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 and June 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. In the June 2018 report we highlighted that oxygen concentrations in the middle and bottom waters 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 June 2018 and DO monitoring data up until the beginning of October 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).

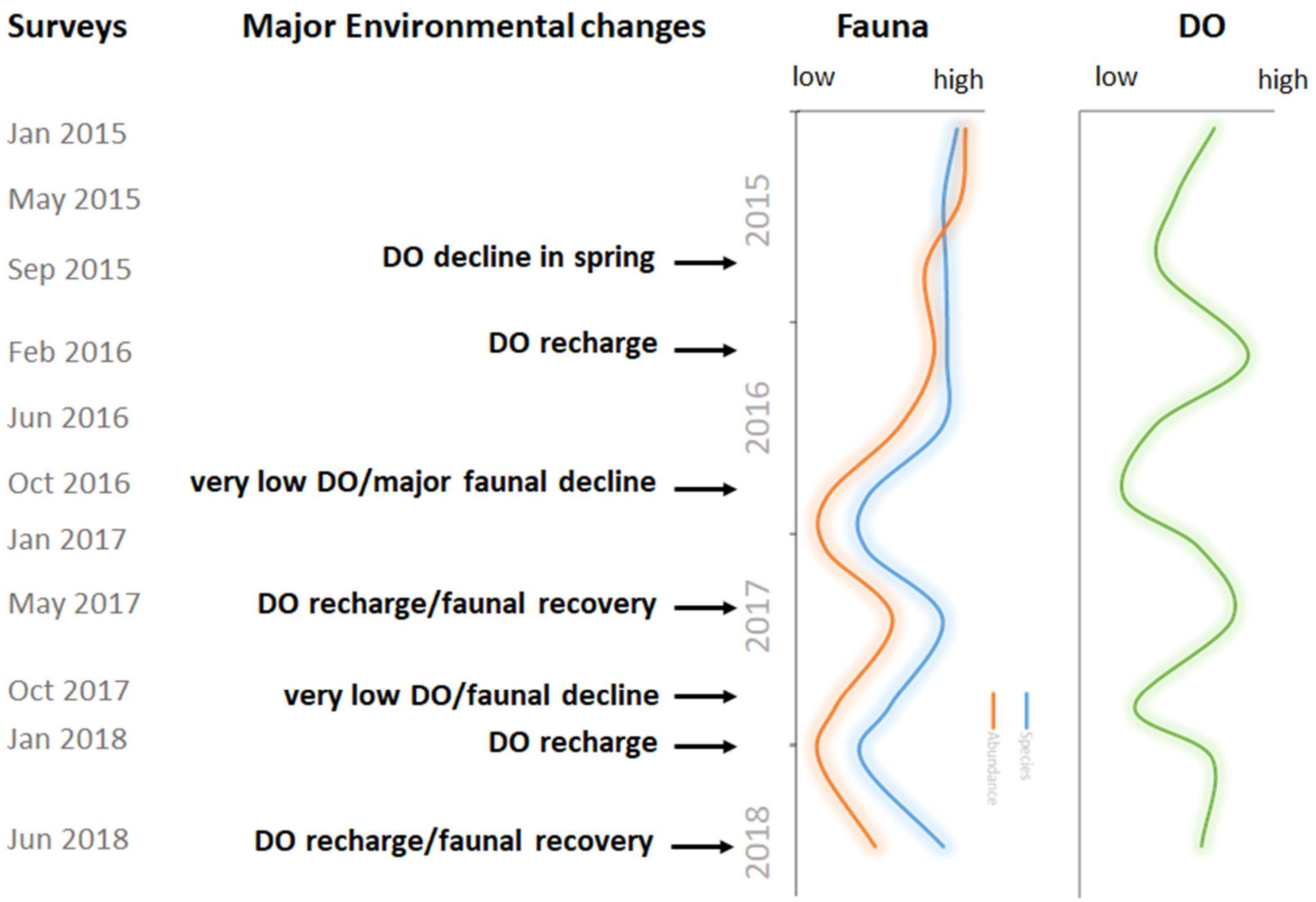
The improved oxygen concentrations observed in the middle and bottom waters during summer 2017/18 extended through to the middle of 2018. This was reflected in the June 2018 survey of benthic fauna; the abundance and number of species increasing at all five leases from that observed in the October 2017 and January 2018 surveys. Faunal abundance and species numbers at the majority of the external sites in the June 2018 survey remain typical of those recorded historically and consistent with observations in recent surveys. At the deeper external sites to the south where abundances have remained low relative to observations prior to the noted decline in spring 2016 – early 2017, there has been some improvement at two of these sites.

The presence of *Beggiatoa* remains low relative to that observed in spring 2016/summer 2017; although it was observed on 21 of 51 lease dives in the May 2018 video survey this corresponded to observations of patches and fewer observations of *Beggiatoa* forming extensive mats. At the external sites, *Beggiatoa* was observed at 3 of the 28 sites and in all cases noted as patchy. In the January 2018 survey we reported a reduction in the number of sites where dorvilleid polychaetes were observed and a reduction in the number of sites with very high dorvilleid scores (>300 abundance categories). In the May video survey, there was a further reduction in the number of observations of the more abundant categories (i.e. > 100 dorvilleids in a dive) and there were no observations at the external sites of >30 dorvilleids per dive.

Since the June faunal survey, oxygen concentrations in the middle and bottom waters again declined into spring, but at this stage it doesn't appear to be to the same extent as observed in recent years. In early October 2018 there was recharge of bottom water oxygen levels in deeper waters, and this corresponded to low river flows, increased surface salinities and a period of low sea levels. The month of October was the third driest on record in Tasmania and inflows from the Gordon River were further reduced due to the shutdown of the power station for maintenance for the month.

The next faunal survey in January 2019 together with the full time series of oxygen through spring 2018 and summer 2019 will show if the fauna in the deeper central region was less affected by the spring 2018 decline in oxygen levels given that it appears to be not as significant as observed in the previous two years; particularly compared to the declining oxygen concentrations in spring 2016 that extended into the summer months.

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).


Surveys
Major Environmental changes
Fauna
DO
low
high
low
high
Jan 2015
May 2015
Sep 2015
Feb 2016
Jun 2016
Oct 2016
Jan 2017
May 2017
Oct 2017
Jan 2018
Jun 2018
DO decline in spring
DO recharge
very low DO/major faunal decline
DO recharge/faunal recovery
very low DO/faunal decline
DO recharge
DO recharge/faunal recovery
2015
2016
2017
2018

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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.

