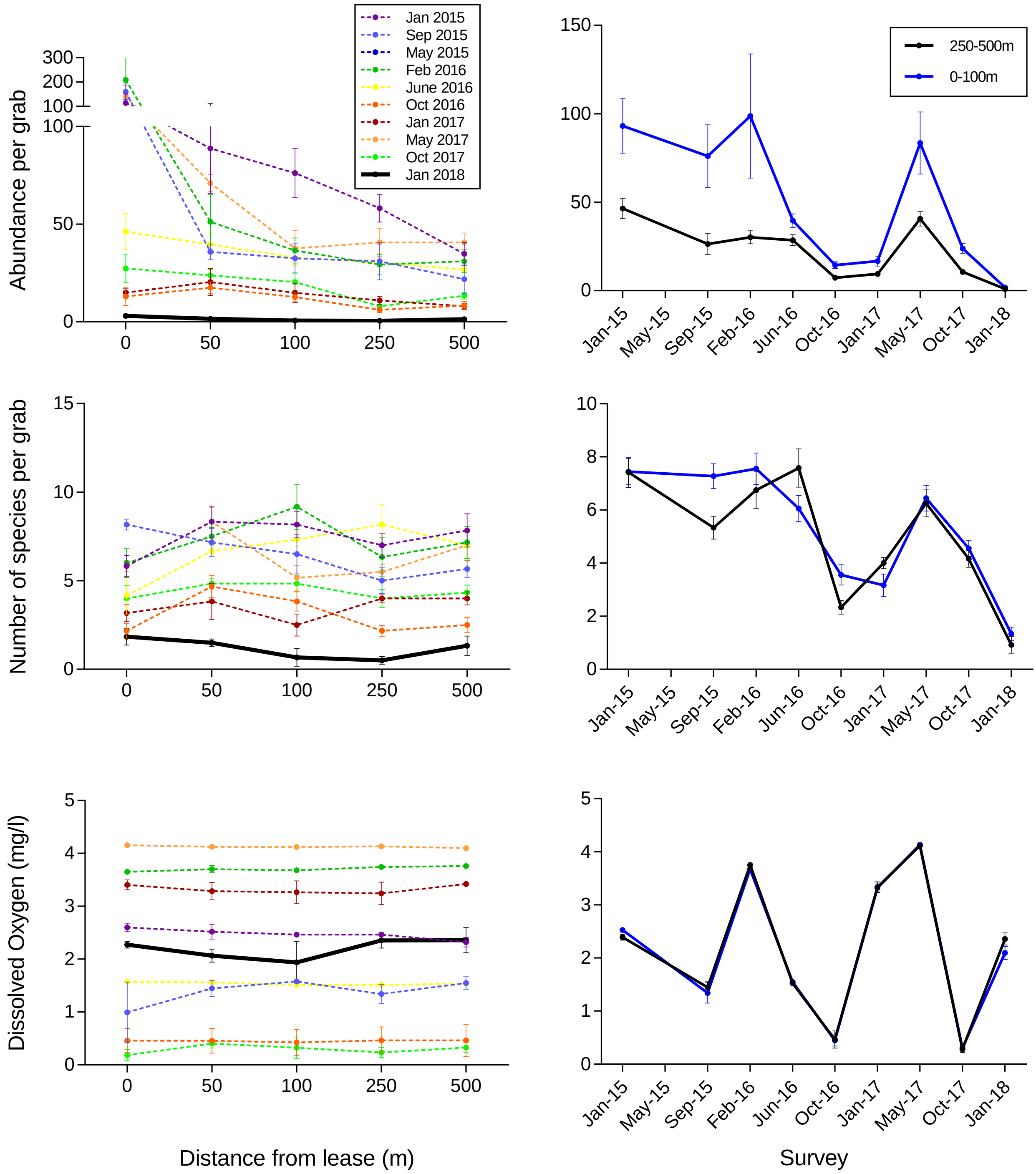


Figure 13 Lease 2 plots of total infaunal (>1mm) abundance (per grab = ~ 0.0675m²; top panel), number of species collected in grabs (n=3; middle panel) and the dissolved oxygen (mg/L) overlying the bottom (bottom panel) in relation to 1 (left panels): distance from the cage (0, 50, 100, 250 and 500m from cages) for each survey, and 2 (right panels) survey date with data pooled into 2 distance categories (i.e. those closest: 0, 50 and 100m sites pooled and more distant: 250 and 500m sites pooled). In the left hand panels the data represents the mean (±SE) from two transects that radiate out from cages on opposite sides of the lease, and in the right hand panels the data represents the mean (±SE) from the two transects for each distance category. In the left hand panels the last 3 surveys have been emphasised to show the change since the decline in fauna and low oxygen levels observed in the October 2016 survey. Note, lease 2 was not surveyed in May 2015.

