Environmental Research in Macquarie Harbour

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

PROGRESS REPORT

Approved by the Project Steering Committee and FRDC

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EXECUTIVE SUMMARY

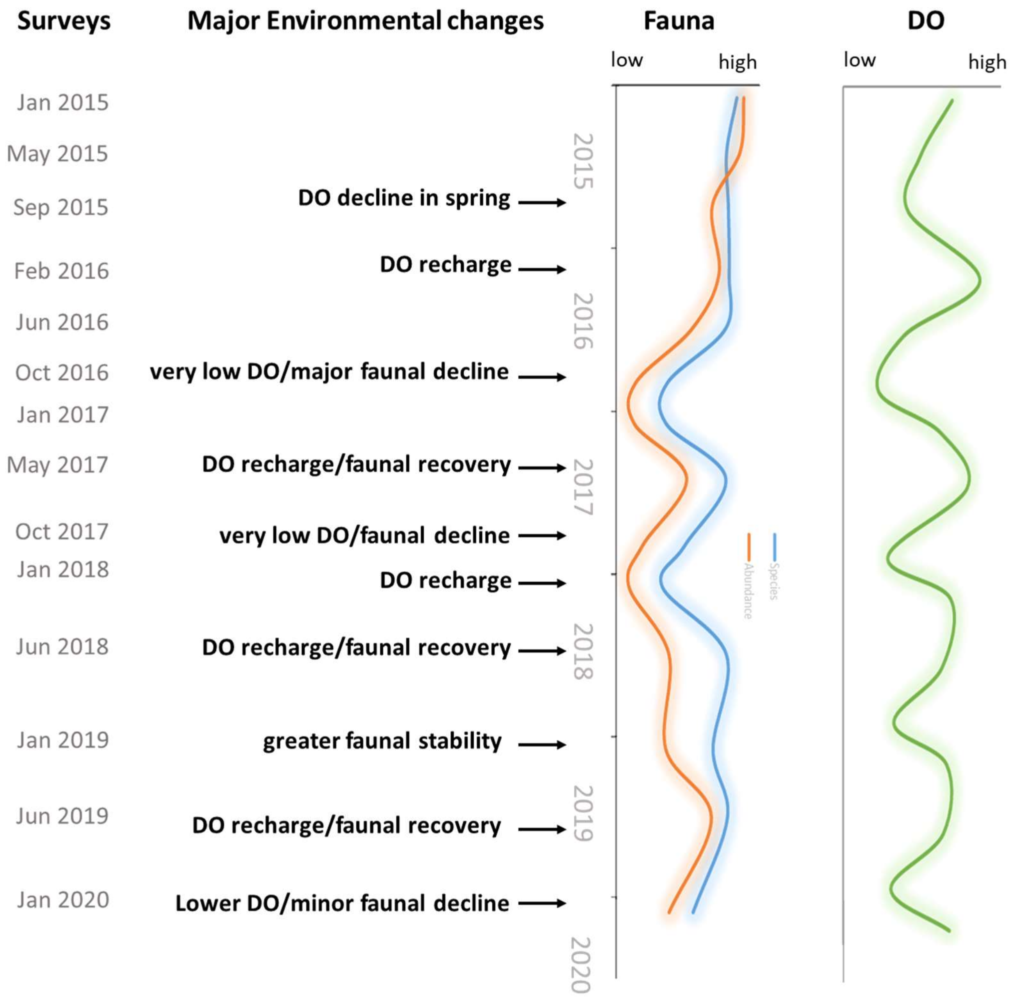
This report provides an update on the status of dissolved oxygen (DO) and benthic conditions in Macquarie Harbour. It follows on from the results previously outlined in the IMAS reports released through 2017 – 2020. These reports first described the deterioration of benthic and water column conditions in spring 2016, early signs of faunal recovery in the following autumn, when oxygen levels had improved, and the subsequent decline in benthic conditions when oxygen concentrations in middle and bottom waters returned to very low levels in spring 2017. Since then, oxygen concentrations in the middle and bottom waters have remained variable, declining each spring, and then increasing through summer and autumn due to oceanic and wind driven recharge. In spring 2018 oxygen levels did not decline as far or for as long compared with the previous springs and faunal abundance and diversity was less affected as a result. Surveys in January and June 2019 documented the improved benthic conditions, highlighting that both faunal abundance and the number of species had returned to or were closely approaching the range observed prior to the decline in spring 2016-early 2017 at the majority of both lease and external sites. This report presents the results and interpretation of a repeat survey of benthic communities in January 2020 and DO monitoring data up until March 2020.

In spring 2019 oxygen concentrations in the middle and bottom waters again declined to low levels and these conditions persisted for longer than in spring 2018. Oceanic recharge of bottom water was not observed until late December 2019 when the river flows decreased, and the halocline became shallower. Despite the extended period of low bottom water dissolved oxygen concentrations, the macrofaunal abundances and diversity in January 2020 was similar that observed in the January 2019 survey. Faunal abundance and the number of species at the external sites throughout the harbour have returned to and remain well within the range reported before the decline in spring 2016 – early 2017.

The presence of *Beggiatoa* continues to remain low relative to that observed in spring 2016/summer 2017. *Beggiatoa* was observed on 15 of 51 lease dives in January 2020, similar to its presence in 2019 when is was observed on 12-15 of the 51 lease dives across the January, June and September ROV surveys. When present, *Beggiatoa* was most often categorised as patchy, however in the January surveys there were more observations of *Beggiatoa* as a thin mat. At the external sites, the presence of *Beggiatoa* also remains lower than observed in 2016/17, it was observed at 5 of the 28 sites in January 2020, and in all cases categorised as patchy. The presence of dorvilleid polychaetes remains highly variable. In January 2019, their presence on farm dives had increased relative to previous surveys, but in June and September 2019 they were less abundant. In January 2020, their abundance again increased, and this change was largely attributed to their increased presence and abundance at leases 3 and 5. At the external sites, they were also more abundant in January 2019 and 2020 compared with June and September 2019. Most observations at the external sites have lower dorvilleid scores.

Each year since the major deterioration of benthic conditions observed in spring 2016, we have reported improved benthic conditions in the following autumn-winter and a subsequent deterioration during the following spring. This response pattern appears to be well aligned with the decline in oxygen concentrations in middle and bottom waters each spring and subsequent replenishment of oxygen due to oceanic and wind driven recharge through late spring to autumn. In 2019 we reported improved benthic conditions compared with previous years and attributed this to the less severe decline in DO in the preceding spring of 2018 relative to that observed in spring 2017 and 2016. As expected, there was a decline in macrofaunal abundance and number of species observed in January 2020 following the decline in DO in the preceding spring of 2019. Despite the more pronounced and prolonged decline in DO in spring 2019 compared to spring 2018, benthic conditions (including macrofaunal abundance and diversity) were similar to those observed at the same time the previous year in 2019. Although the latest results are consistent with improved benthic conditions over recent years, oxygen levels in the middle and bottom waters of the harbour remain low. The more prolonged and pronounced decline in DO in late 2019 again demonstrate the pivotal role that the weather (e.g. wind, river flow) plays in influencing the magnitude and extent of the seasonal DO decline, and thus, the capacity to reach levels that may lead to a deterioration in benthic conditions.

For a timeline[1] 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).



[1] It is important to note that there were no faunal surveys in spring 2018 and spring 2019, and as such there may well have been a decline which is not represented in the schematic below. However, the faunal declines of the previous two springs were evident in the following January survey.

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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 throughout 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 reductions in the harbour wide biomass limit and fallowing of multiple cage sites across the harbour. Key challenges facing farmers and regulators are understanding the capacity of the harbour to support finfish aquaculture 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.

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[2] 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 2018 funding for this project was extended for a further two years. This includes all three work

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

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 January 2020 and water column observations up until March 2020.

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).