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

[1] 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 winter 2018 and water column observations up until late October 2018.

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).

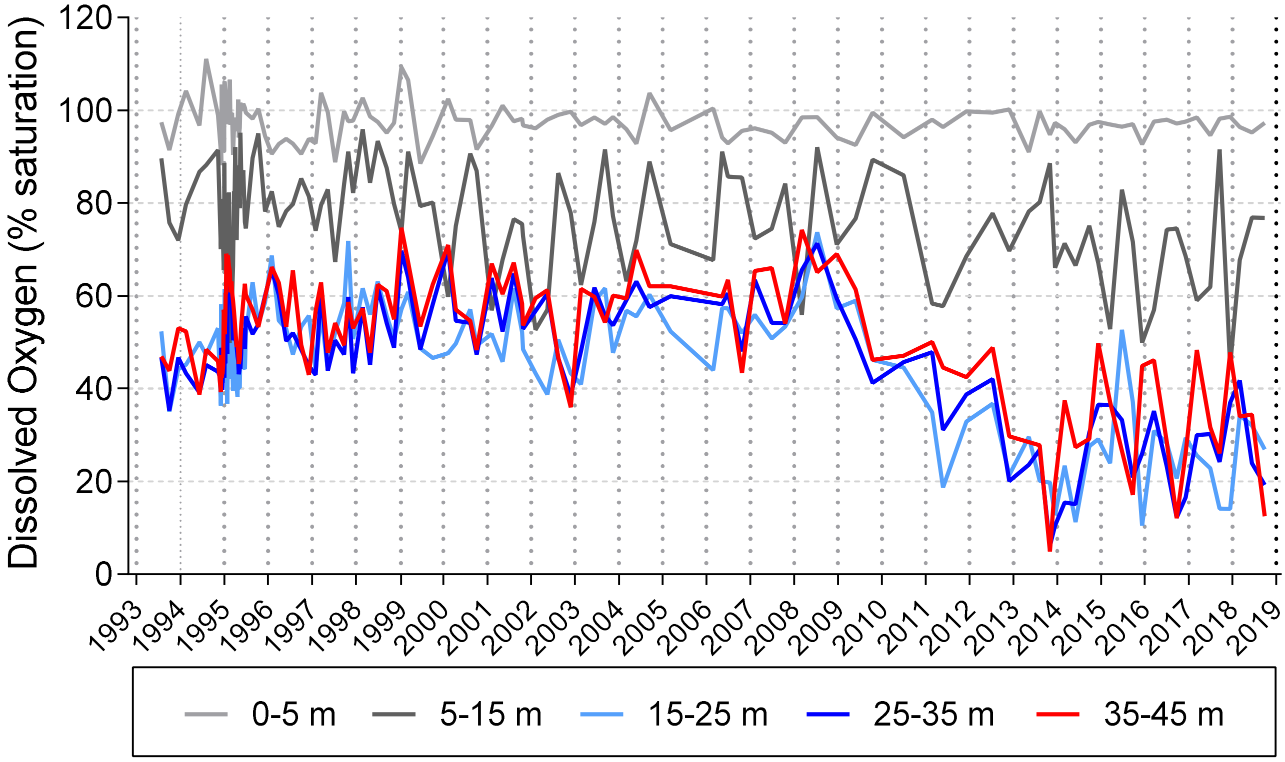

Figure 1 Long term trend in DO within a number of depth ranges at EPA site 12 (updated from MHDOWG 2014).

The contour plots produced from the three real time strings have been updated to include data up until late October 2018 (Figure 3-5). These figures demonstrate the recharge and replenishment of bottom waters that has extended from early November 2017 through to the middle of 2018. Whilst DO concentrations in the middle and bottom waters are again declining in spring, it doesn't appear to be to the same extent as in previous years and certainly not like that observed in 2016. The oxygen figures for Strahan, the deeper of the 3 sites, indicate that there has been some recharge and replenishment of bottom water oxygen levels in early October 2018. This is further highlighted in Figure 6 where it is evident that the replenishment of bottom water oxygen levels coincided with low river flows, increased surface water salinities and a period of low sea levels. The month of October was the third driest on record[2] in Tasmania and inflows from the Gordon River were further reduced due to the shutdown of the power station for maintenance for the month.

[2] *http://www.bom.gov.au/climate/current/month/tas/archive/201810.summary.shtml*

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.