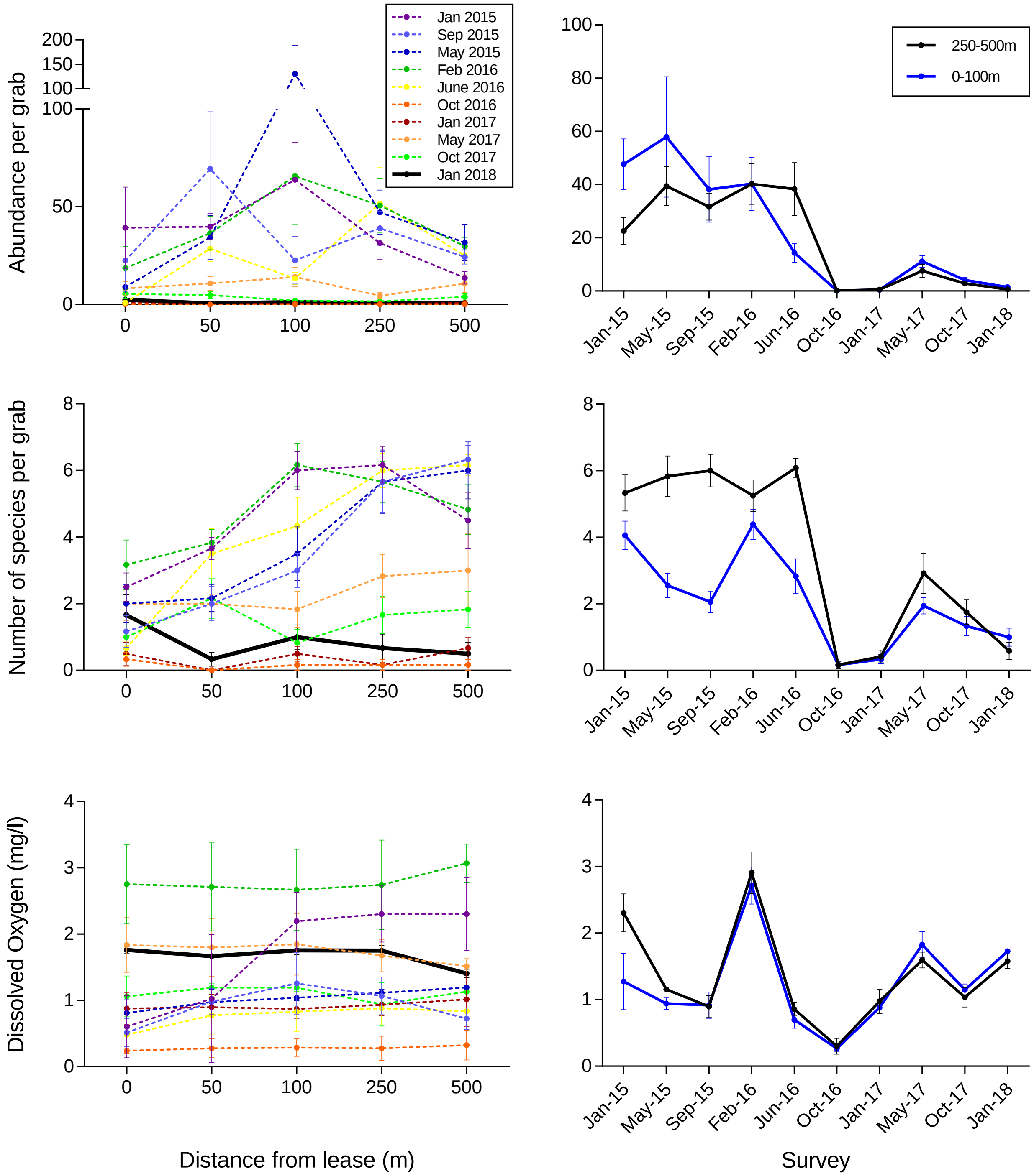


Figure 14 Lease 1 plots of total infaunal (>1mm) abundance (per grab = ~ 0.0675m²; top panel), number of species collected in grabs (n=3; middle panel) and the dissolved oxygen (mg/L) overlying the bottom (bottom panel) in relation to 1 (left panels): distance from the cage (0, 50, 100, 250 and 500m from cages) for each survey, and 2 (right panels) survey date with data pooled into 2 distance categories (i.e. those closest: 0, 50 and 100m sites pooled and more distant: 250 and 500m sites pooled). In the left hand panels the data represents the mean (±SE) from two transects that radiate out from cages on opposite sides of the lease, and in the right hand panels the data represents the mean (±SE) from the two transects for each distance category. In the left hand panels the last 3 surveys have been emphasised to show the change since the decline in fauna and low oxygen levels observed in the October 2016 survey.