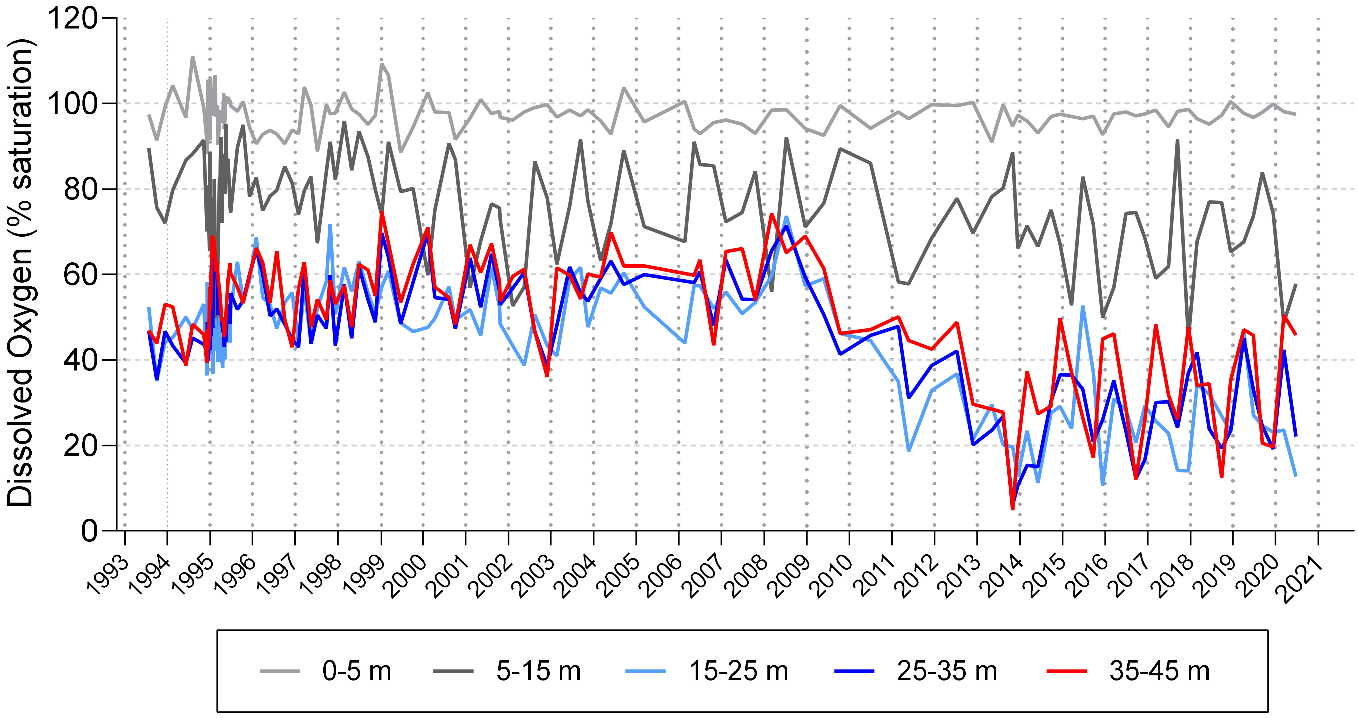

Figure 1 Long term trend in DO within a number of depth ranges at EPA site 12 (updated from MHDOWG 2014).

The contour plots produced from the three real time strings have been updated to include data up until mid-March 2020 (Figure 3-5). These figures demonstrate the cycle of recharge and replenishment of oxygen in the bottom waters through summer and autumn and the decline in winter and spring. Following the sustained period of recharge that extended from October 2018 through to May 2019, bottom water oxygen levels declined to the very low levels reported previously through spring and early summer (Figure 3-5), coinciding with a period of higher river flows and limited oceanic recharge. Data from the CSIRO mooring (Figure 6) highlight the deeper halocline through mid - winter 2019 to the end of the year. Oceanic recharge of bottom water was not observed until late December when the river flows decreased and the halocline became shallower; this is most evident from the CSIRO profile mooring (Figure 6). Compared to the previous year, oxygen levels were lower and persisted for longer in the spring – early summer of 2019. This is reflected in the timing of bottom water recharge of oxygen not commencing until the end of December 2019 compared with October 2018 (Figure 6).

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 was directly adjacent to the Strahan environmental string until mid-2018 before it was moved to near the King River Basin site to help better capture the intrusion of oceanic water into the harbour.

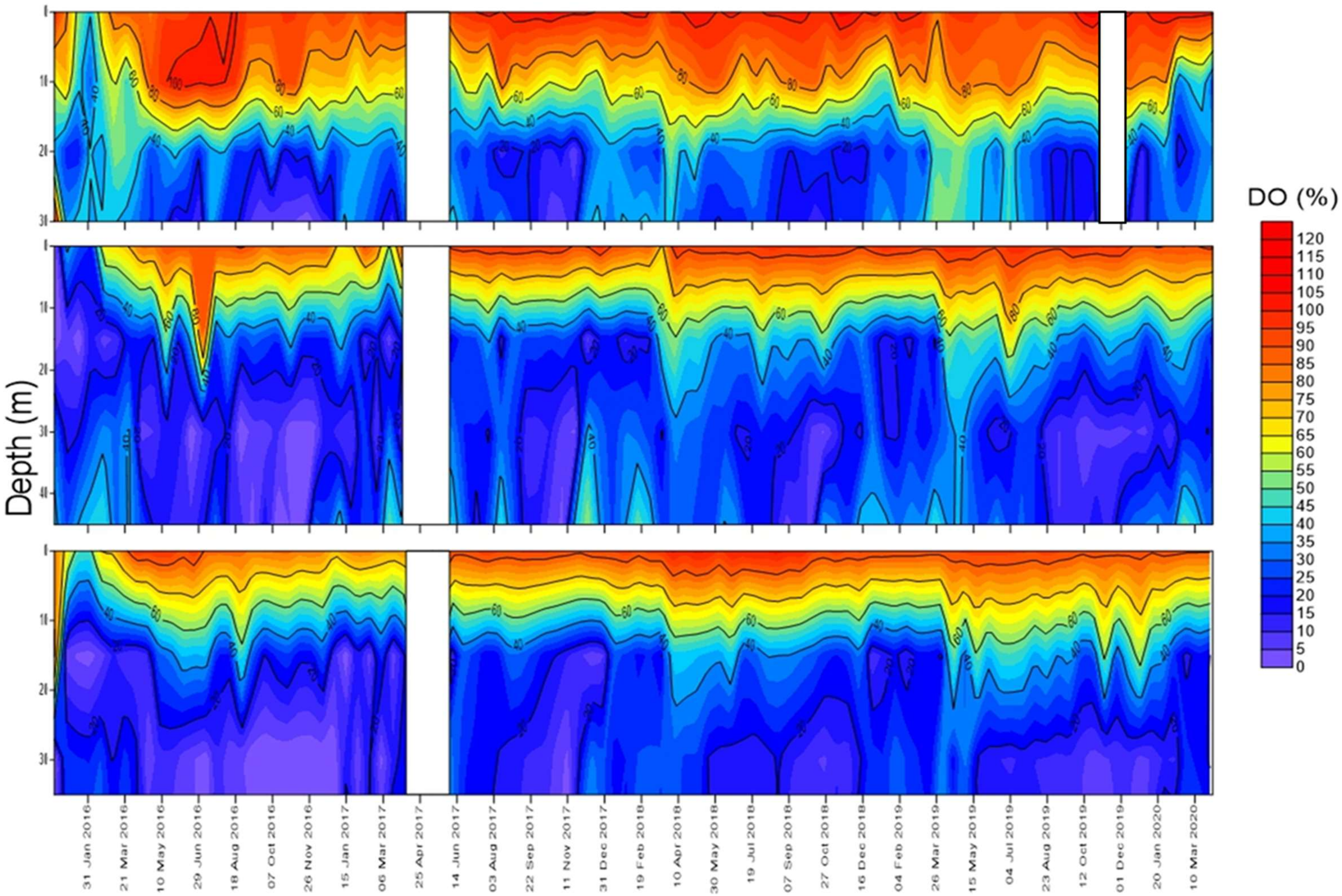

Figure 3 Contour plots showing DO profiles through the water column from the environmental strings at Table Head Central (top panel), Strahan (middle panel) and Franklin (bottom panel) over the period from December 2015 to mid-March 2020. Note, the data that underpins these plots for the period Dec 2015 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).

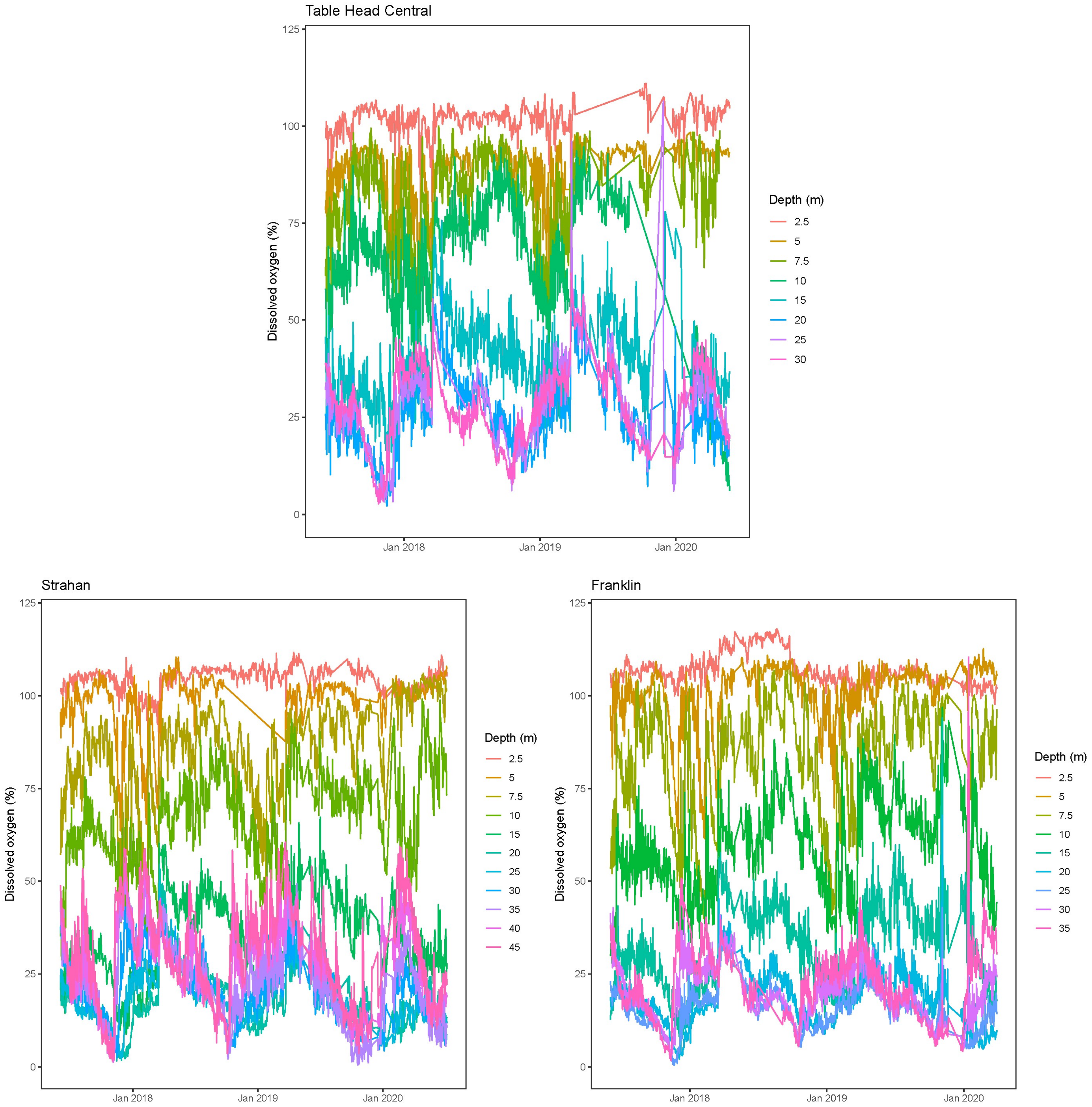

Figure 4 Daily mean DO (% saturation) levels at sensor depths from strings at Table Head Central, Strahan and Franklin over the period from the beginning of June 2017 to March 2020.