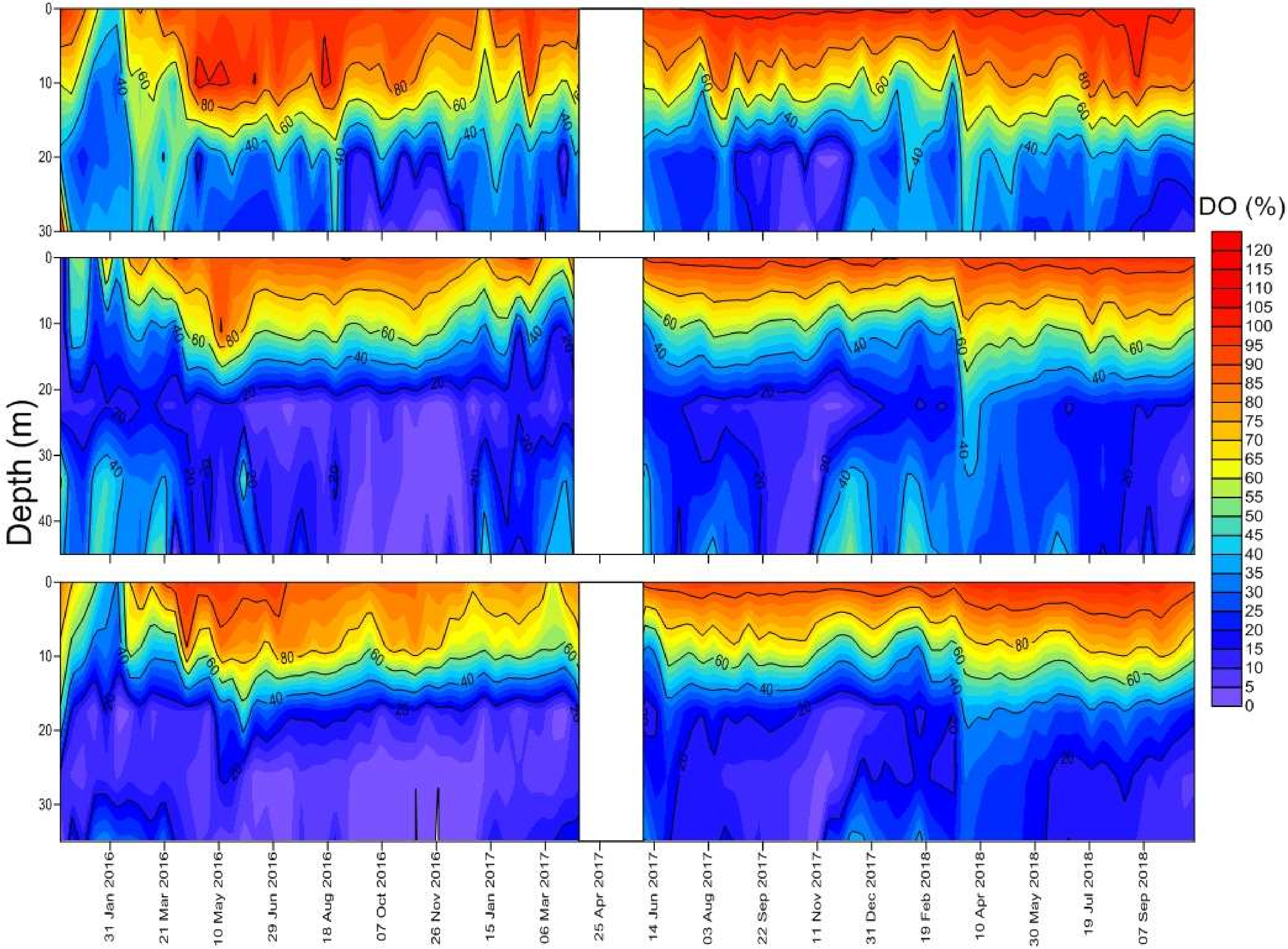

Figure 3 Contour plots showing DO profiles through the water column from the environmental strings at Table Head Central (top panel), Strahan (middle panel) and Franklin (bottom panel) over the period from December 2015 to late October 2018. Note, the data that underpins these plots for the period Dec 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).

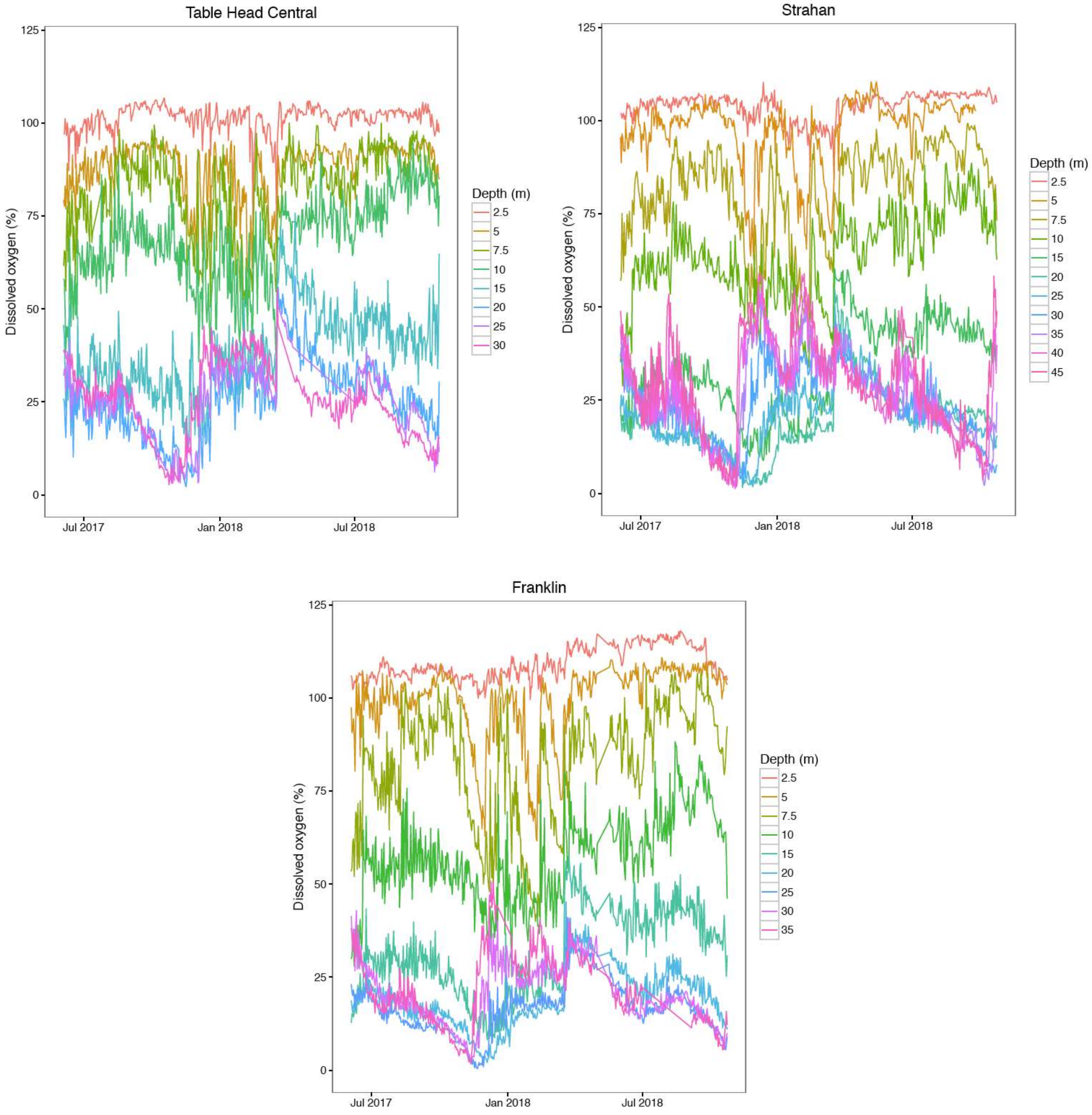

Figure 4 Daily mean DO (% saturation) levels at sensor depths from strings at Table Head Central, Strahan and Franklin over the period from the beginning of June 2017 to late October 2018.