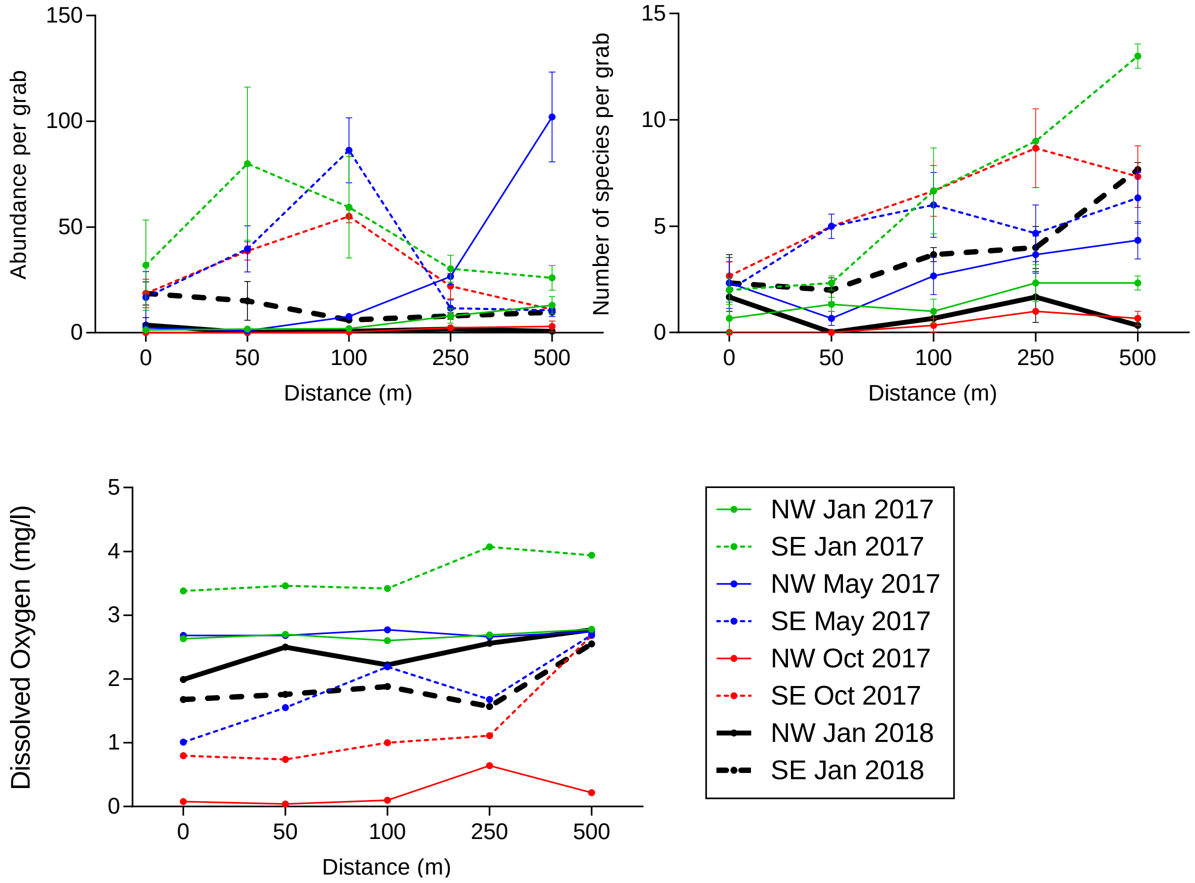


Figure 15 Plots of total infaunal (>1mm) abundance (per grab = ~ $0.0675m^2$), number of species collected in grabs (n=3; middle panel) and the dissolved oxygen (mg/L) overlying the bottom (at 0, 50, 100, 250 and 500m from cages at lease 5 during the January, May, October 2017 and January 2018 surveys. The data shows the mean (± SE) for the North-western (solid) and South-eastern (dashed) transects.