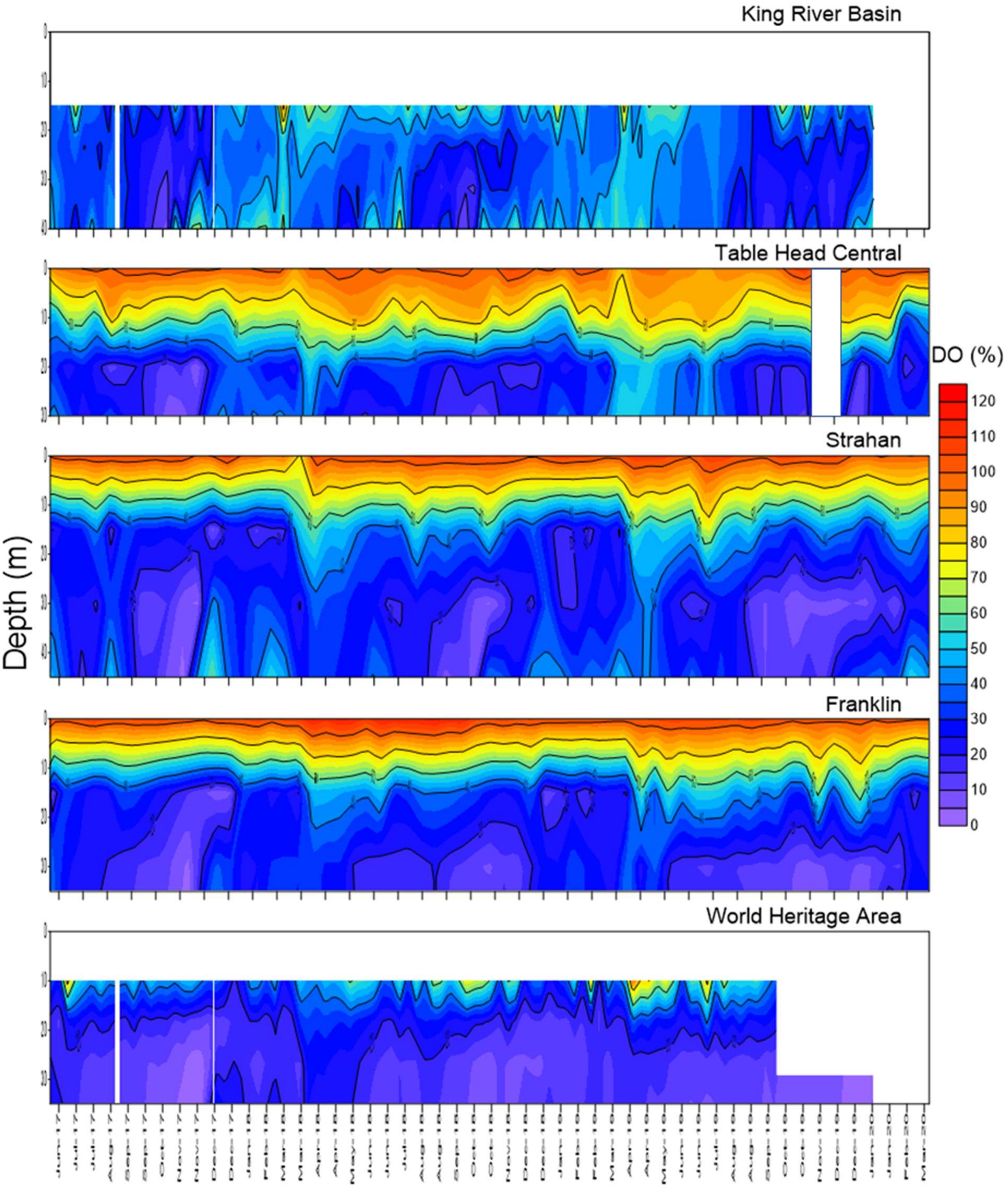

Figure 5 Contour plots showing DO profiles through the water column from the environmental strings at King River Basin, Table Head Central, Strahan, Franklin and the World Heritage Area over the period from the beginning of June 2017 to January 2020 (delayed logger strings) and March 2020 (near real time strings). 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. Data from the 10, 20 and 25m loggers on the World Heritage Area string could not be downloaded from Sep 2019-Jan 2020 and the loggers have been sent to the manufacturer to retrieve the data.

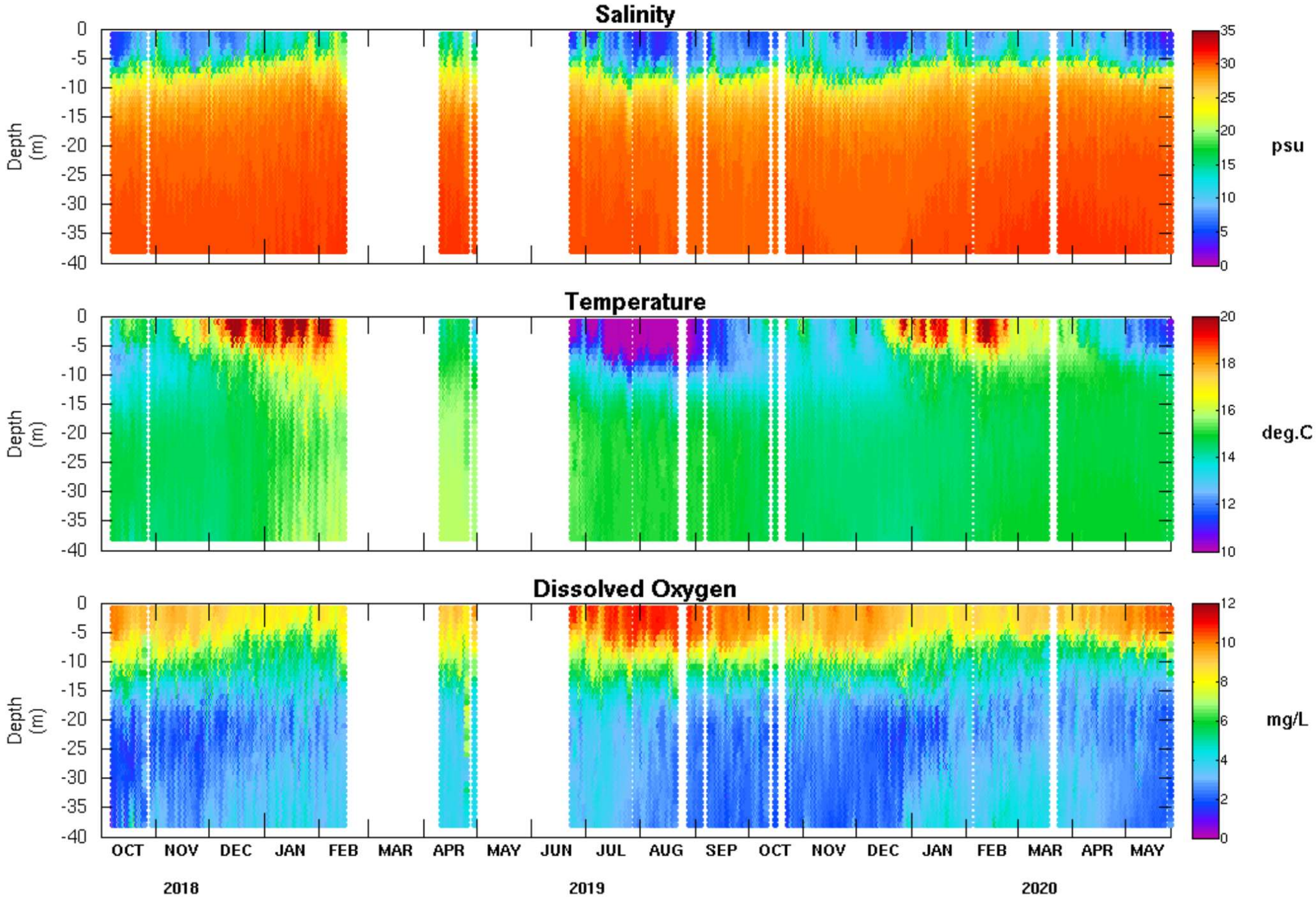

Figure 6 Observations from the CSIRO profile mooring at King River Basin site (Figure 2) showing the temporal change of water column salinity, temperature and dissolved oxygen concentration from October 2018 to May 2020. Profiling operations were suspended (i.e. the gaps in the figure) during very rough weather to avoid entanglement, and on a few occasions to enable platform maintenance.

