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

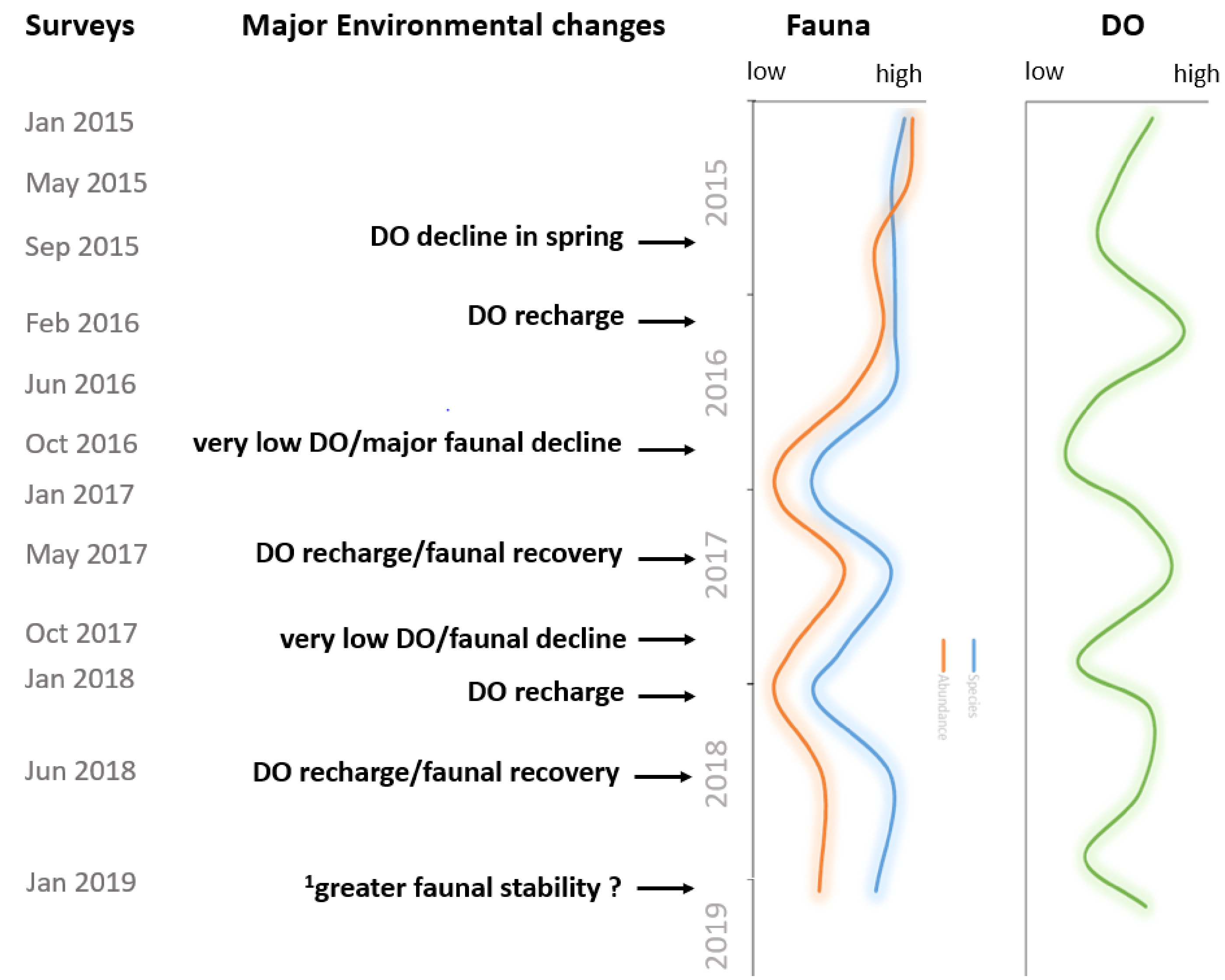
This report provides an ongoing update on the status of dissolved oxygen (DO) and benthic conditions in Macquarie Harbour. It follows on from the results previously outlined in the IMAS reports released throughout 2017 and 2018. These reports first described the deterioration of benthic and water column 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. In the most recent report we described a continuation of this cycle; an increase in faunal numbers in mid-2018 following improved oxygen concentrations in the middle and bottom waters through the summer of 2017/18. This report presents the results and preliminary interpretation of a repeat survey of benthic communities in January 2019 and DO monitoring data up until late May 2019.

Following the June 2018 faunal survey, oxygen concentrations in the middle and bottom waters again declined into early spring. However, this decline wasn't as low as observed in the previous two springs and didn't continue for as long. Improved oxygen concentrations in the middle and bottom waters have extended from the middle of spring 2018 through to late autumn 2019 due to recharge events that commenced in early October 2018. The faunal survey in January 2019 demonstrates that benthic conditions have improved relative to that observed at the same time of year in 2018 and 2017. Notably, at the deeper external sites to the south where abundances have remained low relative to observations prior to the decline in spring 2016 – early 2017, faunal numbers had improved at 3 of the 4 sites in the latest survey; abundance and the number of species have returned to or are closely approaching the range observed prior to the decline.

The presence of *Beggiatoa* continues to remain low relative to that observed in spring 2016/summer 2017. *Beggiatoa* was only observed on 13 of 51 lease dives, less than in the three most recent previous surveys in January, May and September 2018. At the external sites, *Beggiatoa* was observed at 4 of the 28 sites and in all cases noted as patchy or thick patchy. Recent surveys have reported a reduction in the number of sites where dorvilleid polychaetes were observed and a reduction in the number of sites with high dorvilleid scores. In the January 2018 video survey, there was an increase in the number of farm and external sites where dorvilleid polychaetes were observed. At the farm sites there was an increase in the more abundant categories (i.e. > 100 dorvilleids in a dive), but there were no observations at the external sites of >30 dorvilleids per dive. Given the improved oxygen conditions, the increase in dorvilleids is consistent with the broader overall increase in faunal numbers. Their increased presence at farm sites reflecting their preference for "moderately" enriched conditions.

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 the improved benthic conditions compared with previous years is consistent with the less severe decline in DO in the preceding spring of 2018 relative to that observed in spring 2017 and 2016. It would appear that there may be a trend developing of less severe DO declines in spring each year, which is in turn associated with improved benthic conditions – certainly, the signs are encouraging. However, it is important to remember that oxygen levels in the middle and bottom waters of the harbour are still lower than observed historically, and as such, the capacity to return to very low levels in spring remains. The cycle observed represents a complex interplay between the many factors that influence the consumption of oxygen (e.g. organic matter and nutrient inputs) and those that drive its resupply (e.g. wind, river flow). Each year our understanding of recovery dynamics in the harbour continues to improve; the next round of faunal surveys are scheduled for June 2019 and January 2020.

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 was no faunal survey in spring 2018, and as such there may well have been a decline which could not be represented in the schematic above. However, the faunal declines of the previous two springs were evident in the following January survey. In contrast, faunal abundance and species numbers in January 2019 remained high relative to the previous January surveys

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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 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.

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 packages described above plus the addition of a fourth work package that will see the installation

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

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 2019 and water column observations up until May 2019.

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).

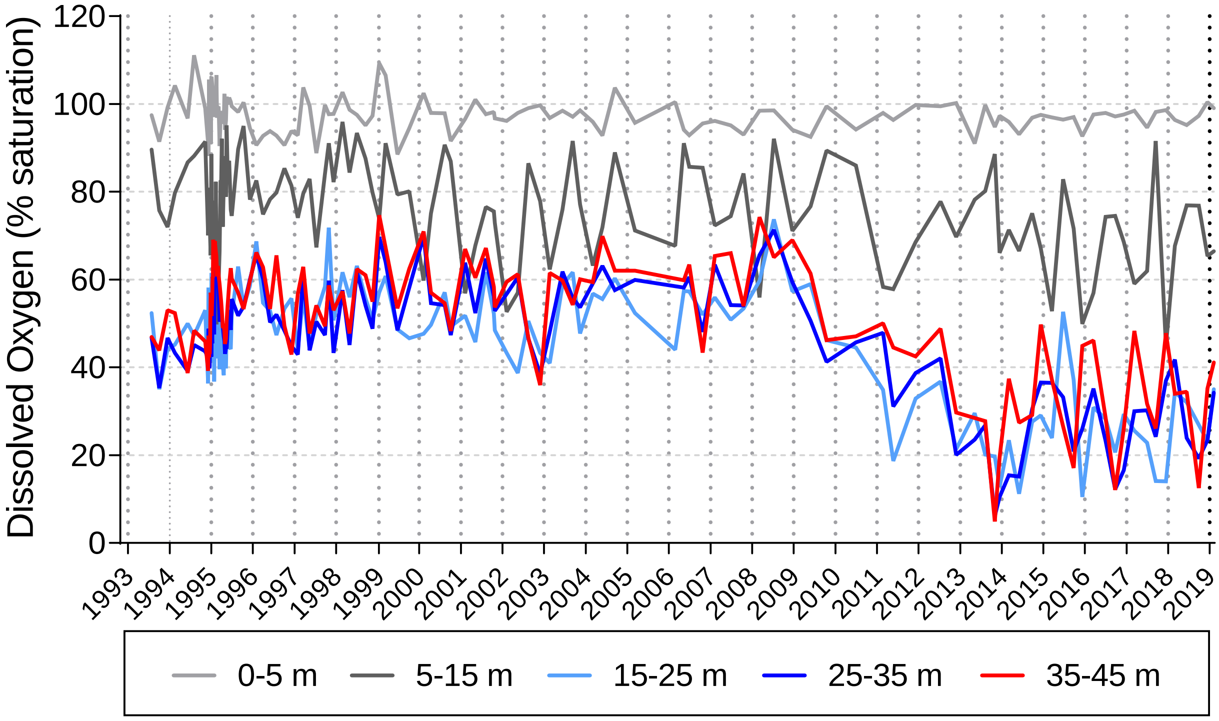

Figure 1 Long term trend in DO within a number of depth ranges at EPA site 12 (updated from MHDOWG 2014).