### *Harbour Wide Change*

Since January 2015 we have included a number of additional external sites in order to better assess the potential for harbour wide changes. These sites are at least 1km from the nearest lease and cover similar depth ranges and habitats. These sites allow comparison of benthic changes in the harbour as a whole alongside changes associated with farming and provide a means to assess temporal changes in benthic ecology. The results suggest that the greatest changes in faunal abundance and number of species at the external sites occurred from the middle to southern end of the harbour (Figure 16). The inclusion of the additional 16 external sites since January 2017 (that overlap with the harbour wide surveys conducted at the start of 2015 and 2016) further revealed the greatest decline in October 2016 was in the deeper central region of the harbour (Figure 17).

In the May 2017 survey we reported an increase in the abundance and number of species at a number of the external sites since October 2016 with faunal abundance and species numbers at many of these external sites within the range that had been recorded historically. In October 2017 we reported no consistent change (improvement/ deterioration) from the patterns observed in May 2017, a pattern again reflected in January 2018 (Figure 17). However, it was noted that faunal abundances at four of the southernmost external sites (39, 42, 43 and 44) in the WHA have remained low relative to that observed prior to the original decline from spring 2016 – early 2017. This remains the case in January 2018, although at the shallower and most southern of these sites (site 44, ~ 16m depth), faunal abundance and the number of species recorded has increased since the October 2017 survey.

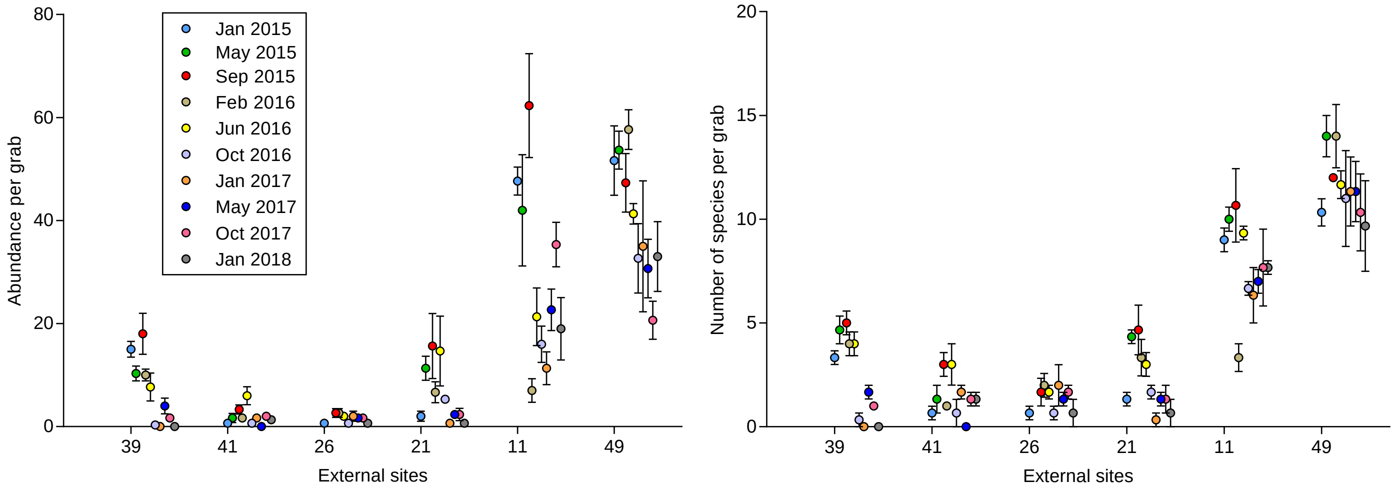


Figure 16 Plots of total infaunal (>1mm) abundance (per grab = ~0.0675m2) and number of species collected in grabs (n=3) at 7 external sites in Macquarie Harbour from surveys between January 2015 and January 2018. The data for each site represents the mean (±SE) from three replicate grabs. Note that site 26 was not surveyed in May 2015.