BENTHIC CONDITION

In January 2020, IMAS conducted a benthic survey of five leases and 24 external sites as part of FRDC 2016-067 (Figure 7, Table 1). This represents the 14th 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[3].

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	16/01/2018-25/01/2018	January 2018	FRDC 2016-067
11	5/06/2018 - 20/06/2018	June 2018	FRDC 2016-067
12	15/01/2019 – 30/01/2019	January 2019	FRDC 2016-067
13	12/06/2019 – 26/06/2019	June 2019	FRDC 2016-067
14	21/01/2020 – 6/2/2020	January 2020	FRDC 2016-067

Following the major decline in fauna observed in spring 2016, we observed signs of benthic faunal recovery in both abundance and number of species in autumn 2017. In spring 2017 there had been a subsequent decline in both the abundance and number of species of benthic fauna at lease sites concomitant with the return of very low DO concentrations in bottom waters throughout the harbour. In the June 2018 survey we again observed a recovery in both abundance and number of species collected from the benthic fauna relative to the decline observed in spring 2017. In the December 2018 report we noted that the subsequent decline in oxygen levels in Spring 2018 wasn't

[3] 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.

as low as observed in the previous two springs and didn't continue for as long. The results of the January 2019 survey of benthic fauna suggested that the fauna was less affected as a result. In the June 2019 survey, abundance and species diversity had increased from that observed in January 2019 consistent with the recovery observed in winter in previous years; however, the results varied by location. In this survey, the prolonged decrease in oxygen over winter/spring 2019 resulted in fewer macrofauna and less species than in the June 2019; however, faunal abundance and species numbers were similar to that observed in January 2019 survey, although again this varied by location.

At lease 4, the northern most of the study leases, total abundance was lower at the 0-100m sites, but similar at 250-500m, in January 2020 compared to the June 2019 survey (Figure 8). The number of species recorded was also slightly lower in January 2020, and this was mostly evident at the 50 and 100m sites (Figure 8). Although abundance and too a much lesser extent, the number of species are in the lower range reported historically at the lease, it is important to keep in mind that feed inputs, and thereby food availability to the sediments has also decreased over the same period. Bottom water DO concentrations were greater than those reported in both the January and June 2019 surveys at all distances and were at the upper range reported historically at this time of the year (Figure 8).

At lease 3, total abundance was lower at the 0 and 50m sites, but higher at 100m, in January 2020 compared to the June 2019 survey. The number of species recorded was lower in January 2020 compared to June 2019, and this was more evident at the sites closest to the cage (i.e. 0 & 50m; Figure 9). Abundances and number of species are in the lower range reported historically at the lease but are greater than the original decline in spring 2016-early 2017. At the more distant sites, abundance and to a lesser extent the number of species, remains low relative to that observed prior to the original decline (Figure 9). Bottom water DO concentrations were slightly lower in comparison to recent surveys and most previous surveys for this time of the year (Figure 9).

At lease 2, total abundance was lower at the 0 and 500m sites, but higher at the 50m site, in January 2020 compared to the June 2019 survey (Figure 10). The number of species recorded was lower in January 2020 compared to June 2019, and this was more evident at the cage site (Figure 10). Importantly, both abundance and the number of species are within the range reported historically at the lease, including prior to the original decline from spring 2016-early 2017. Bottom water DO concentrations were within the range reported for this time of year in previous surveys (Figure 10).

At lease 1, the most southern lease, abundances were lower at all distances in comparison to the June 2019 survey, but were similar to those recorded in the January 2019 survey. The decline in abundances is likely a result of the prolonged low DO concentrations that extended until the end of December 2019 (Figure 3-5). The number of species was lower at most distances relative to the two previous surveys. Importantly though, both faunal abundances and species numbers remain higher than recorded in spring and summer of 2016/2017 and 2017/2018 (Figure 11). Species numbers and abundance have now returned to (or are approaching) the range observed prior to the decline (Figure 11). It is important to keep in mind that feed inputs, and thereby food availability to the sediments has also decreased over the same period, and as such, we wouldn't expect faunal abundances to return to the levels seen in the first 4 or 5 surveys when feed inputs were much greater. This highlights the complex interplay between the direct effects of farm enrichment on food availability and sediment condition and the influence of bottom water dissolved oxygen concentrations.

At lease 5, abundances were similar to or higher at most distances on both transects in January 2020 compared to June 2019 (Figure 12). Except for at 0m on the NW transect, species numbers were relatively similar across the January 2020 and June 2019 surveys. Bottom water oxygen concentrations on both transects were lower than recorded in the previous two surveys but within the range reported previously at this lease (Figure 12).

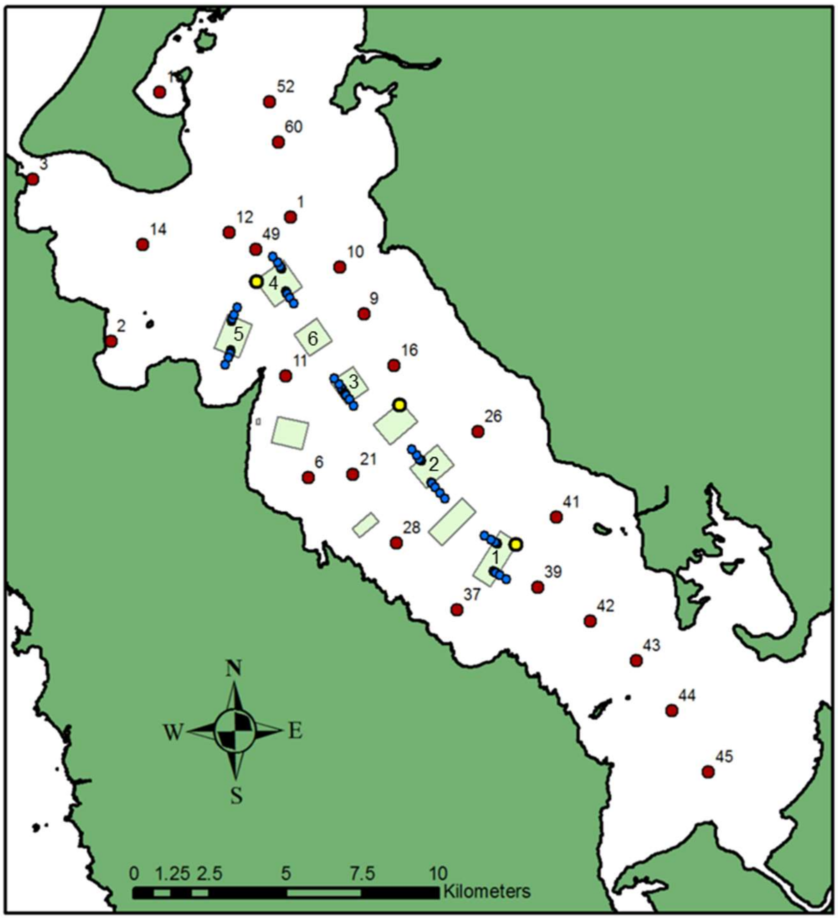

Figure 7 Maps showing external (red), lease (blue) and environmental string (yellow) sites. There are 2 transects from each of the study leases with five sites (at 0, 50, 100, 250 and 500m) on each transect.