The contour plots produced from the three real time strings have been updated to include data up until late May 2019 (Figure 3-5). These figures demonstrate the sustained period of recharge and replenishment of bottom waters that extended from October 2018 through to May 2019. The replenishment of bottom water oxygen levels has coincided with low river flows and increased surface water salinities through much of this period (Figure 6 & 7).

In late summer/early Autumn 2019, there were several wind driven oxygenation events of the water column. Consistent with similar events reported previously (e.g. Ross et al., 2018) the mixing of the water column was concomitant with a period of strong west to north-westerly winds and low atmospheric pressure (Figure 1Figure 7). The most notable of these events occurred in late March (~24-26th); at the Table Head site this saw the mixing and oxygenation of the entire water column (Figure 5). At the Strahan site further up the harbour, the salinity and DO profiles provide evidence of the influence throughout the entire water column (Figure 8).

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.

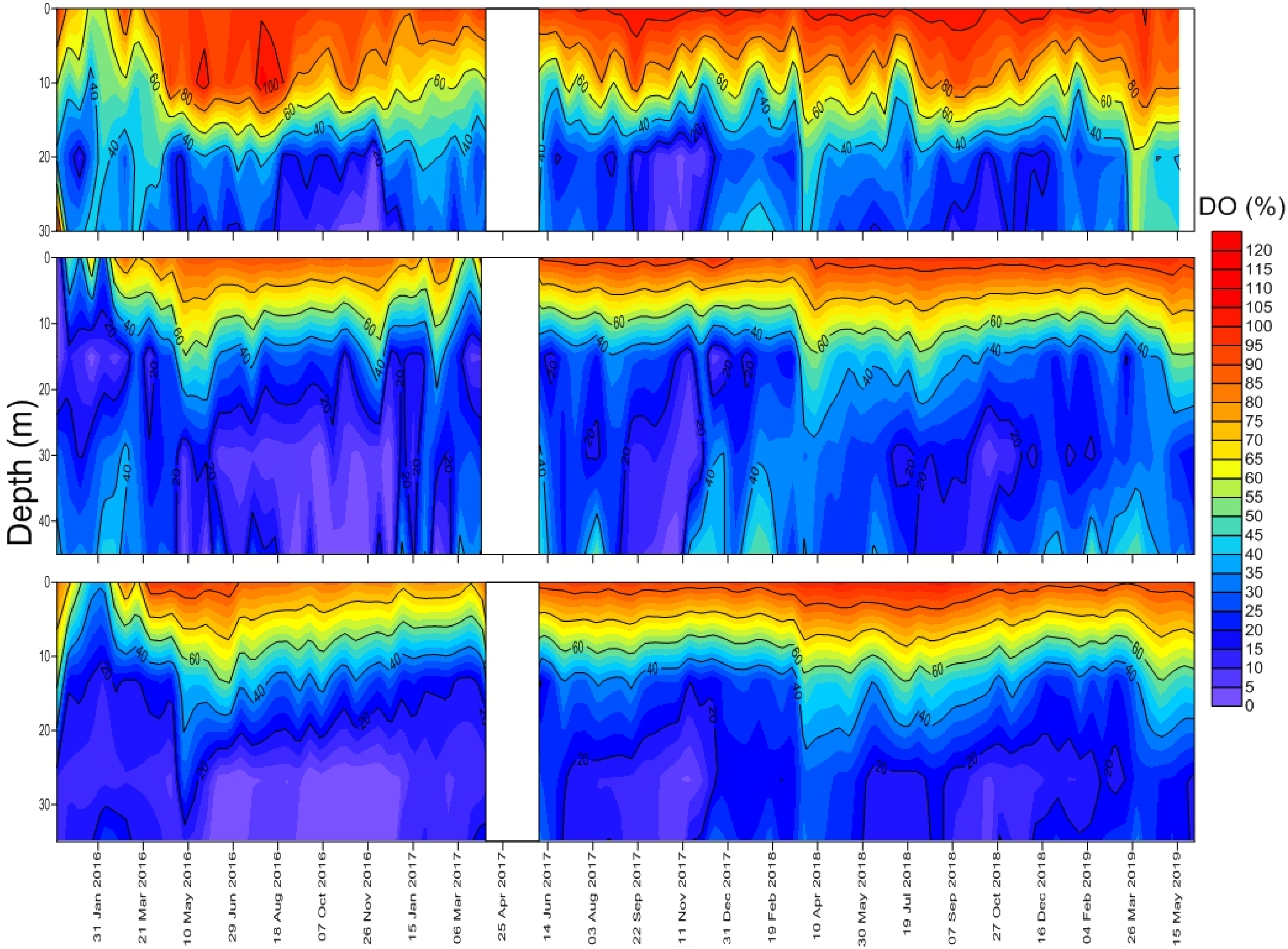

Figure 3 Contour plots showing DO profiles through the water column from the environmental strings at Table Head Central (top panel), Strahan (middle panel) and Franklin (bottom panel) over the period from December 2015 to late May 2019. Note, the data that underpins these plots for the period Dec 2015 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).

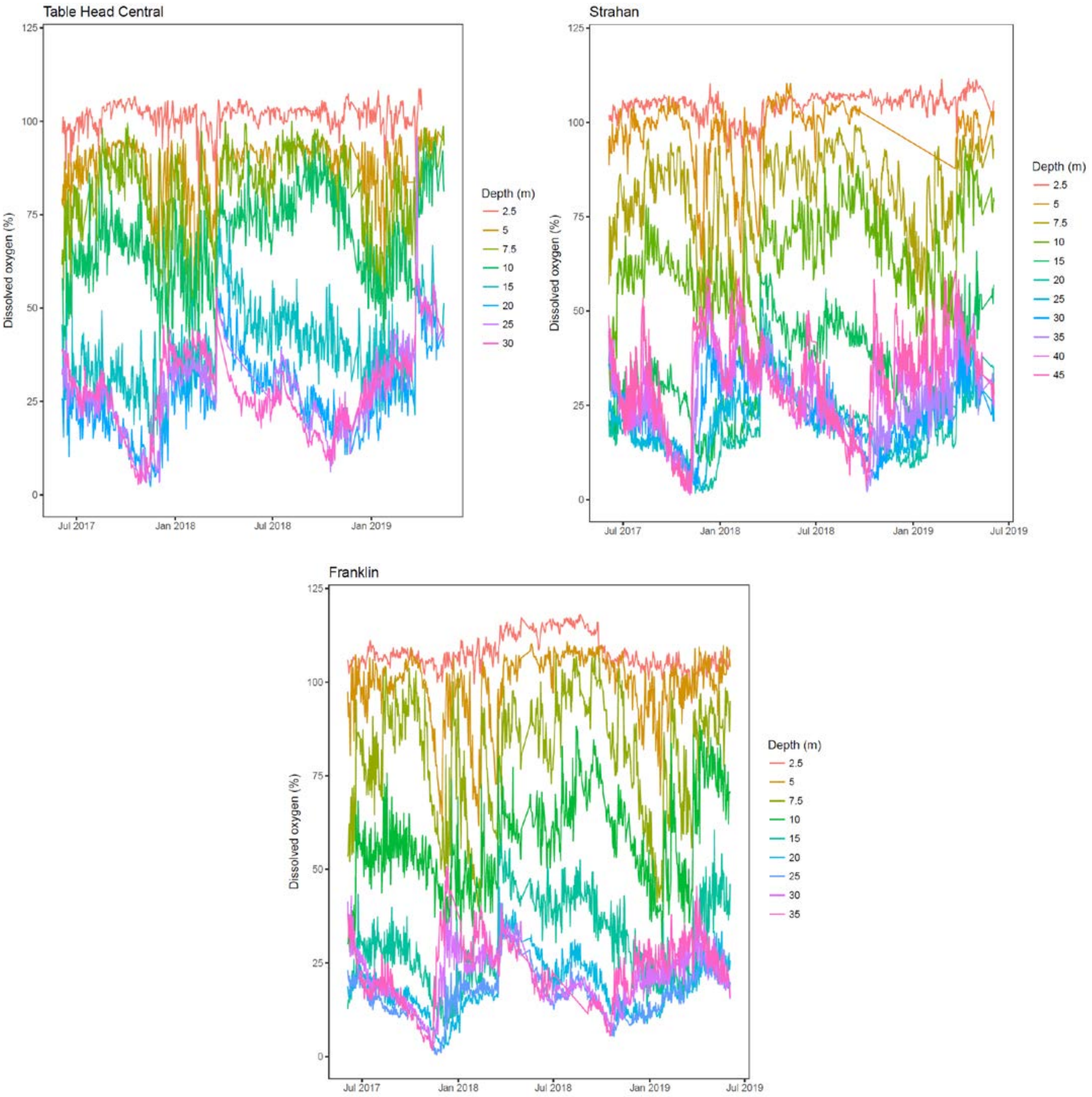

Figure 4 Daily mean DO (% saturation) levels at sensor depths from strings at Table Head Central, Strahan and Franklin over the period from the beginning of June 2017 to May 2019.