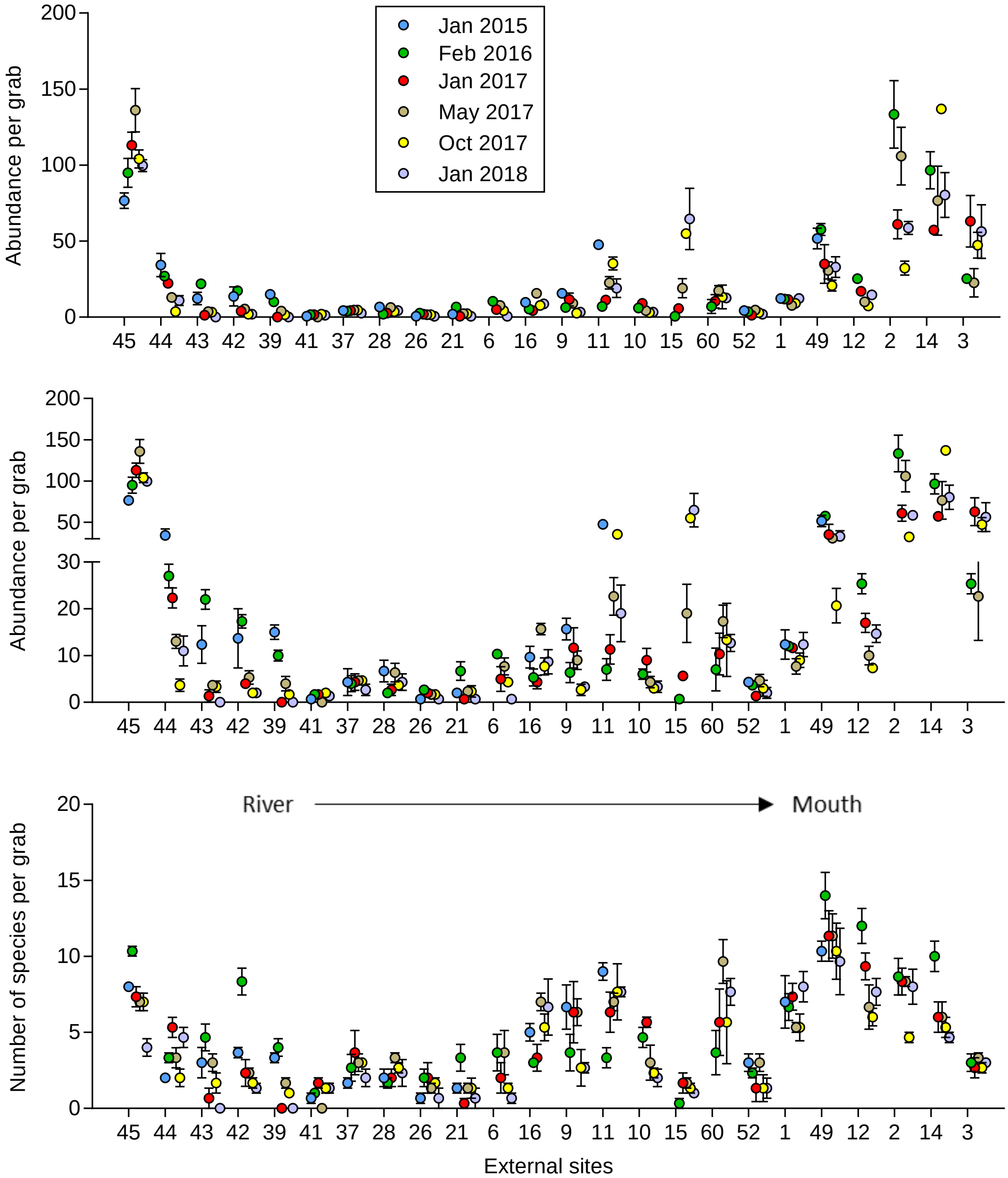


Figure 17 Plots of total infaunal (>1mm) abundance (per grab = ~0.0675m²; top 2 panels) and number of species collected in grabs (n=3; bottom panel) at 23 external sites in Macquarie Harbour from surveys in January 2015, February 2016, January 2017 and May 2017, September 2017 and January 20018. In the middle panel the axis is split to better show differences between surveys at the sites with lower abundances. The data for each lease represents the mean (±SE) from three replicate grabs. Note that sites 2, 3, 10, 14 and 15 were not sampled in the January 2015 survey.

*Video Assessments*

As part of the ongoing benthic faunal surveys video assessments of the study sites using an ROV have been conducted in parallel with the infaunal sampling[3]. Three minutes of footage was collected at each site and the footage assessed following the methods described by Crawford et al. (2001). In Macquarie Harbour the scoring categories have been expanded for Dorvilleids to provide greater detail on their distribution and relative abundance (Table 2); the scoring categories for *Beggiatoa* are shown in Table 3.