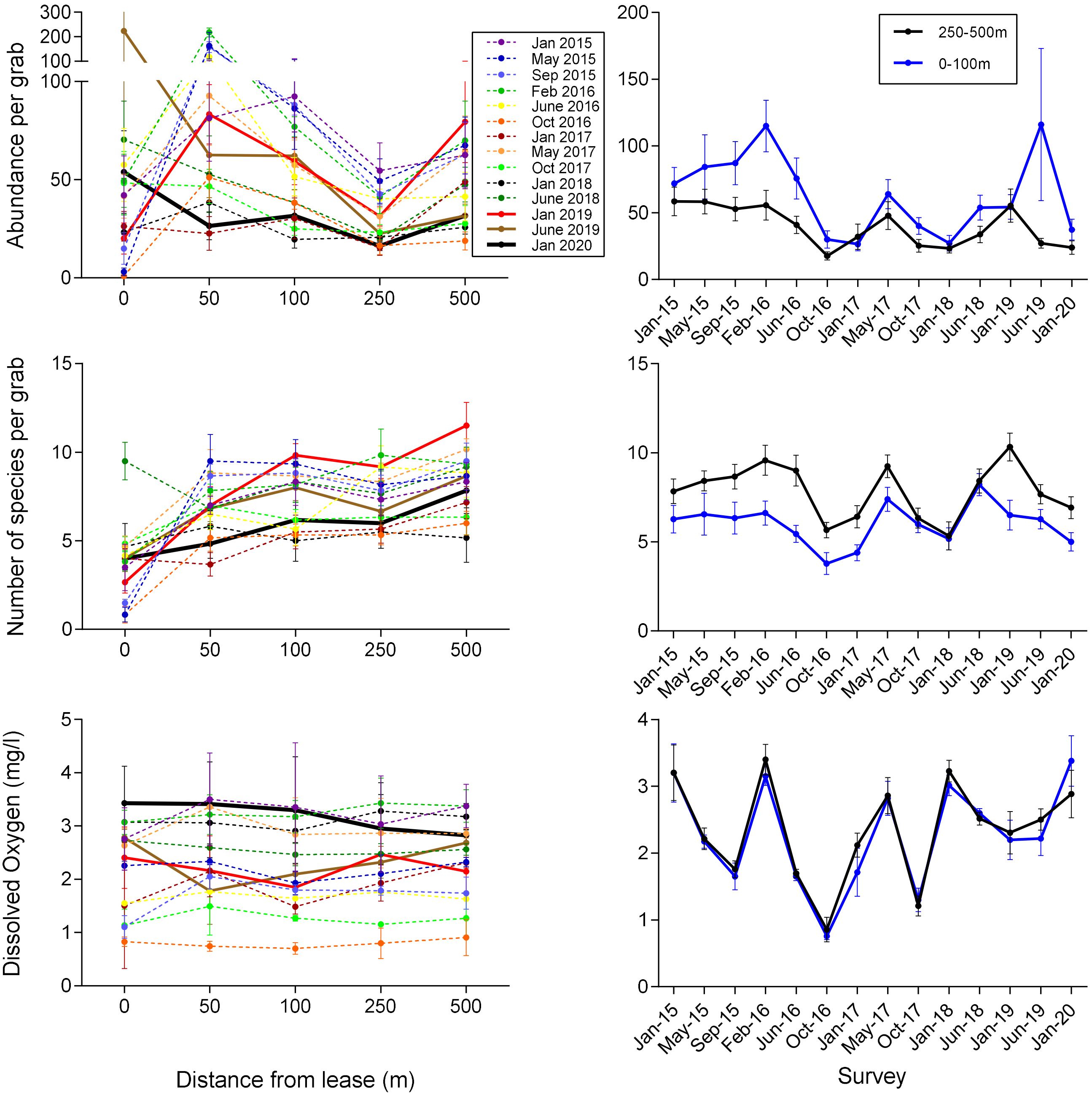

Figure 8 Lease 4 plots of total infaunal (>1mm) abundance (per grab = ~ 0.0675m²; top panel), number of species collected in grabs (n=3; middle panel) and the dissolved oxygen (mg/L) overlying the bottom (bottom panel) in relation to 1 (left panels): distance from the cage (0, 50, 100, 250 and 500m from 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 (January 2020) has been highlighted with a thick solid black line.

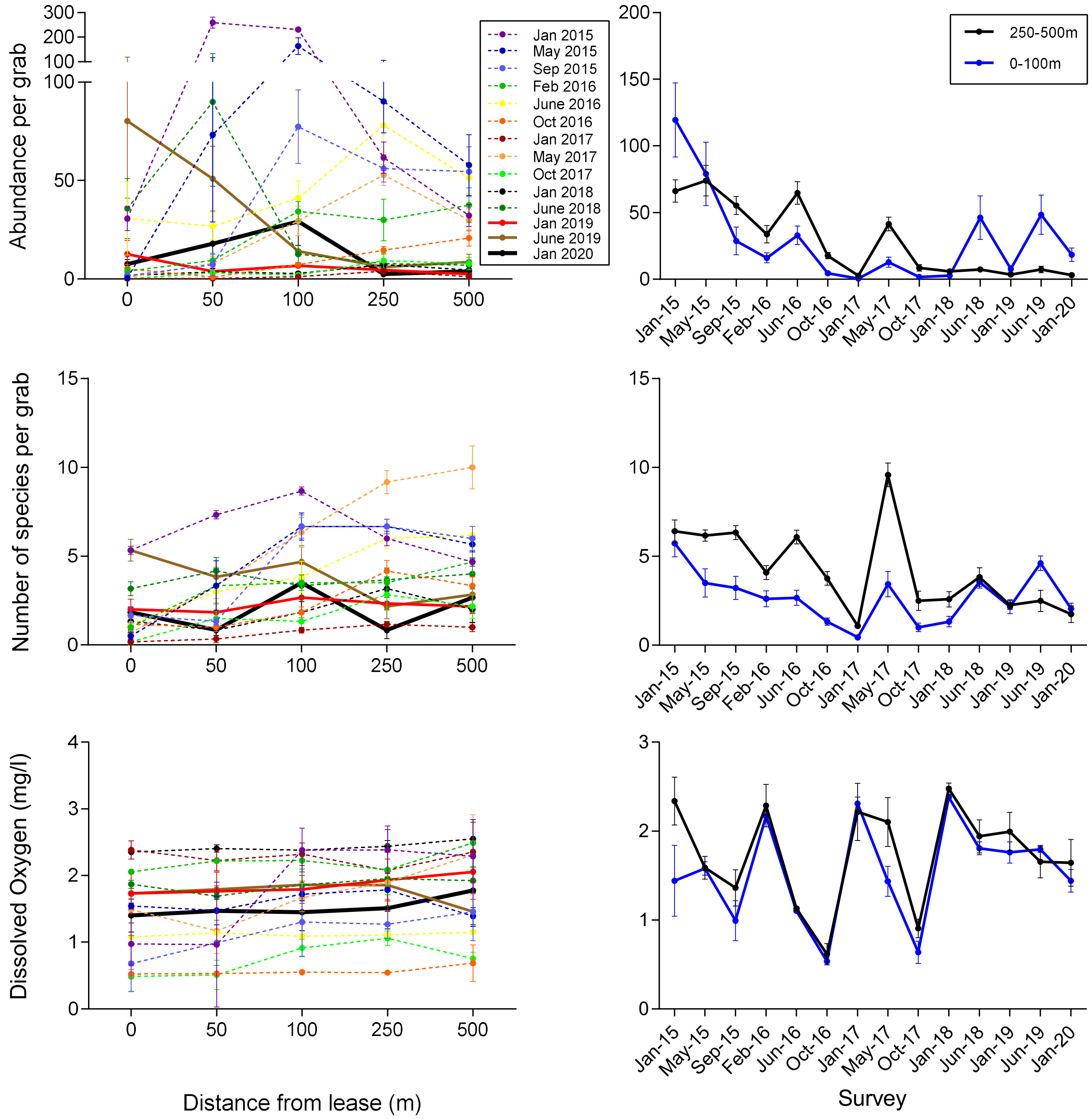

Figure 9 Lease 3 plots of total infaunal (>1mm) abundance (per grab = ~ 0.0675m²; top panel), number of species collected in grabs (n=3; middle panel) and the dissolved oxygen (mg/L) overlying the bottom (bottom panel) in relation to 1 (left panels): distance from the cage (0, 50, 100, 250 and 500m from 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 survey (January 2020) has been highlighted with a thick solid black line.

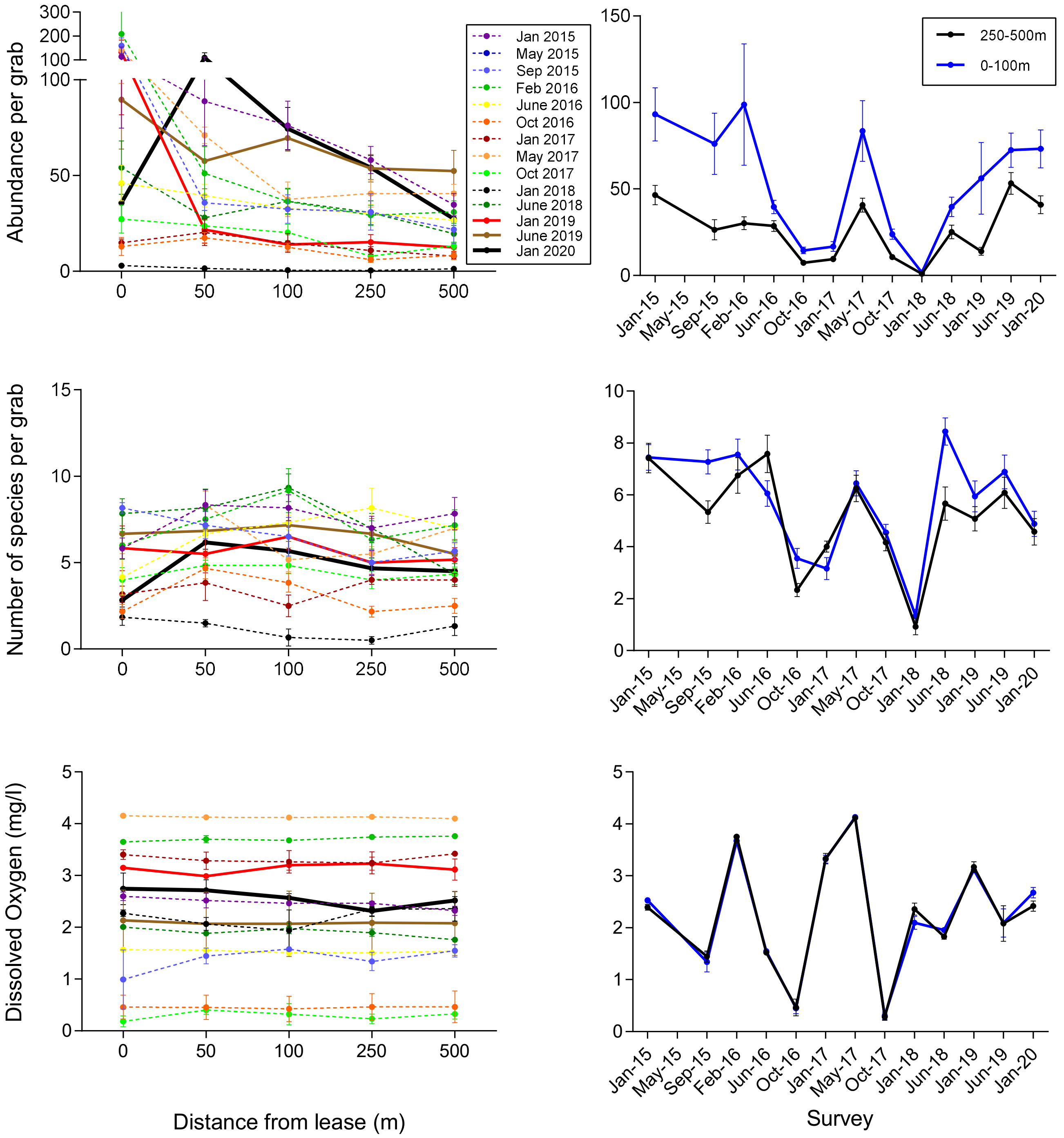

Figure 10 Lease 2 plots of total infaunal (>1mm) abundance (per grab = ~ 0.0675m^2; top panel), number of species collected in grabs (n=3; middle panel) and the dissolved oxygen (mg/L) overlying the bottom (bottom panel) in relation to 1 (left panels): distance from the cage (0, 50, 100, 250 and 500m 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 (January 2020) has been highlighted with a thick solid black line. Note, lease 2 was not surveyed in May 2015.