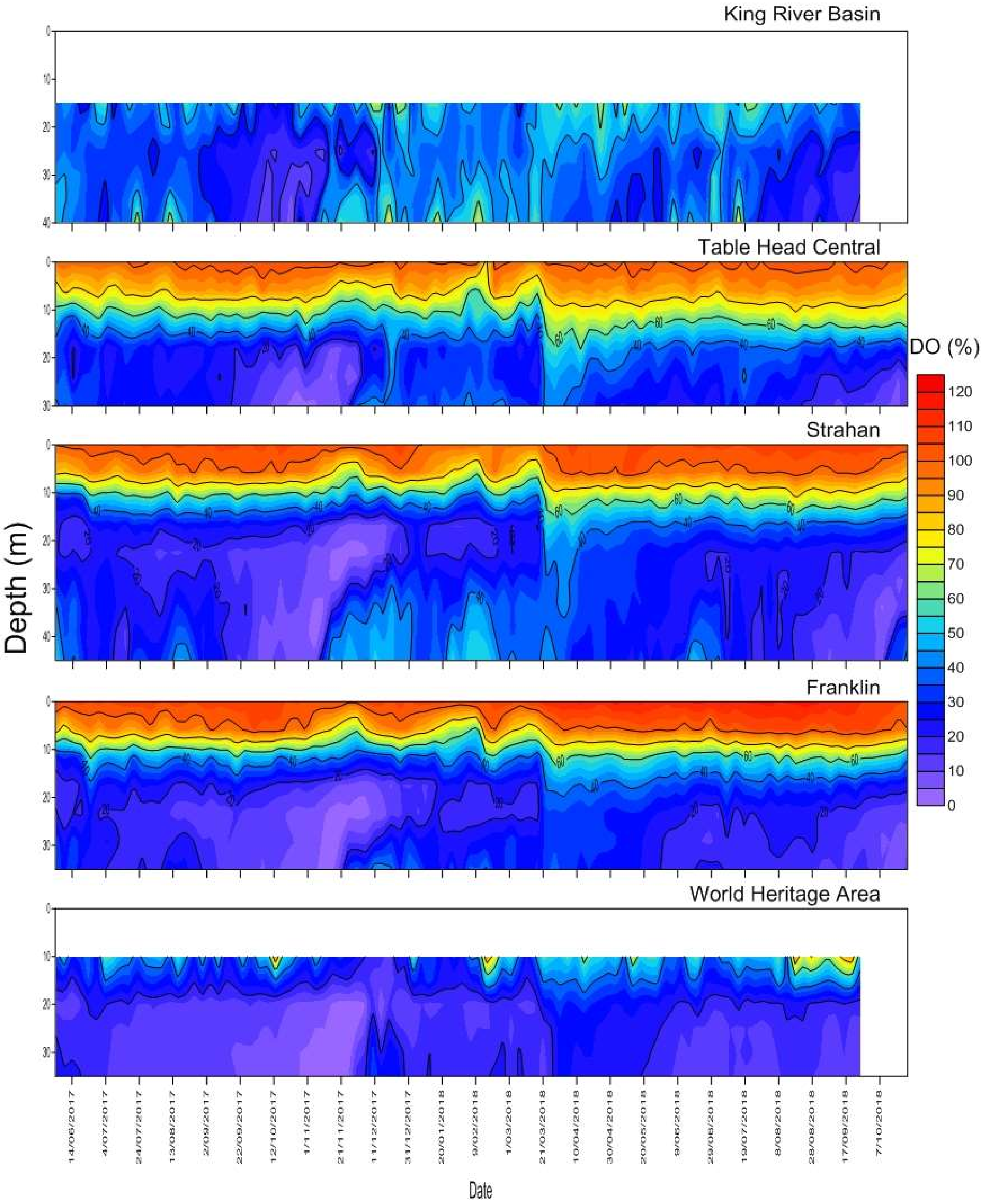

Figure 5 Contour plots showing DO profiles through the water column from the environmental strings at King River Basin, Table Head Central, Strahan, Franklin and the World Heritage Area over the period from the beginning of June 2017 to late October 2018. This represents the data from the upgrade to 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.

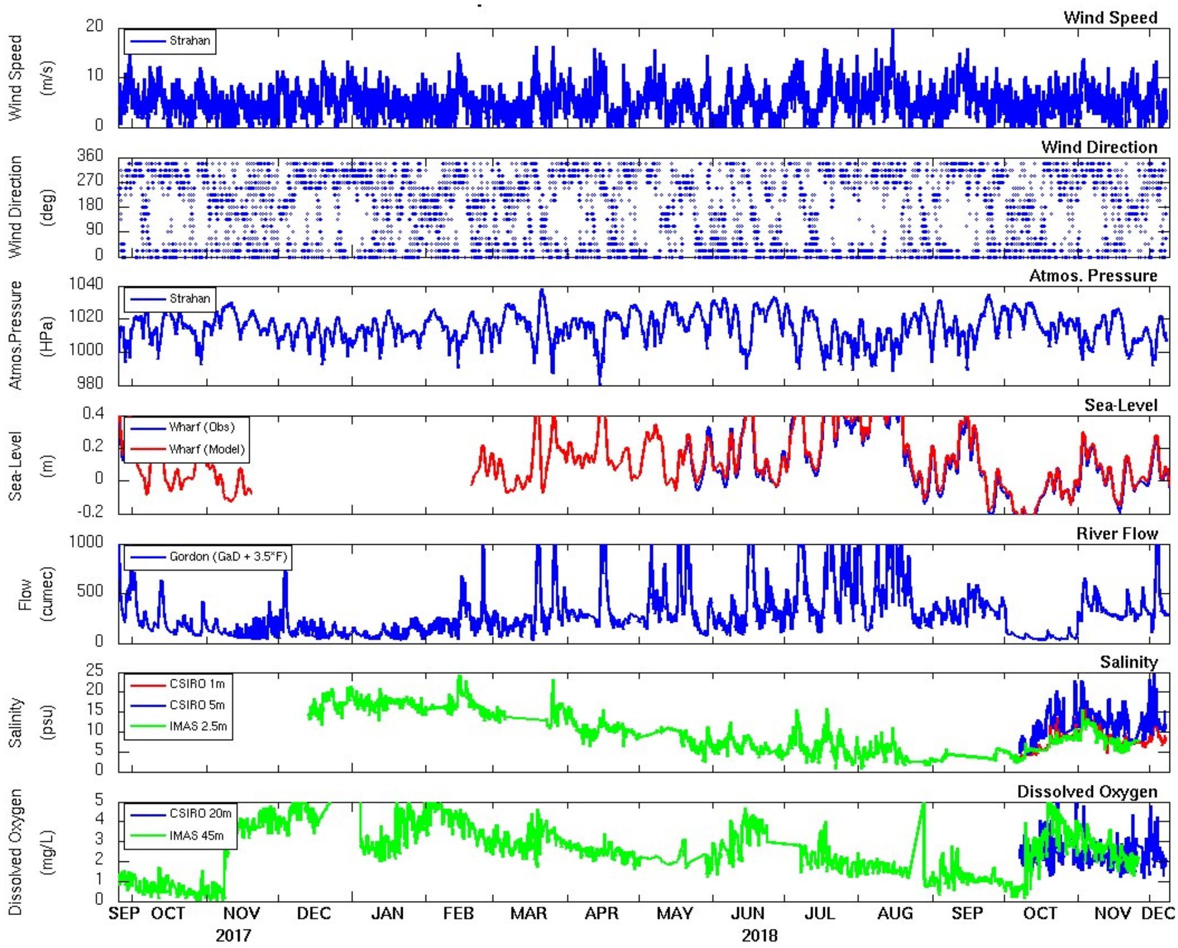

Figure 6 Time-series (September 2017 – December 2018) of concurrent environmental phenomena which may suggest favourable conditions for oxygen recharge.