Table 2 Scoring categories of Dorvilleid abundance for video assessment

| Dorvilleid abundance |
|---|
| 0 |
| 1-30 |
| 31-100 |
| 101-300 |
| 301-1000 |
| >1000 |

Table 3 Scoring categories of *Beggiatoa* cover for video assessment

| Beggiatoa cover |
|---|
| absent |
| patchy |
| thick patches |
| thin mat |
| thick mat |
| streaming |

The last report (Ross et al., 2018) highlighted the clear reduction in the presence of *Beggiatoa* at both lease and external sites (Table 4) observed in the May and September[4] 2017 surveys relative to that observed in the October 2016 and January 2017 surveys. In the January 2018 survey, *Beggiatoa* was observed on more of the lease dives (21 of 51) relative to the previous two surveys (19 and 15 of 51 respectively); this corresponded to more observations of patches of *Beggiatoa* at lease sites and fewer observations of *Beggiatoa* forming extensive mats relative to the previous two surveys. The majority of the occurrences in January 2018, were on leases 3, 4 and 5; these were well within the lease boundaries on lease 3 and mainly on the NW transect at lease 5. At lease 4 that has been fallowed since May 2017, the observations of patches of *Beggiatoa* were all well within the lease boundary and the single observation of a thin matt was directly adjacent to where there had been a cage. At the external sites, *Beggiatoa* was observed at the same number (2) of the 28 sites in the January 2018 survey as it was in the September 2017 survey.

As we have described in the previous reports, the ROV footage clearly shows an association between the presence of Dorvilleid polychaetes and farming (see Table 5). However, unlike *Beggiatoa* the distribution of Dorvilleids typically extends further from the cages, and Dorvilleids are more commonly observed at external sites. Of the 79 ROV dives in the recent survey in January, Dorvilleids were observed on 56% of dives compared with 63% and 71% in September and May 2017 respectively. Over this time we have also seen a reduction in the observations of the more abundant categories (i.e. > 300 Dorvilleids in a dive). As described in previous surveys, Dorvilleids were more commonly observed at the external sites in the southern region of the harbour. Ross et al. (2016) noted that the broader distribution is largely associated with the Dorvilleid *Schistomeringos loveni,* which appears to be less tolerant of highly enriched sediments

[3] ROV assessments have generally been conducted within 2-3 weeks of the benthic grab sampling. The ROV assessments are conducted by the 3 growers, and in some cases by Aquenal Pty. Ltd. They are then independently assessed by DPIPWE and EPA.

[4] The ROV surveys were conducted in September 2017, approximately a month earlier than the benthic grab survey.

than the colony forming Dorvilleid *Ophryotrocha shieldsi* that is typically found closely associated with stocked cages. In the January 2018 survey Dorvilleid colonies were more commonly observed than in recent surveys, but most often in close proximity to the cages and not at external sites. Thus, we would suggest that the broader distribution of Dorvilleids seen in Figure 19 is still largely associated with *Schistomeringos loveni* and its preference for more moderately enriched sediments.

Table 4 Percentage of lease and external sites for each category of Beggiatoa cover for each survey.

| | | N | absent | patchy | thick patchy | thin mat | thick mat | streaming |
|---|---|---|---|---|---|---|---|---|
| Jan-15 | External | 25 | 100% | | | | | |
| | Lease | 87 | 80% | 10% | 1% | 8% | | |
| May-15 | External | 6 | 100% | | | | | |
| | Lease | 30 | 63% | 23% | 3% | 3% | 7% | |
| Sep-15 | External | 19 | 89% | 11% | | | | |
| | Lease | 41 | 73% | 2% | | 17% | 7% | |
| Feb-16 | External | 28 | 86% | 14% | | | | |
| | Lease | 41 | 73% | 12% | | 10% | 5% | |
| Jun-16 | External | 19 | 79% | 21% | | | | |
| | Lease | 41 | 66% | 15% | | 10% | 10% | |
| Oct-16 | External | 18 | 72% | 33% | | | | |
| | Lease | 42 | 52% | 12% | 7% | 10% | 17% | |
| Jan-17 | External | 28 | 75% | 21% | | 4% | | |
| | Lease | 51 | 43% | 25% | | 12% | 16% | 4% |
| May-17 | External | 28 | 96% | 4% | | | | |
| | Lease | 51 | 63% | 12% | 2% | 14% | 10% | |
| Sep-17 | External | 28 | 93% | 7% | | | | |
| | Lease | 51 | 71% | 8% | 2% | 10% | 10% | |
| Jan-18 | External | 28 | 96% | 4% | | | | |
| | Lease | 51 | 59% | 25% | | 8% | 8% | |

Table 5 Percentage of lease and external sites for each category of Dorvilleid abundance for each survey.