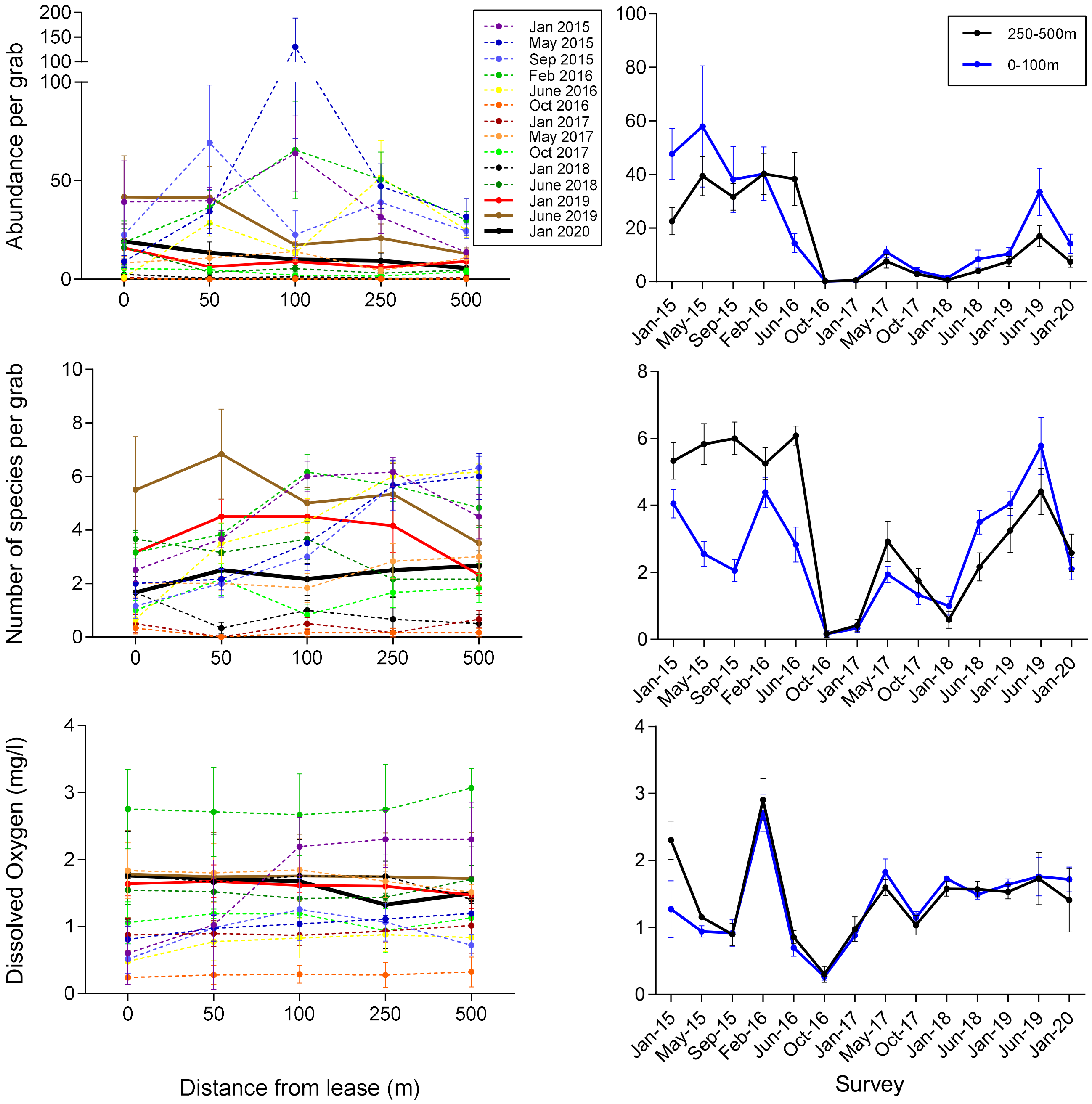

Figure 11 Lease 1 plots of total infaunal (>1mm) abundance (per grab = ~ 0.0675m²; top panel), number of species collected in grabs (n=3; middle panel) and the dissolved oxygen (mg/L) overlying the bottom (bottom panel) in relation to 1 (left panels): distance from the cage (0, 50, 100, 250 and 500m 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 survey (January 2020) has been highlighted with a thick solid black line.

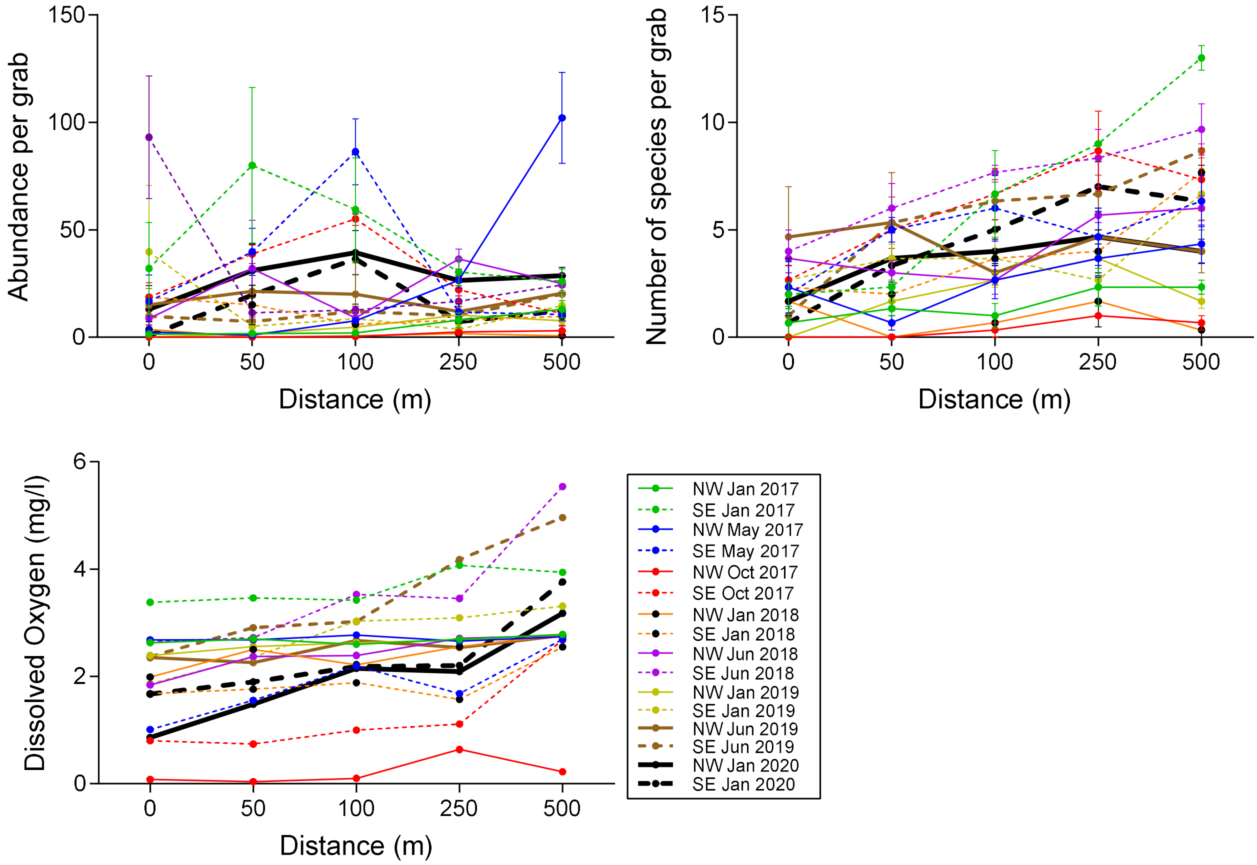

Figure 12 Plots of total infaunal (>1mm) abundance (per grab = ~ 0.0675m^2), number of species collected in grabs (n=3; middle panel) and the dissolved oxygen (mg/L) overlying the bottom (at 0, 50, 100, 250 and 500m from cages at lease 5 during the January 2017 – January 2020 surveys. The data shows the mean (± SE) for the North-western (solid) and South-eastern (dashed) transects.

Harbour Wide Change

Since January 2015 we have included several additional external sites 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 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 these external (harbour scale) sites occurred from the middle to southern end of the harbour (Figure 13). 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 that the greatest decline in October 2016 was in the deeper central region of the harbour (Figure 14).

In the June 2019 survey, faunal abundance and species numbers at the majority of the external sites were within the range recorded in our surveys prior to the decline in spring 2016 – early 2017 (Figure 14). At the four southernmost external sites (39, 42, 43 and 44), where abundances have been the slowest to recover from the original decline in spring 2016 – early 2017, faunal abundances and the number of species had returned to well within the range reported previous to the decline. In this survey both abundances and the number of species remain high at the southern sites. At mid-harbour sites, abundance and the number of species has increased at some sites and decreased at others, but overall, the patterns remain similar and within the range recorded in previous surveys.