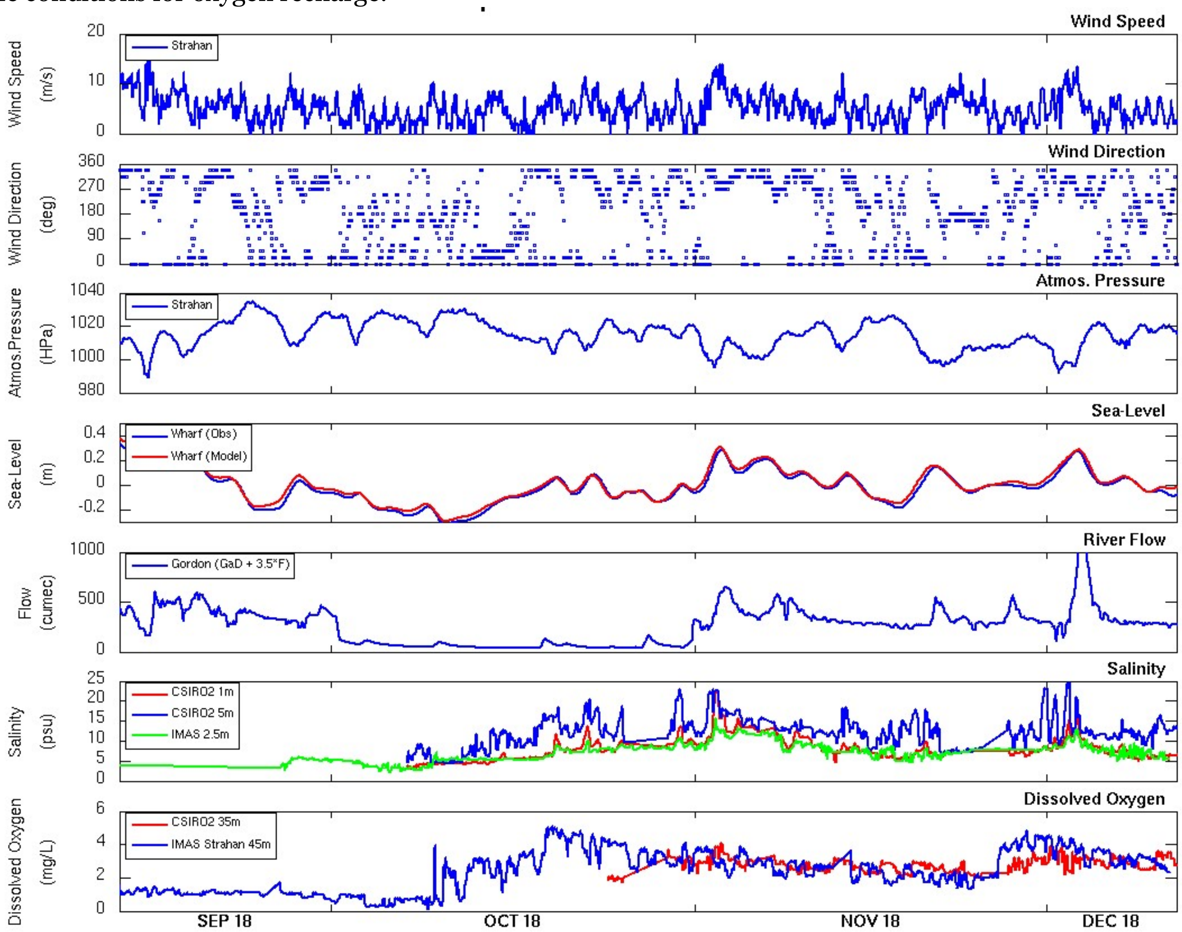

Figure 7 Time-series of concurrent environmental phenomena for the past 4 months to highlight conditions associated with the oxygen recharge in early October 2018.

BENTHIC CONDITION

In June 2018, IMAS conducted a benthic survey of five leases and 24 external sites as part of FRDC 2016-067 (Figure 8, Table 1). This represents the 11th 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

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 have observed an increase in the total abundance and number of species collected from the benthic fauna relative to the previous two surveys at the lease sites.

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 October 2017 and January 2018, and most notably at the 0 m sites (Figure 9). Dissolved oxygen levels recorded on the bottom during the June survey remained relatively high compared to that observed in the previous spring surveys. This was the site which had the smallest faunal decline in both spring

[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.

2016 and 2017. At lease 3 there had also been an increase in the total abundance and number of species, but this was most evident at the sites between 0 and 100m from the cages (Figure 10).

At lease 2, where there had been marked decline in the total abundance and number of species recovered from samples in January 2018, there was a major increase observed at all distances from the cage in June 2018 (Figure 11). Lease 1 – which is the most southern lease has seen a small increase in total abundance, but a much larger increase in the number of species from that observed in the previous two surveys (Figure 12).

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 due to the increase in total abundance and number of species along the deeper NW transect (Figure 13). The number of species, and to a lesser extent total abundance also increased on the SE transect.