| | | N | 0 | 0-30 | 30-100 | 100-300 | 300-1000 | >1000 |
|---|---|---|---|---|---|---|---|---|
| Jan-15 | External | 25 | 44% | 36% | 12% | 8% | | |
| | Lease | 87 | 14% | 8% | 10% | 3% | 17% | 47% |
| May-15 | External | 6 | 100% | | | | | |
| | Lease | 30 | 10% | 33% | 10% | 27% | 17% | 3% |
| Sep-15 | External | 19 | 79% | 21% | | | | |
| | Lease | 41 | 37% | 17% | 15% | 2% | 12% | 17% |
| Feb-16 | External | 28 | 43% | 39% | 7% | 11% | | |
| | Lease | 41 | 27% | 20% | 7% | 5% | 20% | 22% |
| Jun-16 | External | 19 | 84% | 16% | | | | |
| | Lease | 41 | 44% | 32% | 2% | 10% | 5% | 7% |
| Oct-16 | External | 18 | 56% | 17% | 6% | 6% | 11% | 6% |
| | Lease | 42 | 36% | 31% | 14% | 7% | 7% | 5% |
| Jan-17 | External | 28 | 57% | 11% | 11% | 14% | 7% | |
| | Lease | 51 | 33% | 16% | 12% | 25% | 12% | 2% |
| May-17 | External | 28 | 50% | 29% | 14% | 4% | 4% | |
| | Lease | 51 | 18% | 24% | 10% | 18% | 24% | 8% |
| Sep-17 | External | 28 | 68% | 14% | 14% | 4% | | |
| | Lease | 51 | 20% | 10% | 18% | 24% | 16% | 14% |
| Jan-18 | External | 28 | 61% | 18% | 14% | 7% | | |
| | Lease | 51 | 35% | 24% | 12% | 14% | 12% | 4% |