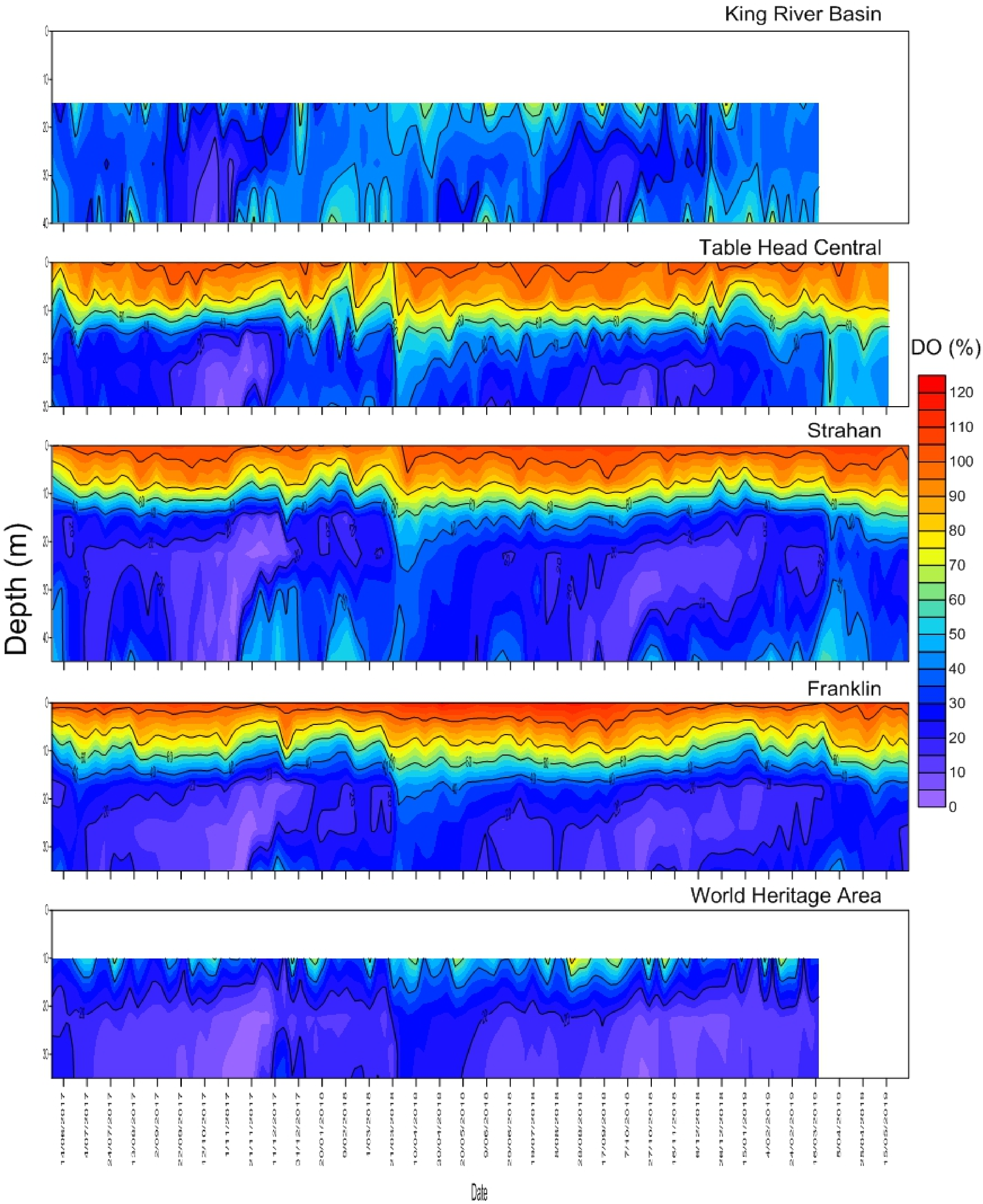

Figure 5 Contour plots showing DO profiles through the water column from the environmental strings at King River Basin, Table Head Central, Strahan, Franklin and the World Heritage Area over the period from the beginning of June 2017 to late May 2019. This represents the data from the upgrade to the 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.

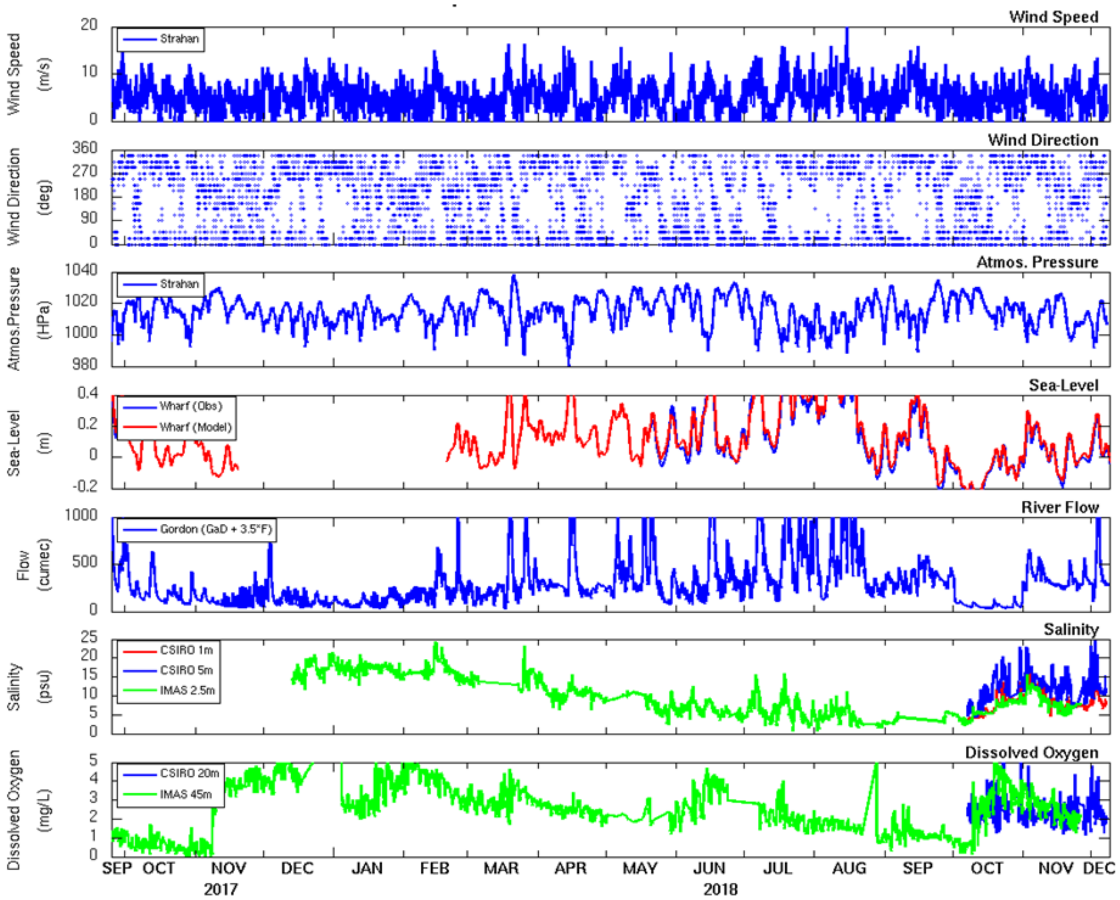

Figure 6 Time-series (September 2017 – December 2018) of concurrent environmental phenomena which may suggest favourable conditions for oxygen recharge.

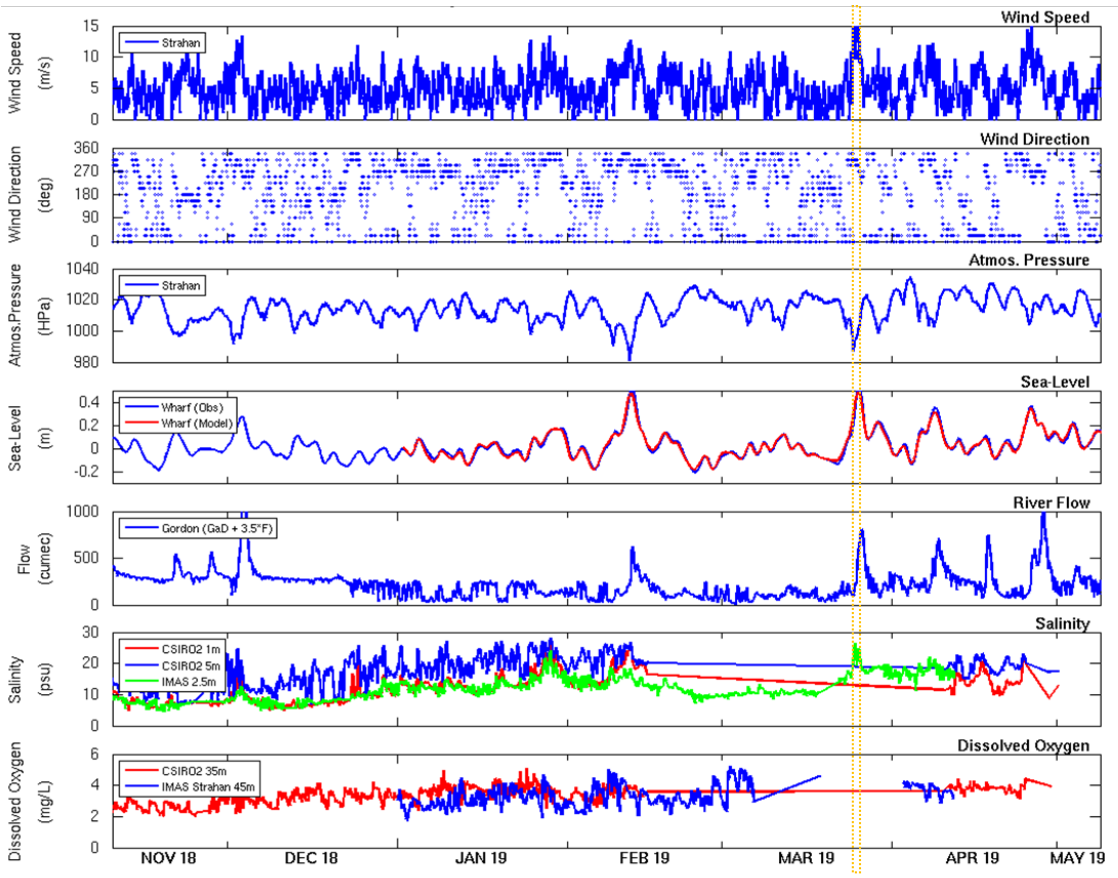

Figure 7 Time-series of concurrent environmental phenomena from November 2018 through May 2019 highlighting conditions associated with the wind driven oxygenation event in late March 2019.