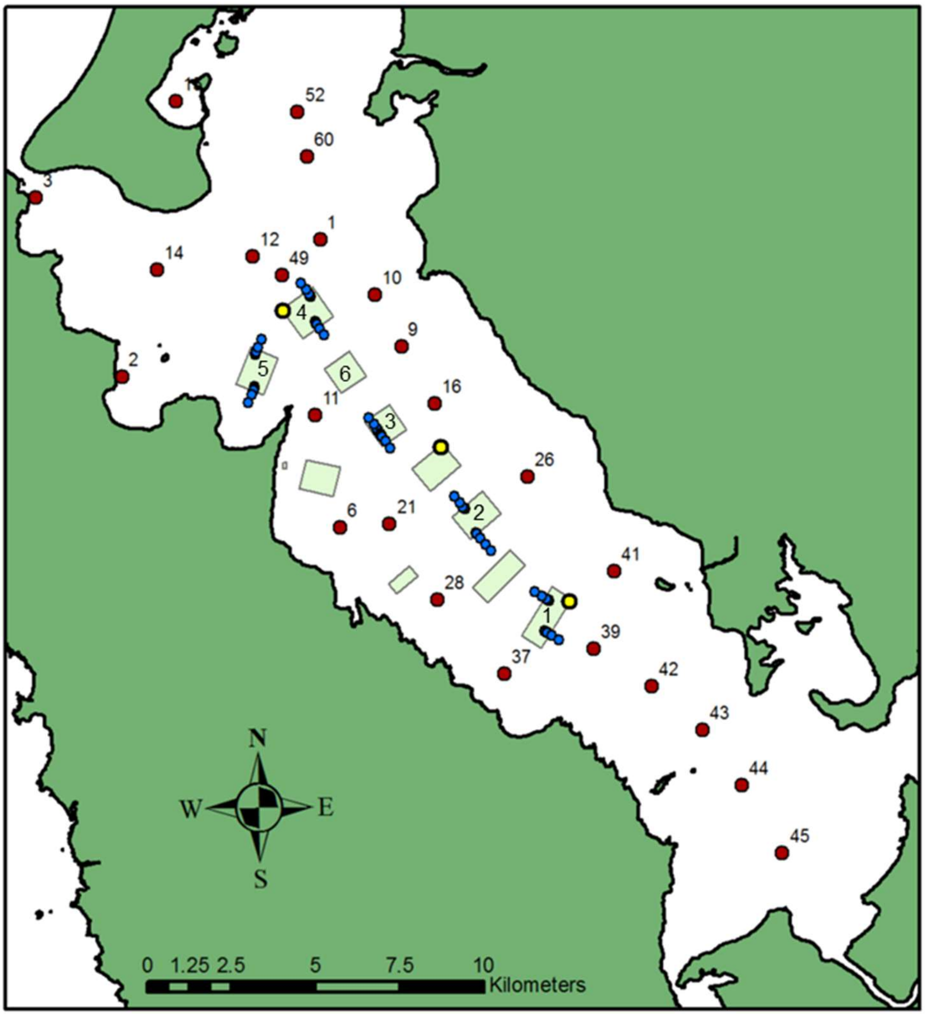

Figure 8 Maps showing external (red), lease (blue) and environmental string (yellow) sites. There are 2 transects from each of the study leases with five sites (at 0, 50, 100, 250 and 500m) on each transect.

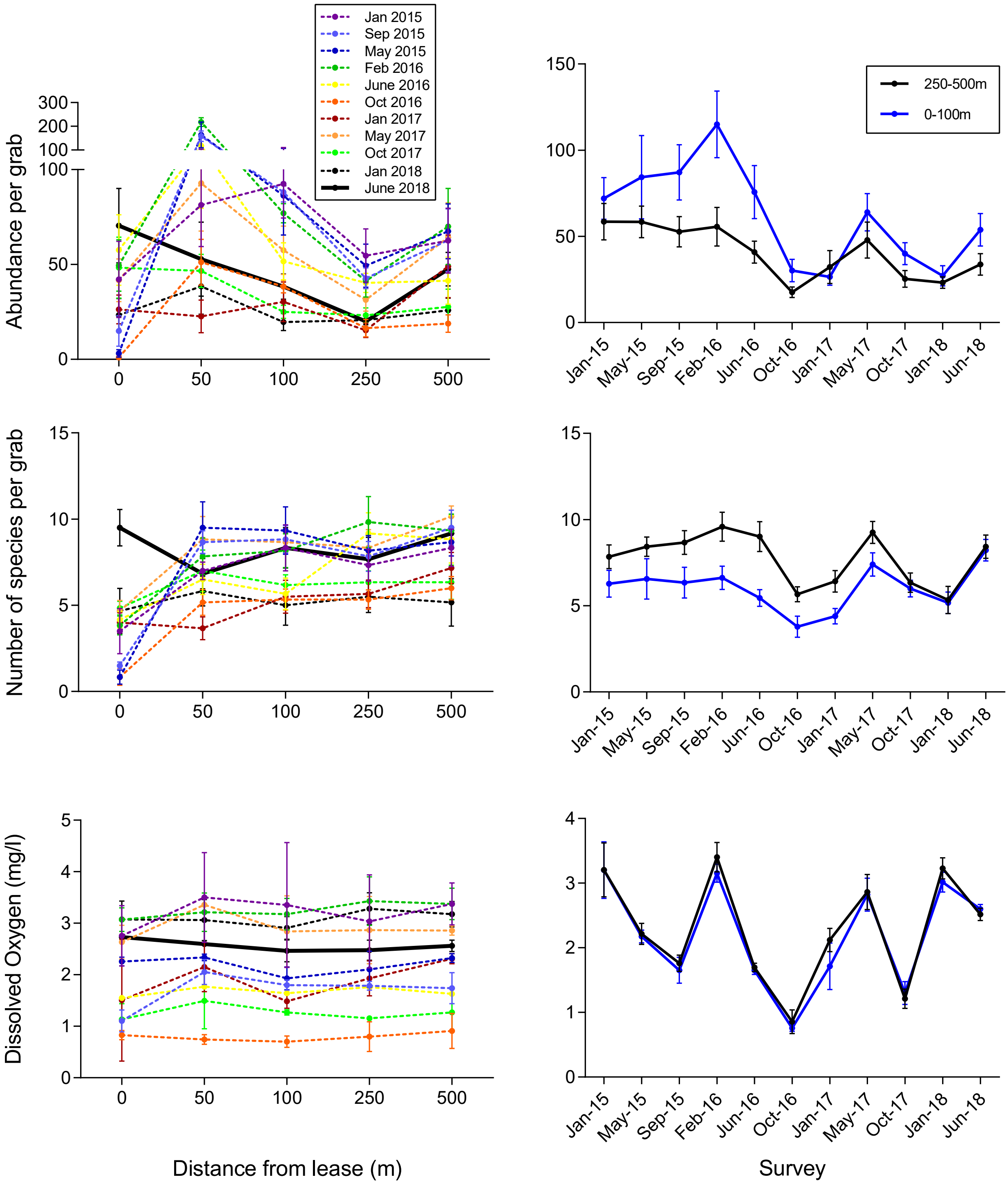

Figure 9 Lease 4 plots of total infaunal (>1mm) abundance (per grab = ~ 0.0675m²; top panel), number of species collected in grabs (n=3; middle panel) and the dissolved oxygen (mg/L) overlying the bottom (bottom panel) in relation to 1 (left panels): distance from the cage (0, 50, 100, 250 and 500m from 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 (June 2018) has been highlighted with a solid black line.