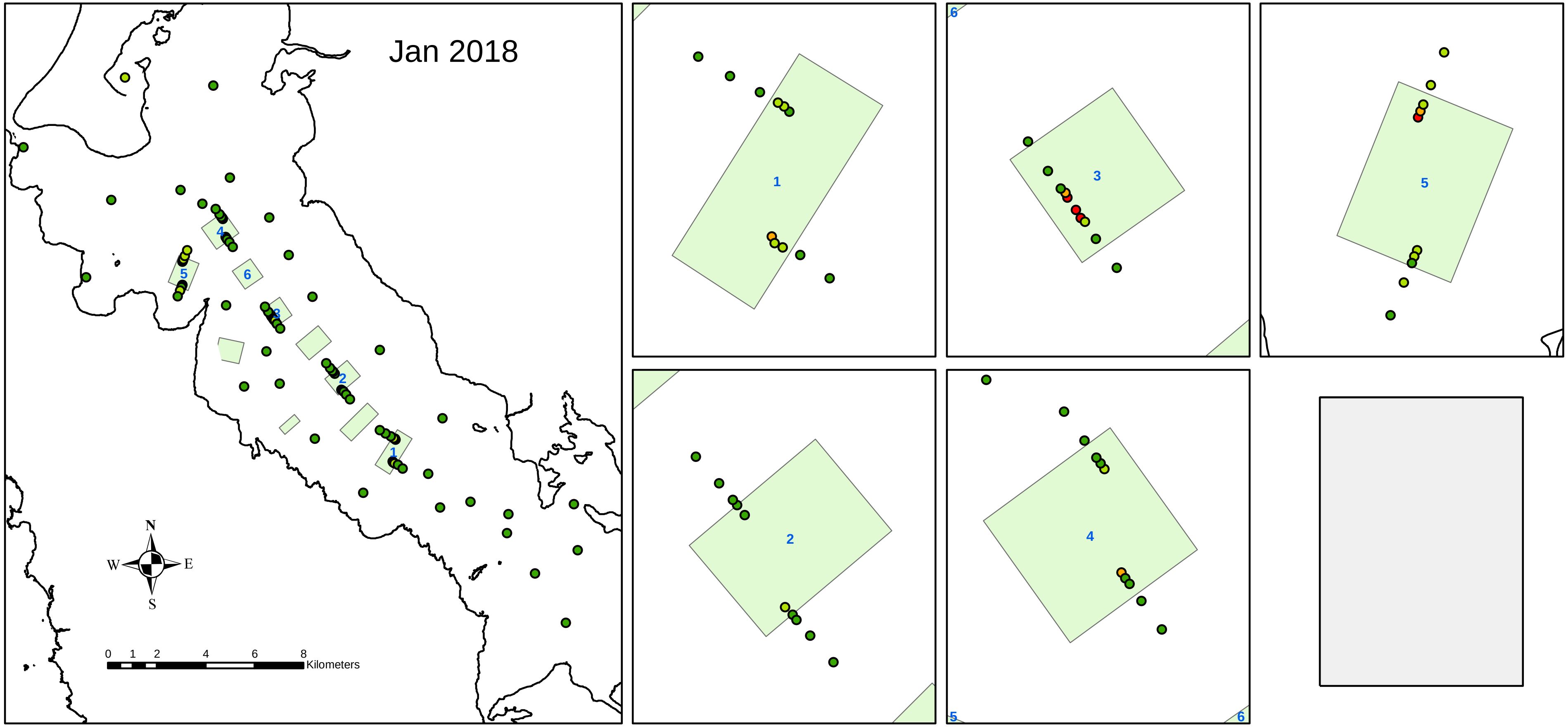


Figure 18 *Beggiatoa* score (severity) from ROV footage at study sites across the harbour on the left panel, and shown in more detail for each of the study leases in the panels on the right.

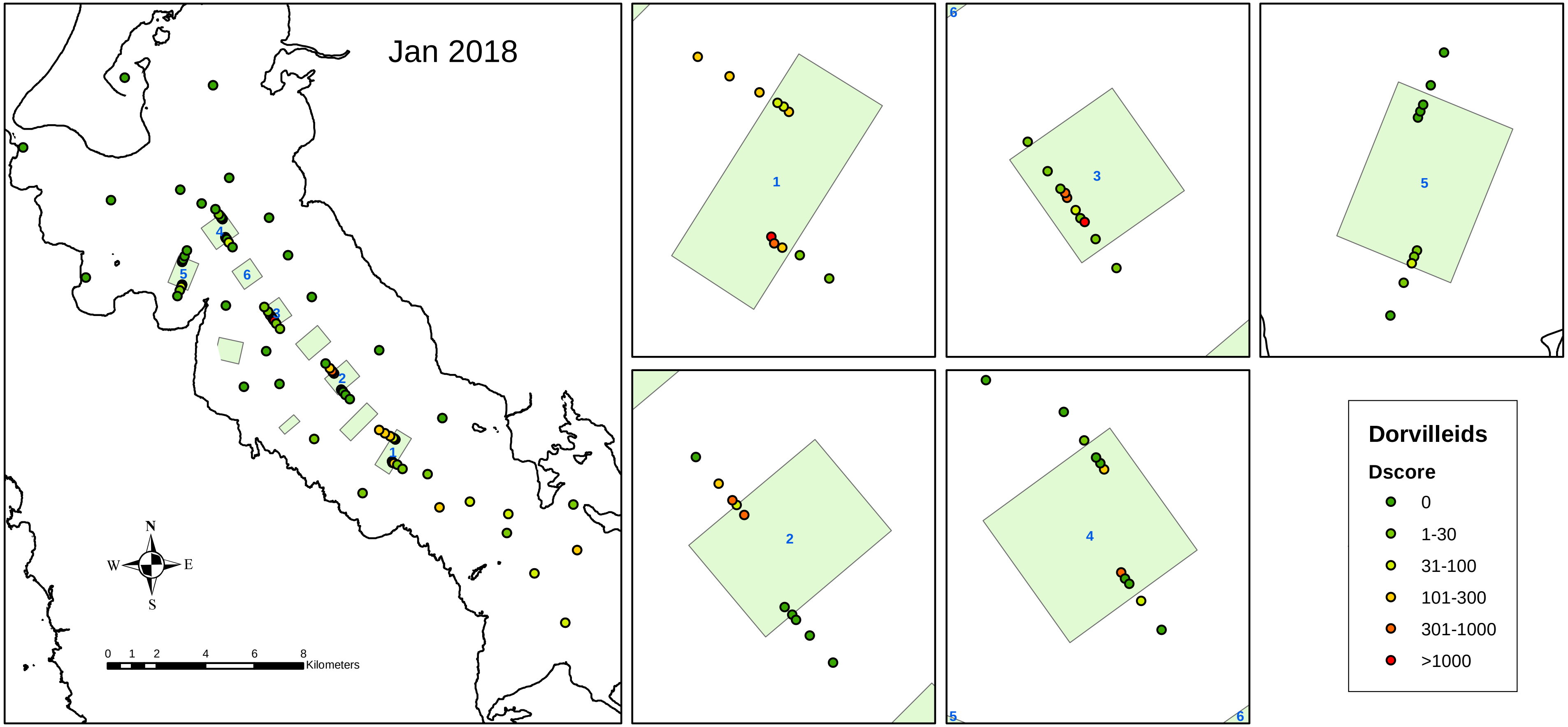


Figure 19 *Dorvilleid* score based on counts from ROV footage at study sites across the harbour on the left panel, and shown in more detail for each of the study leases in the panels on the right.

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