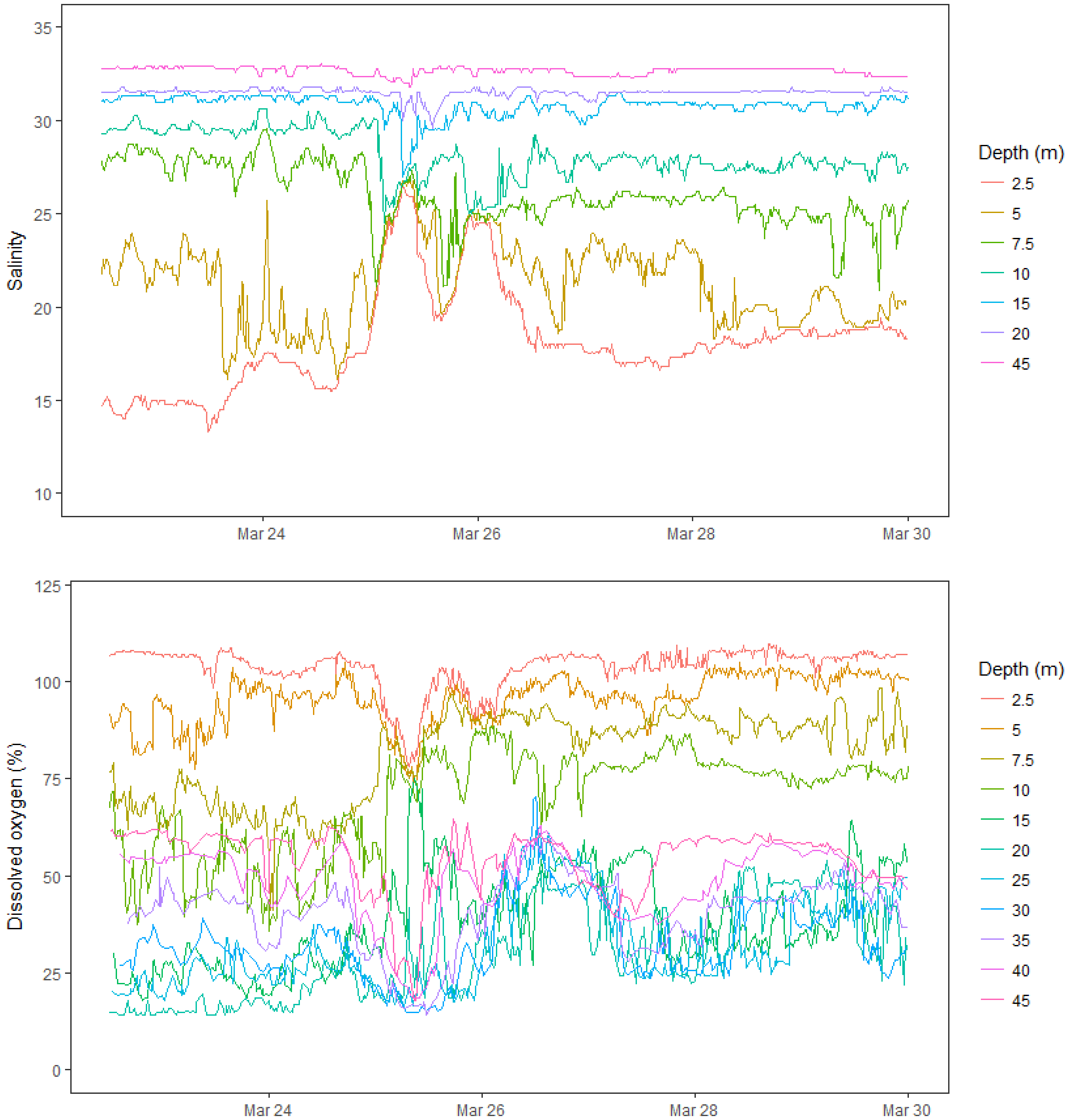

Figure 8 Salinity (ppt) and dissolved oxygen concentrations (% saturation) at sensor depths on the Strahan string during the late March 2019 wind driven mixing event.

BENTHIC CONDITION

In June 2018, IMAS conducted a benthic survey of five leases and 24 external sites as part of FRDC 2016-067 (Figure 9, Table 1). This represents the 12th 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

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 last report we noted that the subsequent decline in oxygen levels in Spring 2018 wasn't 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 suggest that the fauna was less affected as a result.

At lease 4, the northern most of the study leases, total abundance and number of species have increased at the majority of distances from the cage from that observed in June 2018, with the exception of the 0 m sites where abundance and the number of species had declined (Figure 10). Importantly, both total abundance and the number of species were higher in January 2019 compared with that observed in the January 2018 and 2017 surveys. This indicates that the faunal decline is spring 2018 was less severe than observed in the previous two springs and/or that faunal recovery was more rapid in summer 2018/19. Dissolved oxygen levels recorded on the bottom during the January survey remained relatively high compared to that observed in the previous spring surveys. Compared to the previous two January surveys, DO levels were lower than those observed in 2018 and similar to 2017. However, when considering the full time series at depth at the nearest string site (Table Head Central; Figure 3) it is evident that bottom water DO concentrations didn't decline to the same levels (or for as long) in spring 2018 compared with the previous two springs.

At lease 3 there was a decrease in the total abundance and number of species from that observed in June 2018, but this was most evident at the sites between 0 and 100m from the cages (Figure 11). Compared to the previous two January surveys, total abundance and the number of species was like that observed in 2018 and slightly greater than observed in 2017. Dissolved oxygen levels at

[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.

the time of the January 2019 surveys were relatively high and typical of this time of year based on previous surveys.

At lease 2, abundances increased at the cage site (o m) and decreased at the other distances compared with June 2018 and the number of species observed decreased slightly at all distances, with the exception of 500m, relative to that observed in June 2018 (Figure 12). Compared to the previous two January surveys, both total abundance and the number of species were greater in January 2019. This again appears consistent with a less severe decline in DO concentrations in bottom waters in spring 2018 (Figure 3).

Lease 1 – which is the most southern lease has seen a further increase in total abundance, and the number of species from that observed in June 2018 (Figure 13). Relative to the previous two January surveys, this site has seen an increase in total abundance, and most notably, the number of species in January 2019. The full time series of DO concentrations at depth at the nearest string site (Franklin; Figure 3) show that bottom water DO concentrations didn't decline to the same levels (or for as long) in spring 2018 compared with the previous two springs.

At lease 5, there are typically higher abundances and more species on the shallower SE transect as compared to the deeper NW transect. However, in the June 2018 survey the differences weren't as distinct as in previous surveys (Figure 14). This was again evident in the January 2019 survey, although both total abundance and the number of species had declined at most distances relative to that observed in June 2018. Compared to the previous two January surveys, both total abundance and the number of species on the SE transect were similar to that observed in 2018 but lower than observed in 2017. On the NW transect, both total abundance and the number of species were generally lower in January 2018 relative to that observed in January 2019 and 2017.

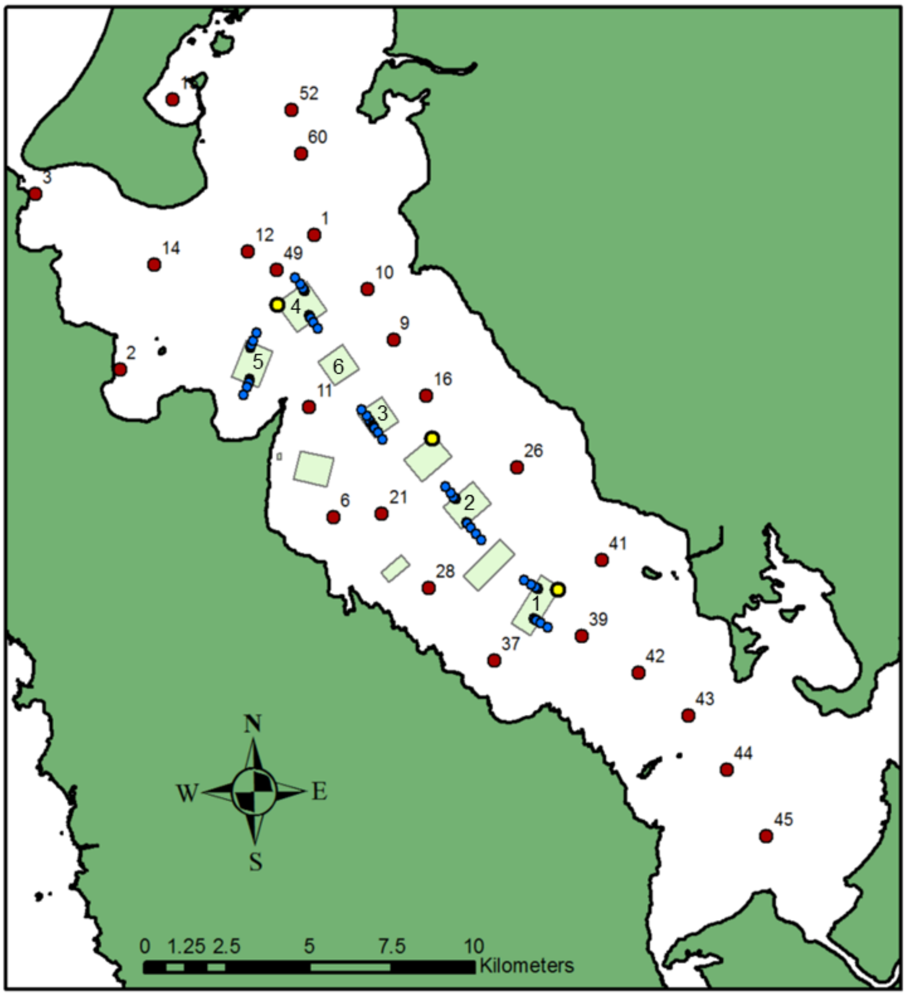

Figure 9 Maps showing external (red), lease (blue) and environmental string (yellow) sites. There are 2 transects from each of the study leases with five sites (at 0, 50, 100, 250 and 50om) on each transect.