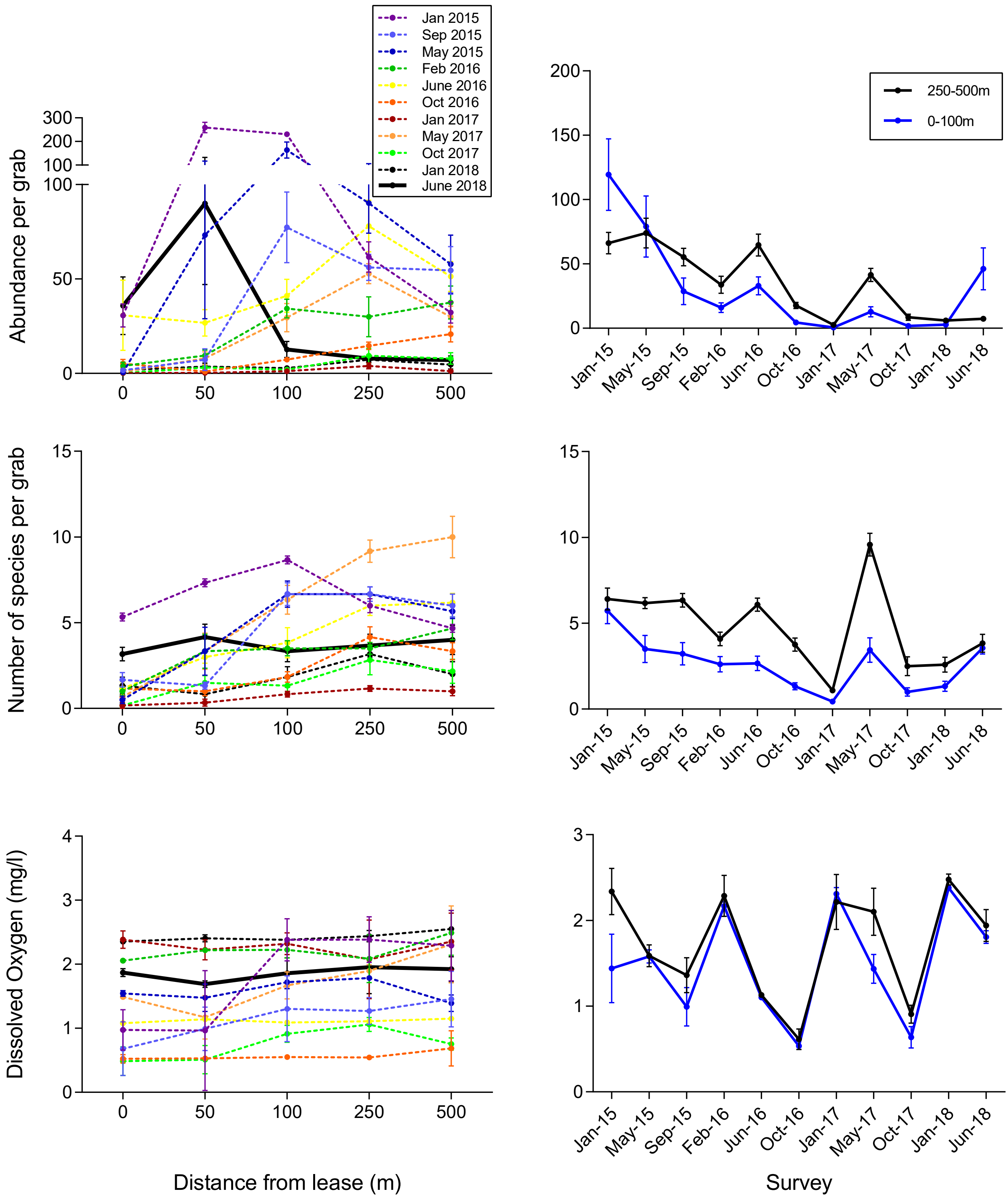

Figure 10 Lease 3 plots of total infaunal (>1mm) abundance (per grab = ~ 0.0675m²; top panel), number of species collected in grabs (n=3; middle panel) and the dissolved oxygen (mg/L) overlying the bottom (bottom panel) in relation to 1 (left panels): distance from the cage (0, 50, 100, 250 and 500m 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 (June 2018) has been highlighted with a solid black line.