At the northern end of the Harbour, the abundance and number of species at the four sites near the entrance to the ocean (i.e. sites 2, 3, 12 and 14) were notably lower in the June 2019 survey. In this survey there was an increase in both abundance and the number of species, and this was particularly notable at sites 2 and 3 where the decline was greatest in June 2019.

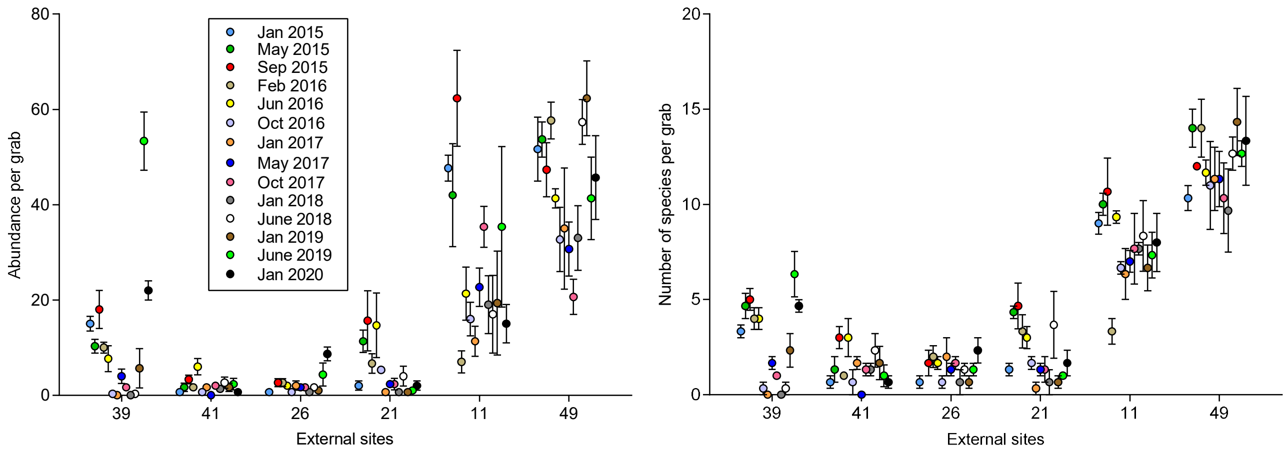

Figure 13 Plots of total infaunal (>1mm) abundance (per grab = ~0.0675m^2) and number of species collected in grabs (n=3) at 7 external sites in Macquarie Harbour from surveys between January 2015 and January 2020. The data for each site represents the mean (±SE) from three replicate grabs. Note that site 26 was not surveyed in May 2015.

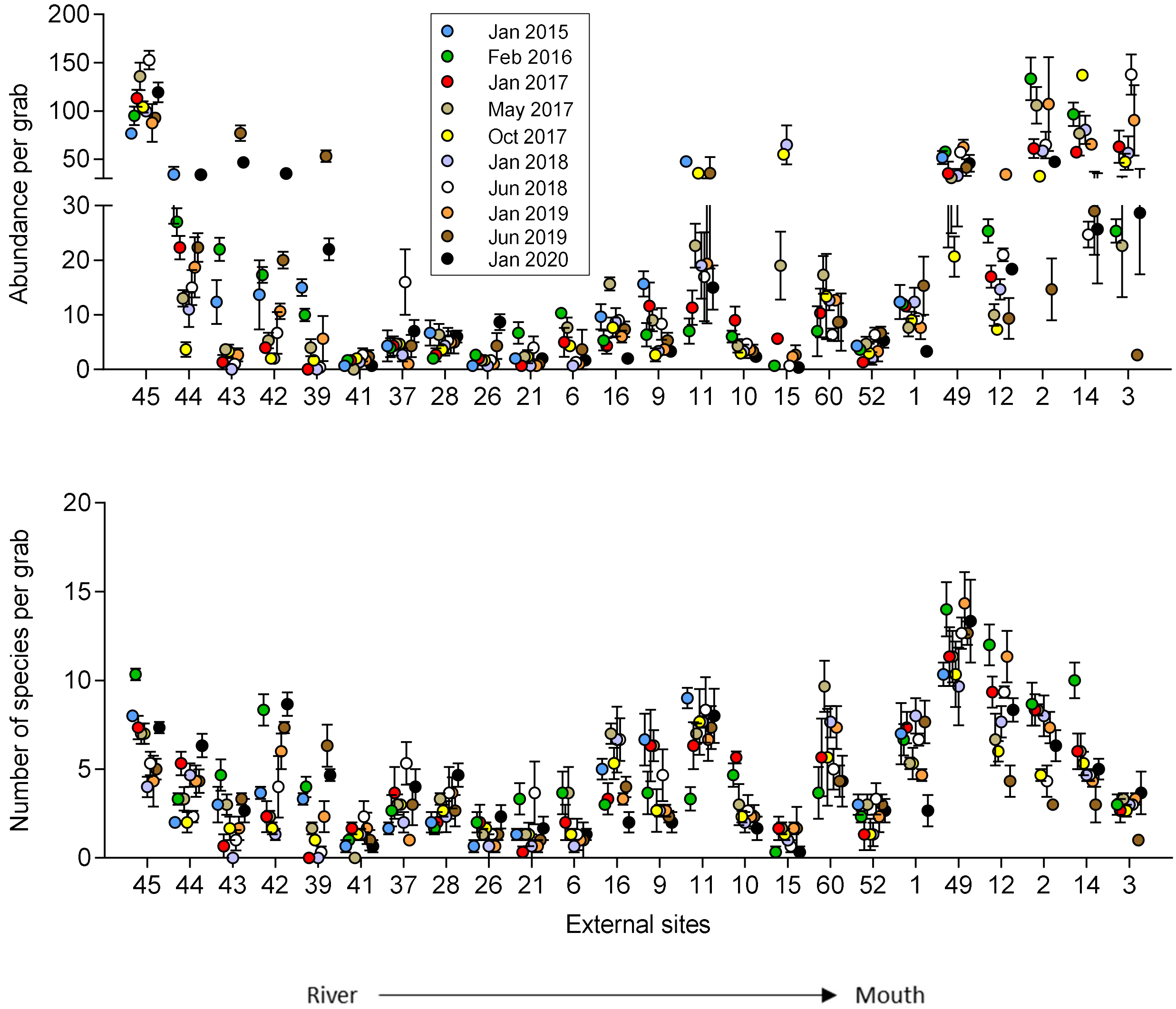

Figure 14 Plots of total infaunal (>1mm) abundance (per grab = ~0.0675m^2) and number of species collected in grabs (n=3; bottom panel) at 23 external sites in Macquarie Harbour from surveys in January 2015, February 2016, January 2017 and May 2017, October2017, January 2018, June 2018, January 2019, June 2019 and January 2020. In the top 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[4]. 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. Although there was no infaunal survey conducted in the of spring 2018 and 2019, a video assessment of all sites was completed, and the results are presented to provide further insight into temporal changes in the presence of *Beggiatoa* and dorvilleids.

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 September 2018 to January 2020 video surveys demonstrated that the presence of *Beggiatoa* remains low relative to that observed in the October 2016 and January 2017 surveys (Table 4). The occurrence of *Beggiatoa* in this survey (observed on 15 of 51 lease dives) was similar to the surveys in 2019; September (14 of 51), June (15 of 51) and January (12 of 21). When present, *Beggiatoa* is most often categorised as patchy, however in January 2019 and 2020 surveys there were more observations of *Beggiatoa* as a thin mat. At the external sites there has also been little change in the presence of Beggiatoa over the same time period; it was observed at 4 of the 28 sites in the January, June and September 2019 surveys, and at 5 of the 18 sites in the January 2020 survey. With the exception of two observations of thick patchy *Beggiatoa* in January 2019 all other observations at external sites across these surveys have being categorised as patchy (Table 4, Figure 15).

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, Figure 16). The distribution of dorvilleids typically extends further from the cages than *Beggiatoa*, and dorvilleids are more commonly observed at external sites. In the September 2018 survey dorvilleids were observed on slightly fewer farm dives (61%) than in the two previous surveys - May (69%) and January 2018 (65%). In January 2019 (88%), there was an increase in the presence of dorvilleids on farm dives relative to the previous three surveys; however, their presence in the June 2019 survey decreased to 69% of farm dives. This also corresponded to a decrease in abundance with less observations of the more abundant categories (i.e. > 300 dorvilleids in a dive) and more observations of the lowest category (i.e. 0-30 dorvilleids in a dive). In the September 2019 survey their presence decreased to 51% of farm dives but there was an increase in the more abundant

[4] 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.

categories, and by January 2020 both their presence (76%) and abundance had increased relative to June 2019. This change is largely attributable to their increased presence and abundance at leases 3 and 5 (Figure 16)

At the external sites, dorvilleids were observed on 18% of dives in June 2019 as compared to 61% in January 2019 and 39-43% across the three surveys prior to that. In the June 2019 survey dorvilleids were not observed at the external sites at levels greater than 30 dorvilleids per dive (Table 5, Figure 16). In the two most recent surveys in September 2019 and January 2020 dorvilleids were observed on 18 and 36 % of external dives respectively, the majority of which were observations of the lowest category (i.e. 0-30 dorvilleids in a dive).