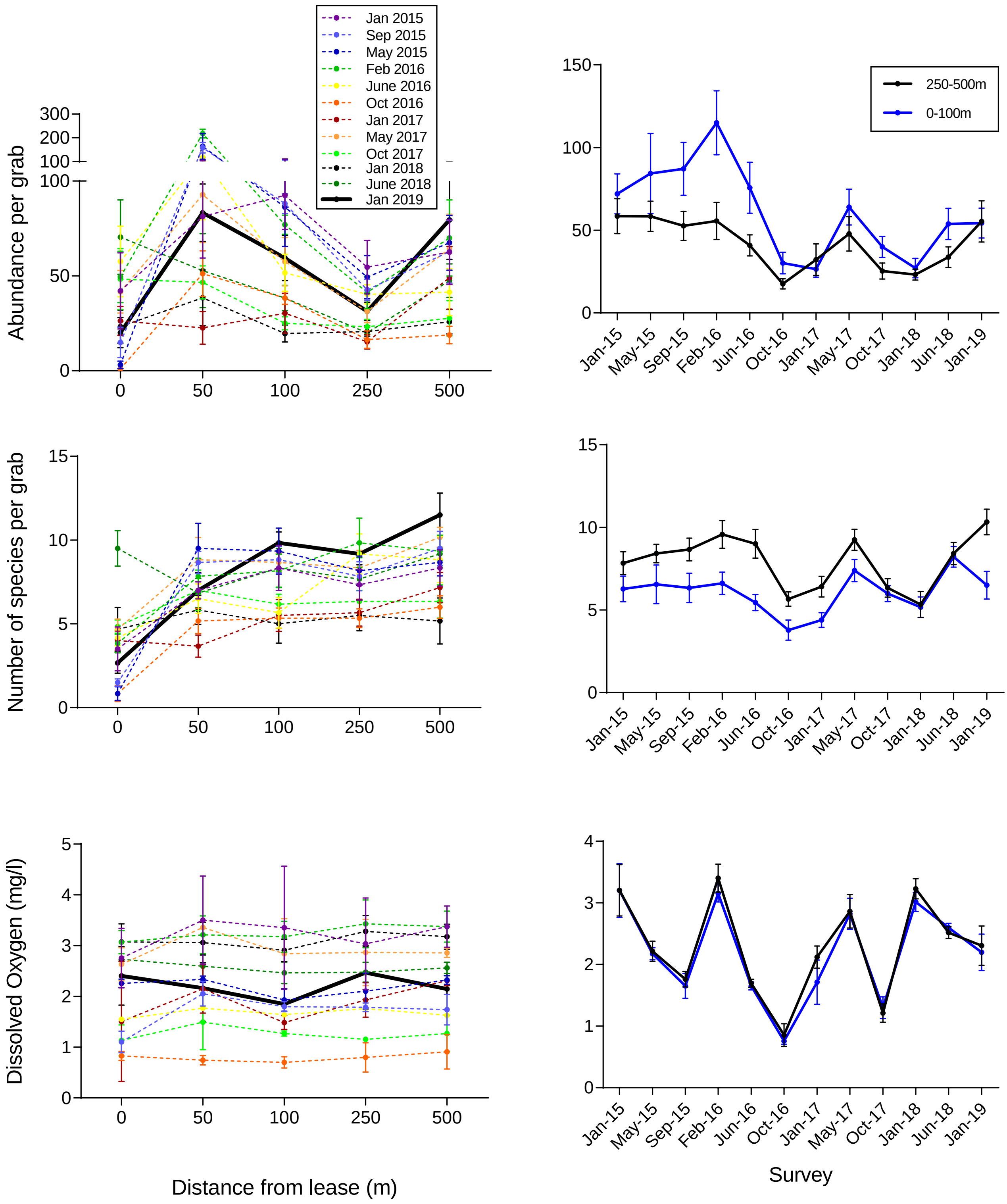

Figure 10 Lease 4 plots of total infaunal (>1mm) abundance (per grab = ~ 0.0675m²; top panel), number of species collected in grabs (n=3; middle panel) and the dissolved oxygen (mg/L) overlying the bottom (bottom panel) in relation to 1 (left panels): distance from the cage (0, 50, 100, 250 and 500m 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 2019) has been highlighted with a thick solid black line.

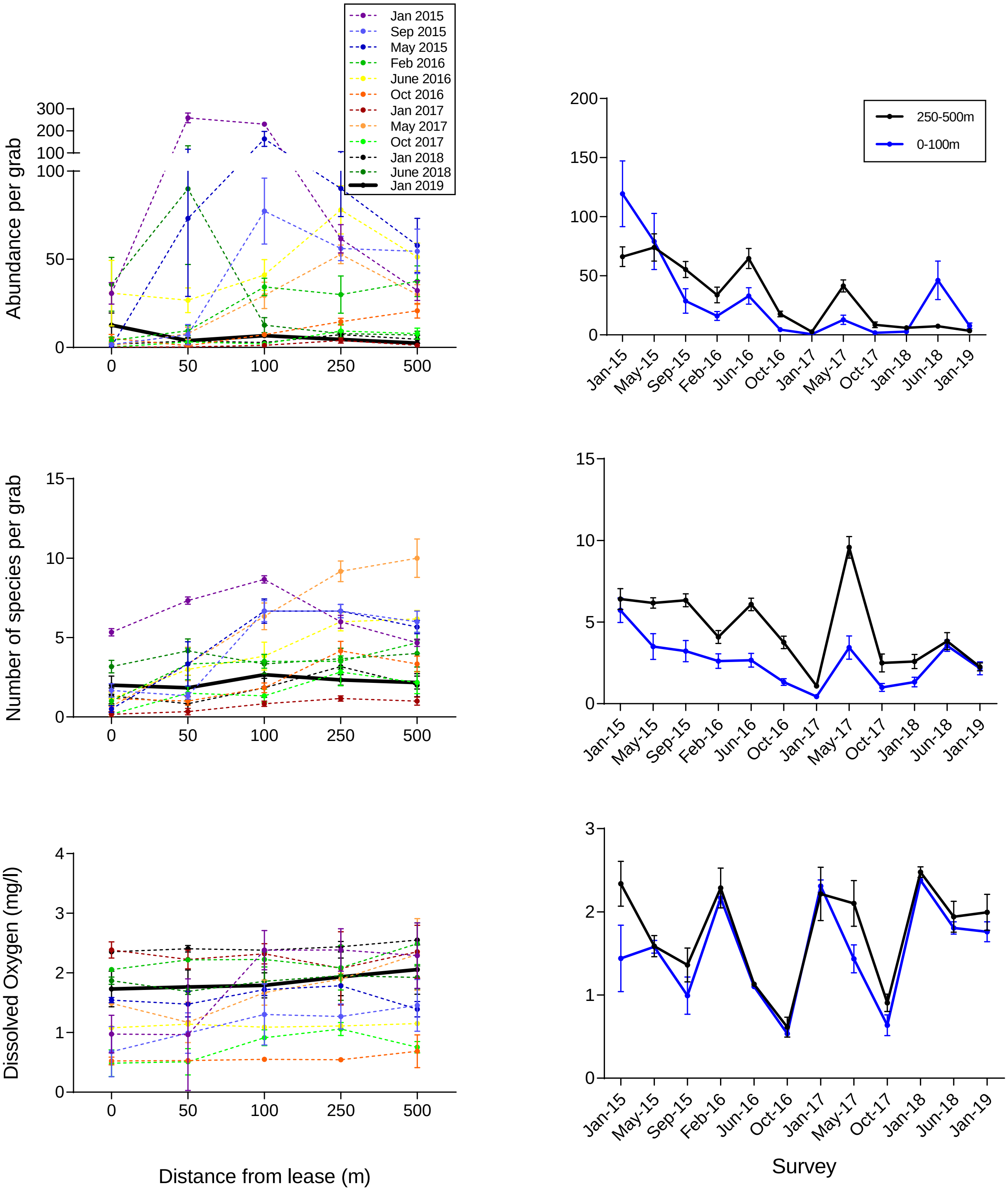

Figure 11 Lease 3 plots of total infaunal (>1mm) abundance (per grab = ~ 0.0675m^2; top panel), number of species collected in grabs (n=3; middle panel) and the dissolved oxygen (mg/L) overlying the bottom (bottom panel) in relation to 1 (left panels): distance from the cage (0, 50, 100, 250 and 500m 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 (Jan 2019) has been highlighted with a thick solid black line.

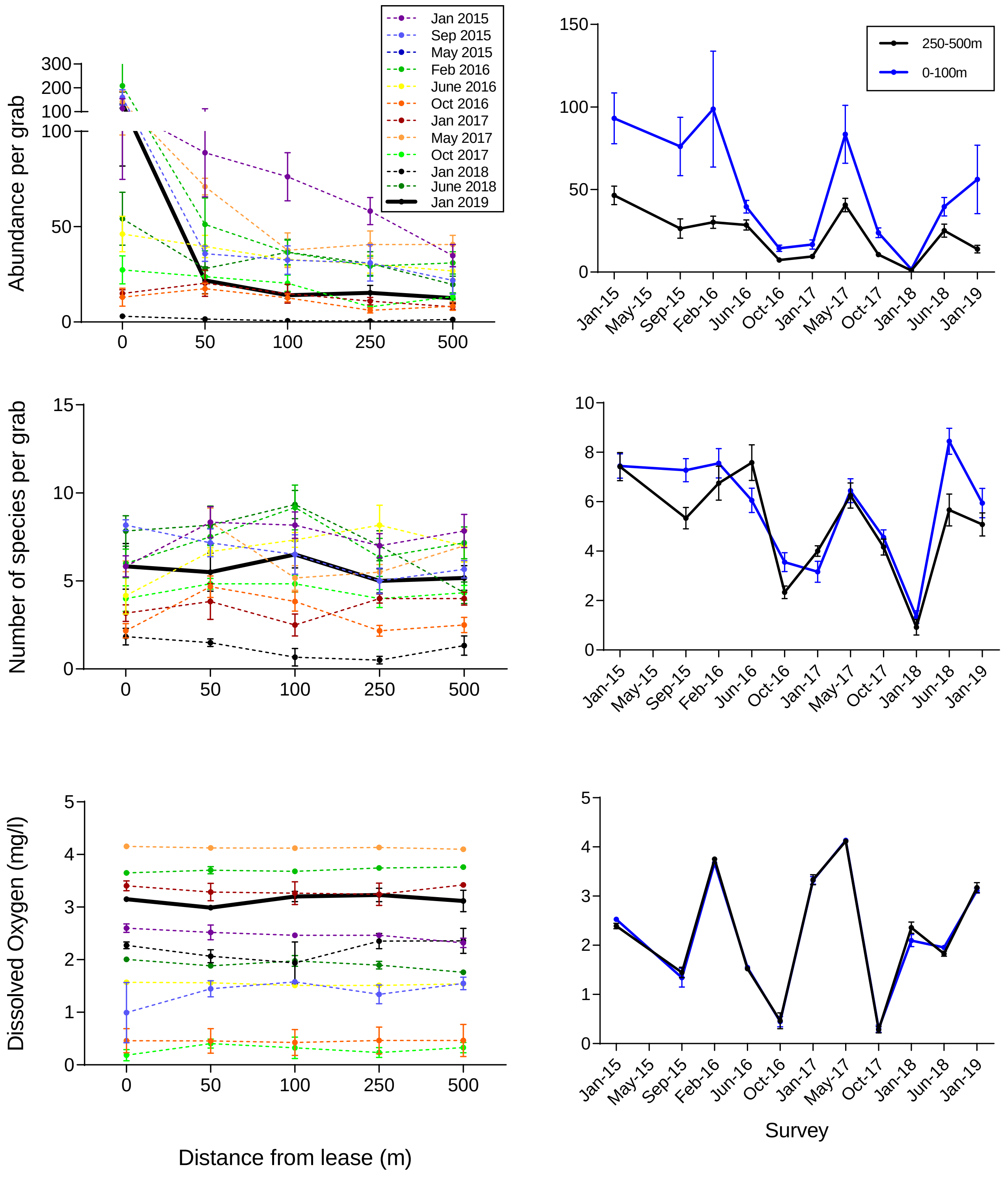

Figure 12 Lease 2 plots of total infaunal (>1mm) abundance (per grab = ~ 0.0675m^2; top panel), number of species collected in grabs (n=3; middle panel) and the dissolved oxygen (mg/L) overlying the bottom (bottom panel) in relation to 1 (left panels): distance from the cage (0, 50, 100, 250 and 500m 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 (Jan 2019) has been highlighted with a thick solid black line. Note, lease 2 was not surveyed in May 2015.

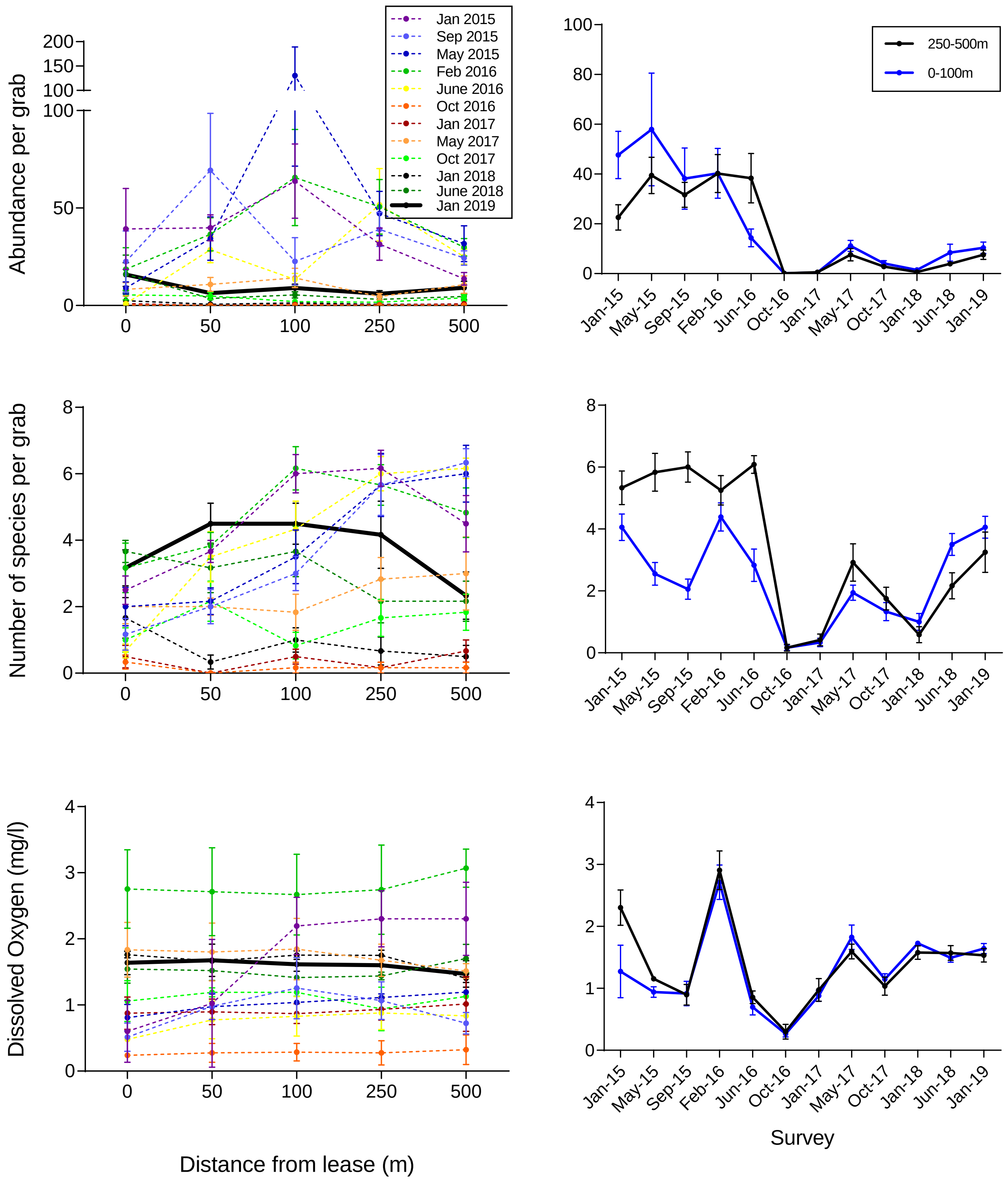

Figure 13 Lease 1 plots of total infaunal (>1mm) abundance (per grab = ~ $0.0675m^2$; top panel), number of species collected in grabs (n=3; middle panel) and the dissolved oxygen (mg/L) overlying the bottom (bottom panel) in relation to 1 (left panels): distance from the cage (0, 50, 100, 250 and 500m 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 (Jan 2019) has been highlighted with a thick solid black line.