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 than the colony forming dorvilleid *Ophryotrocha shieldsi* that is typically found closely associated with stocked cages. Colonies were observed on less dives in September 2019 (1 of 79 dives) and January 2020 (2 of 79 dives) compared with the previous two surveys in June 2019 (3 of 79 dives) and January 2019 (6 of 79 dives). All these observations were on leases, near the cages and not at external sites. The broader distribution of dorvilleids seen in Figure 16 is still largely associated with *Schistomeringos loveni* and reflects 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%	
May-18	External	28	89%	11%				
	Lease	51	59%	33%	2%	6%		
Sep-18	External	28	86%	14%				
	Lease	51	61%	22%		8%	6%	4%
Jan-19	External	28	86%	7%	7%			
	Lease	51	75%	12%	2%	10%		2%
Jun-19	External	28	86%	14%				
	Lease	51	71%	24%	4%	2%		
Sep-19	External	28	86%	14%				
	Lease	51	73%	22%		4%	2%	
Jan-20	External	28	82%	18%				
	Lease	51	71%	16%	2%	10%	2%	

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%	32%	12%	8%	4%	
	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	53%	16%	11%	5%	11%	5%
	Lease	42	37%	32%	12%	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%	18%	11%	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%
May-18	External	28	61%	39%				
	Lease	51	31%	22%	22%	16%	8%	2%
Sep-18	External	28	57%	43%				
	Lease	51	39%	29%	14%	10%	6%	2%
Jan-19	External	28	39%	50%	11%			
	Lease	51	12%	18%	25%	18%	10%	18%
Jun-19	External	28	82%	18%				
	Lease	51	31%	39%	6%	16%	2%	6%
Sep-19	External	28	82%	18%				
	Lease	51	49%	20%	4%	6%	10%	12%
Jan-20	External	28	64%	25%	11%			
	Lease	51	24%	27%	14%	6%	14%	16%

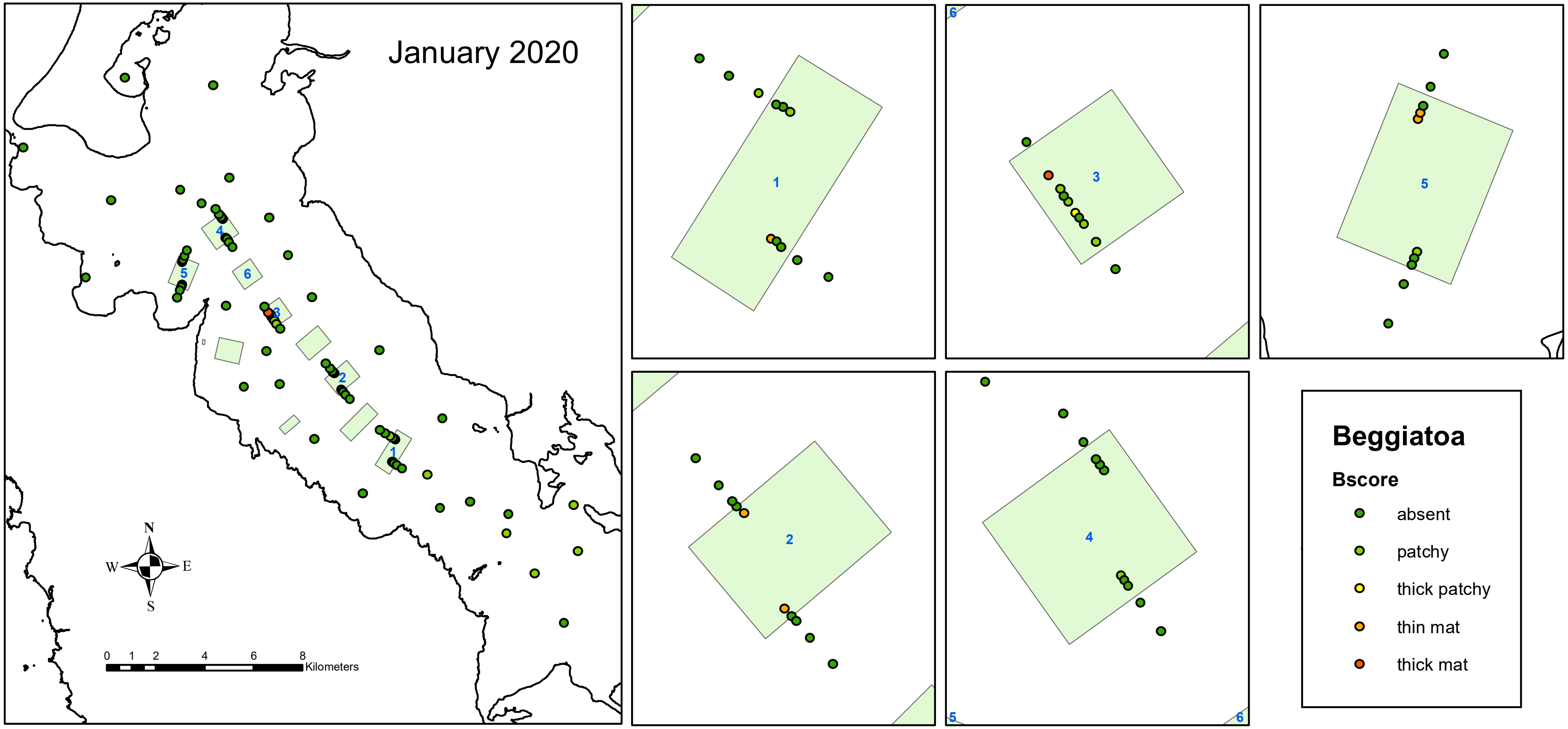

Figure 15 *Beggiatoa* score (severity) from ROV footage at study sites across the harbour on the left panel and shown in more detail for each of the study leases in the panels on the right.

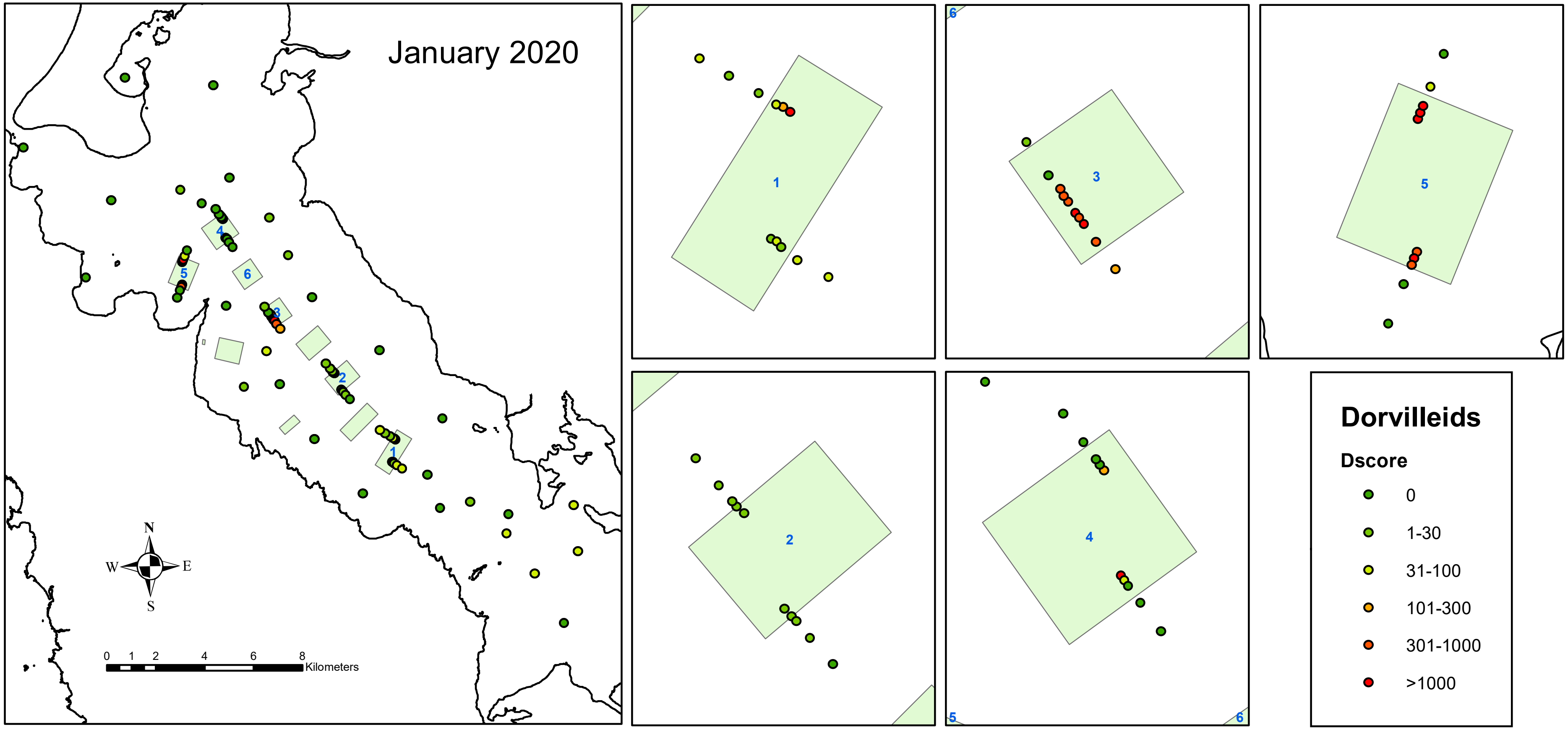

Figure 16 *Dorvilleid* score based on counts from ROV footage at study sites across the harbour on the left panel and shown in more detail for each of the study leases in the panels on the right.

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