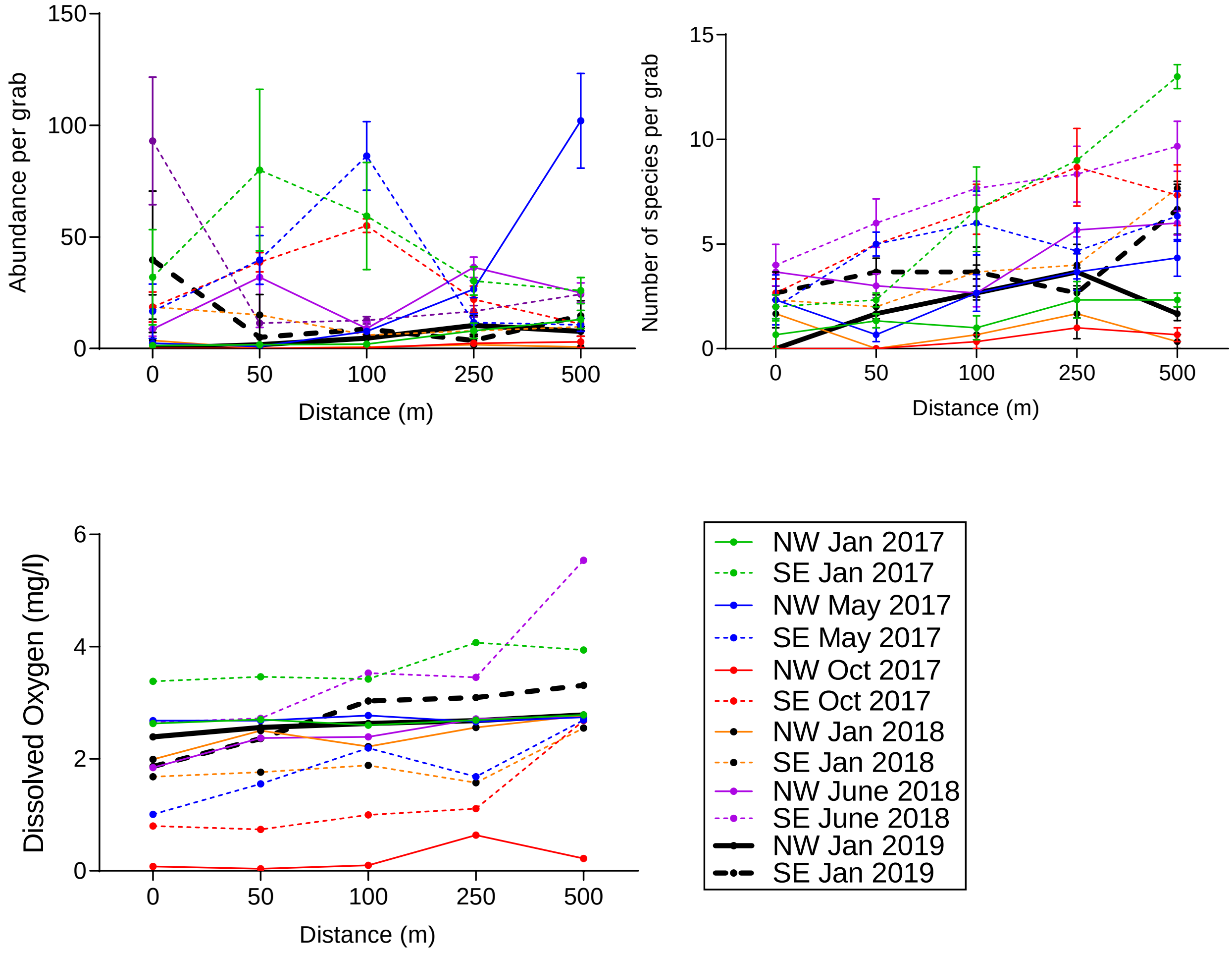

Figure 14 Plots of total infaunal (>1mm) abundance (per grab = ~ $0.0675m^2$), number of species collected in grabs (n=3; middle panel) and the dissolved oxygen (mg/L) overlying the bottom (at 0, 50, 100, 250 and 500m from cages at lease 5 during the January 2017 – January 2019 surveys. The data shows 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 15). 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 16).

Faunal abundance and species numbers at most of the external sites in the January 2019 survey was within the range recorded in our surveys prior to the decline in spring 2016 – early 2017, and consistent with observations in the more recent surveys. Faunal abundances at four of the southernmost external sites (39, 42, 43 and 44) has remained low relative to that observed prior to the original decline from spring 2016 – early 2017, however, abundance increased at all of these sites in the January 2019 survey. At three of these sites (39, 42 and 44) abundances are arguably within (if not closely approaching) the range observed prior to the decline. For species numbers this is even more notable, with the numbers observed in January 2019 at all 4 sites well within the range observed prior to the decline.

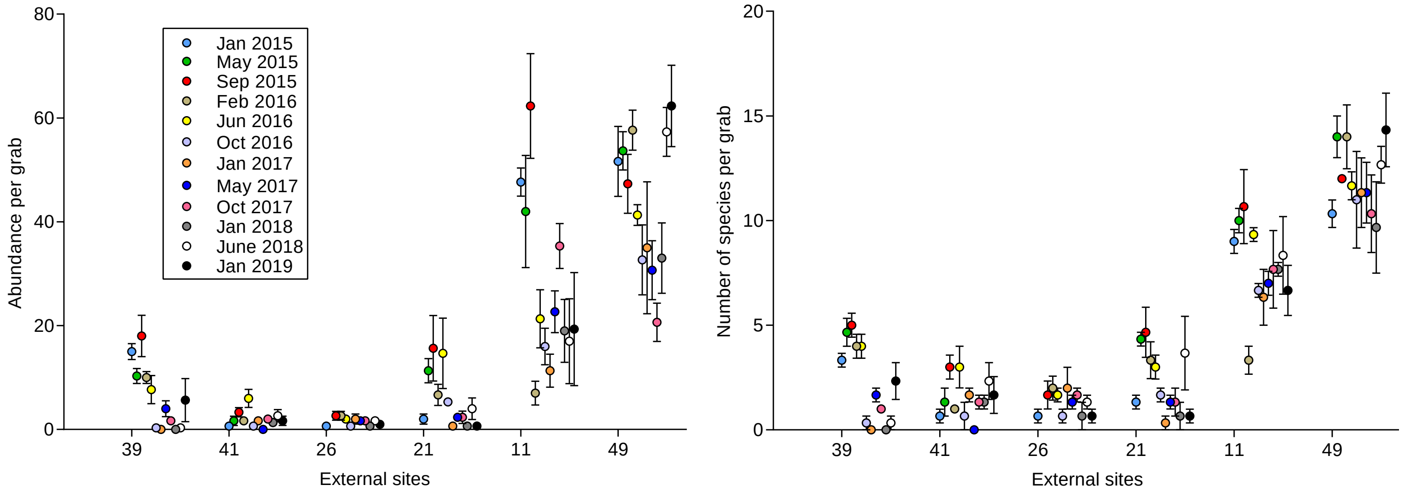

Figure 15 Plots of total infaunal (>1mm) abundance (per grab = ~0.0675m²) and number of species collected in grabs (n=3) at 7 external sites in Macquarie Harbour from surveys between January 2015 and Jan 2019. The data for each site represents the mean (±SE) from three replicate grabs. Note that site 26 was not surveyed in May 2015.

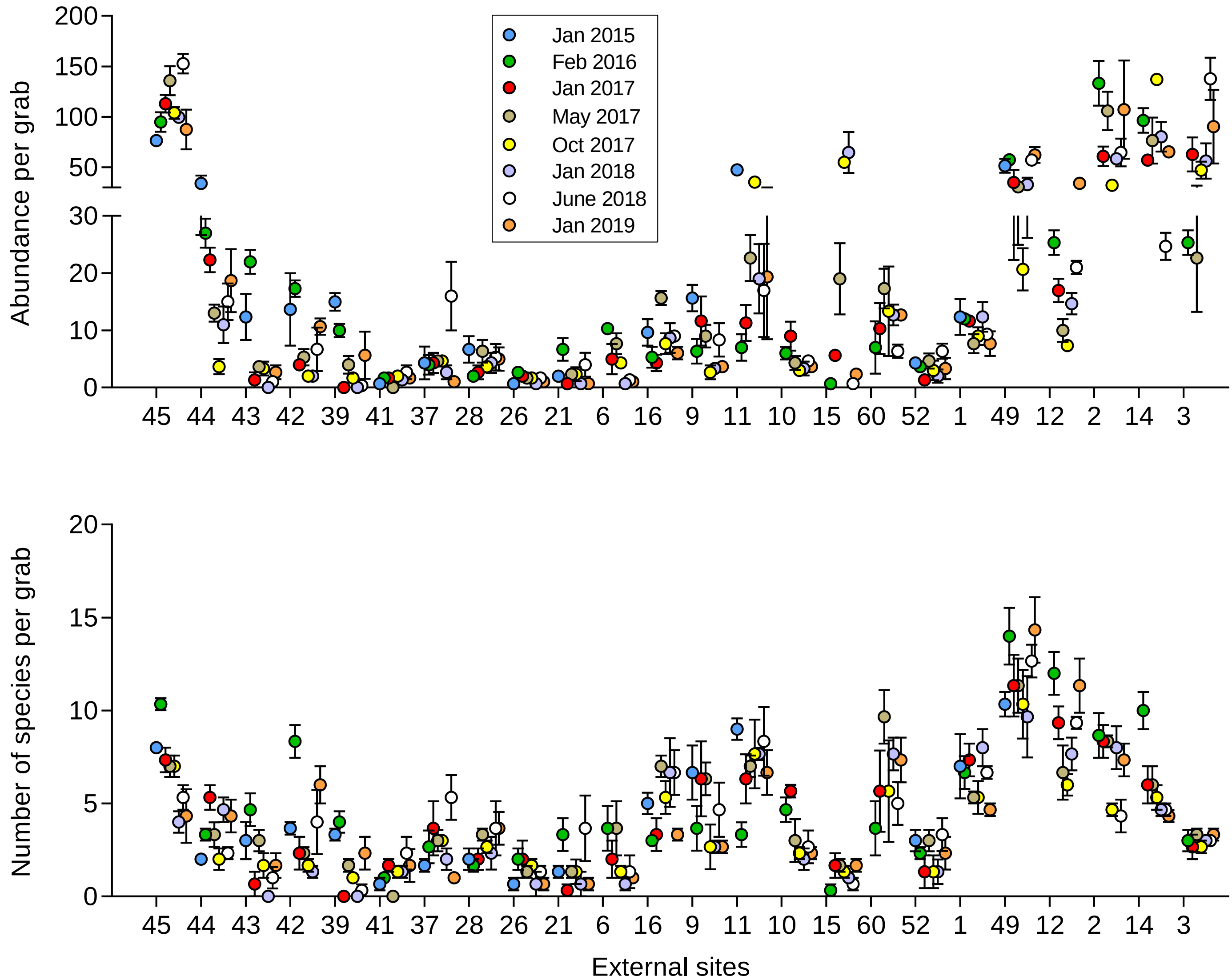

Figure 16 Plots of total infaunal (>1mm) abundance (per grab = ~0.0675m²) and number of species collected in grabs (n=3; bottom panel) at 23 external sites in Macquarie Harbour from surveys in January 2015, February 2016, January 2017 and May 2017, September 2017, January 2018 and June 2018. In the top 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 spring 2018, a video assessment of all sites was completed in September 2018. The results of this survey have been included 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 and January 2019 video surveys demonstrated that the presence of *Beggiatoa* remains low relative to that observed in the October 2016 and January 2017 surveys (Table 4). In the January 2019 survey, *Beggiatoa* was observed on fewer of the lease dives (13 of 51) than the previous three surveys in January, May and September 2018 (20-21 of 51). In September 2018 there were two observations of streaming *Beggiatoa* and three observations of *Beggiatoa* forming thick mats. In January 2019, there was also one observation of streaming *Beggiatoa*. Most of these occurrences were on leases 3 and 5 and all observations scoring higher than patchy (thick patchy/thin mat/thick mat/streaming) were within 50m of the cage and within the lease boundaries. There was one observation of patchy *Beggiatoa* outside the lease boundaries in September 2018 and none in the January 2019 survey. At the external sites, *Beggiatoa* was observed at 4 of the 28 sites in the September 2018 and January 2019 surveys, with all cases being categorised as patchy/thick patchy (Table 4, Figure 17). All four observations of *Beggiatoa* were at more southern sites beyond the leases.

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). 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%). But in January 2019 (88%), there was an increase in the presence of dorvilleids on farm dives relative to the previous three surveys. The increase in January 2019 also coincided with an

[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.

increase in the observations of the more abundant categories (i.e. > 100 dorvilleids in a dive), with the majority of these being either within 100m of the cage or on the lease (Figure 18). There was also an increase in dorvilleids at the external sites; with dorvilleids observed on 61% of dives in January 2019 as compared to 39-43% across the three surveys prior. In the January 2019 survey dorvilleids were not observed at the external sites at levels greater than 100 dorvilleids per dive, and most observations were in the central and southern regions of the harbour (Figure 18).

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 5 and 6 of 79 ROV dives in September 2018 and January 2019 respectively. All these observations were in close proximity to the cages and not at external sites. The broader distribution of dorvilleids seen in Figure 18 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%	0%	0%		
	Lease	51	61%	22%	0%	8%	6%	4%
Jan-19	External	28	86%	7%	7%			
	Lease	51	75%	12%	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%	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%
May-18	External	28	61%	39%				
	Lease	51	31%	22%	22%	16%	8%	2%
Sep-18	External	28	57%	43%				
	Lease	51	39%	27%	16%	10%	6%	2%
Jan-19	External	28	39%	50%	11%			
	Lease	51	12%	18%	25%	18%	10%	18%

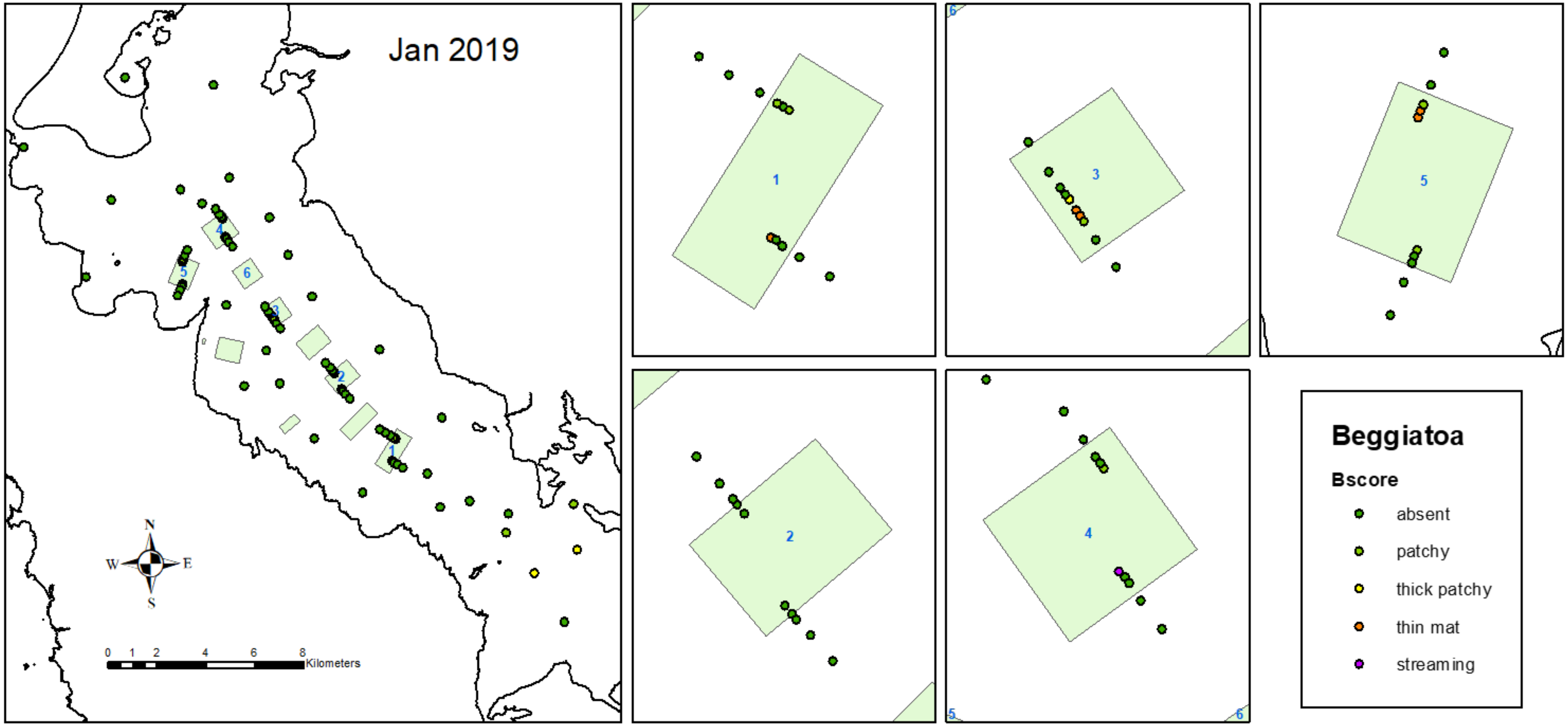

Figure 17 *Beggiatoa* score (severity) from ROV footage at study sites across the harbour on the left panel and shown in more detail for each of the study leases in the panels on the right.

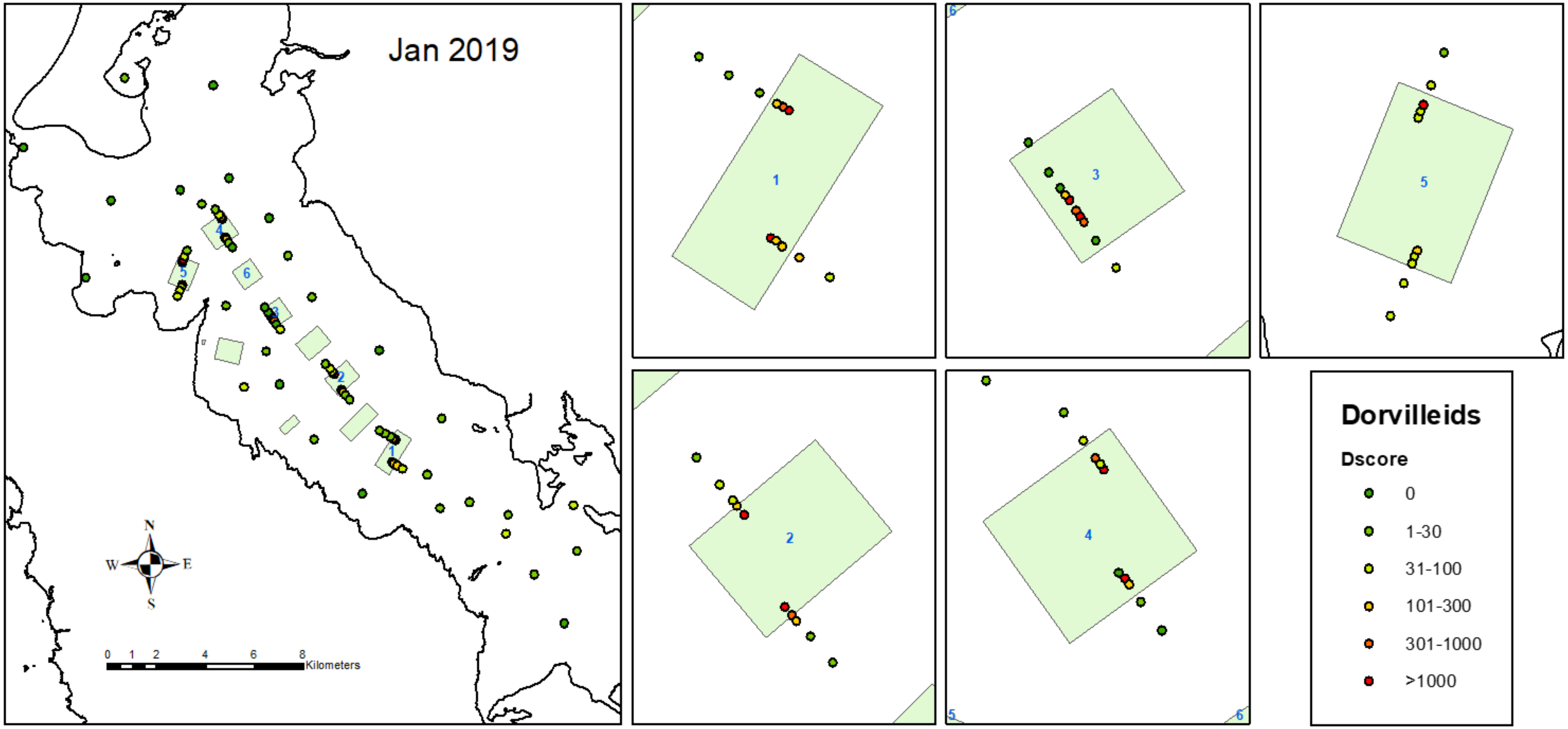

Figure 18 *Dorvilleid* score based on counts from ROV footage at study sites across the harbour on the left panel and shown in more detail for each of the study leases in the panels on the right.

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