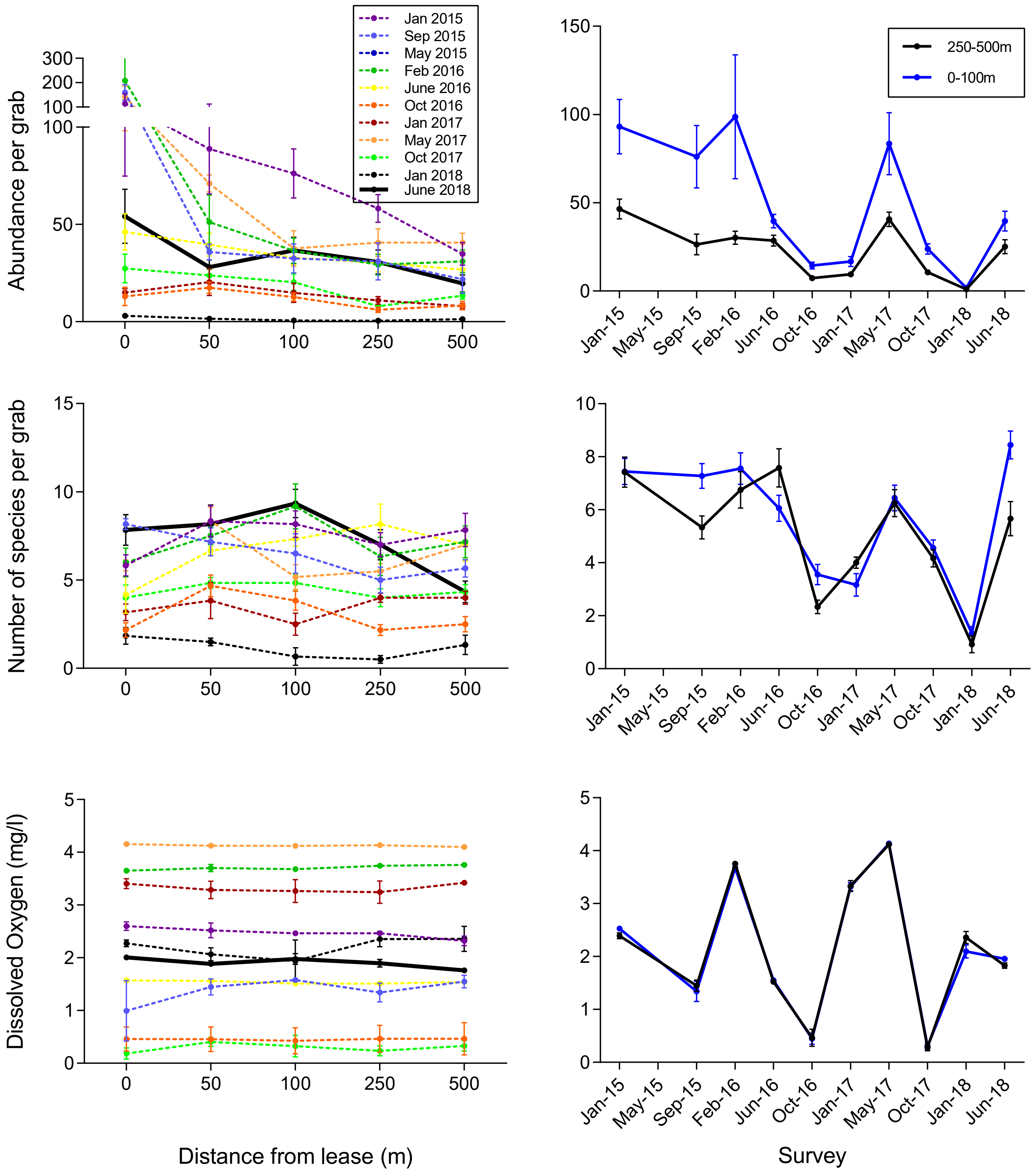

Figure 11 Lease 2 plots of total infaunal (>1mm) abundance (per grab = ~ 0.0675m²; top panel), number of species collected in grabs (n=3; middle panel) and the dissolved oxygen (mg/L) overlying the bottom (bottom panel) in relation to 1 (left panels): distance from the cage (0, 50, 100, 250 and 500m 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 survey (June 2018) has been highlighted with a solid black line. Note, lease 2 was not surveyed in May 2015.

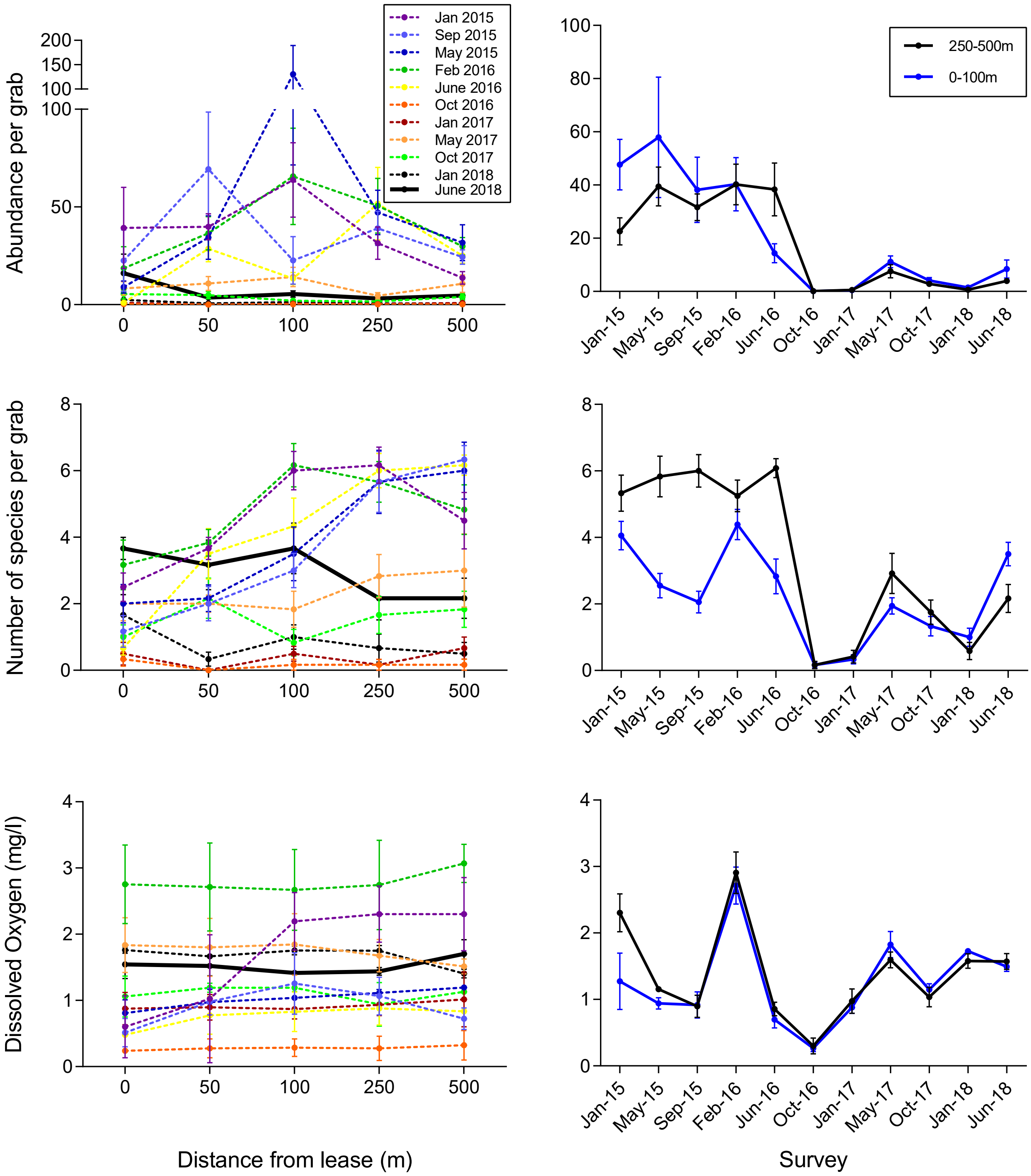

Figure 12 Lease 1 plots of total infaunal (>1mm) abundance (per grab = ~ 0.0675m²; top panel), number of species collected in grabs (n=3; middle panel) and the dissolved oxygen (mg/L) overlying the bottom (bottom panel) in relation to 1 (left panels): distance from the cage (0, 50, 100, 250 and 500m 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 (June 2018) has been highlighted with a solid black line.

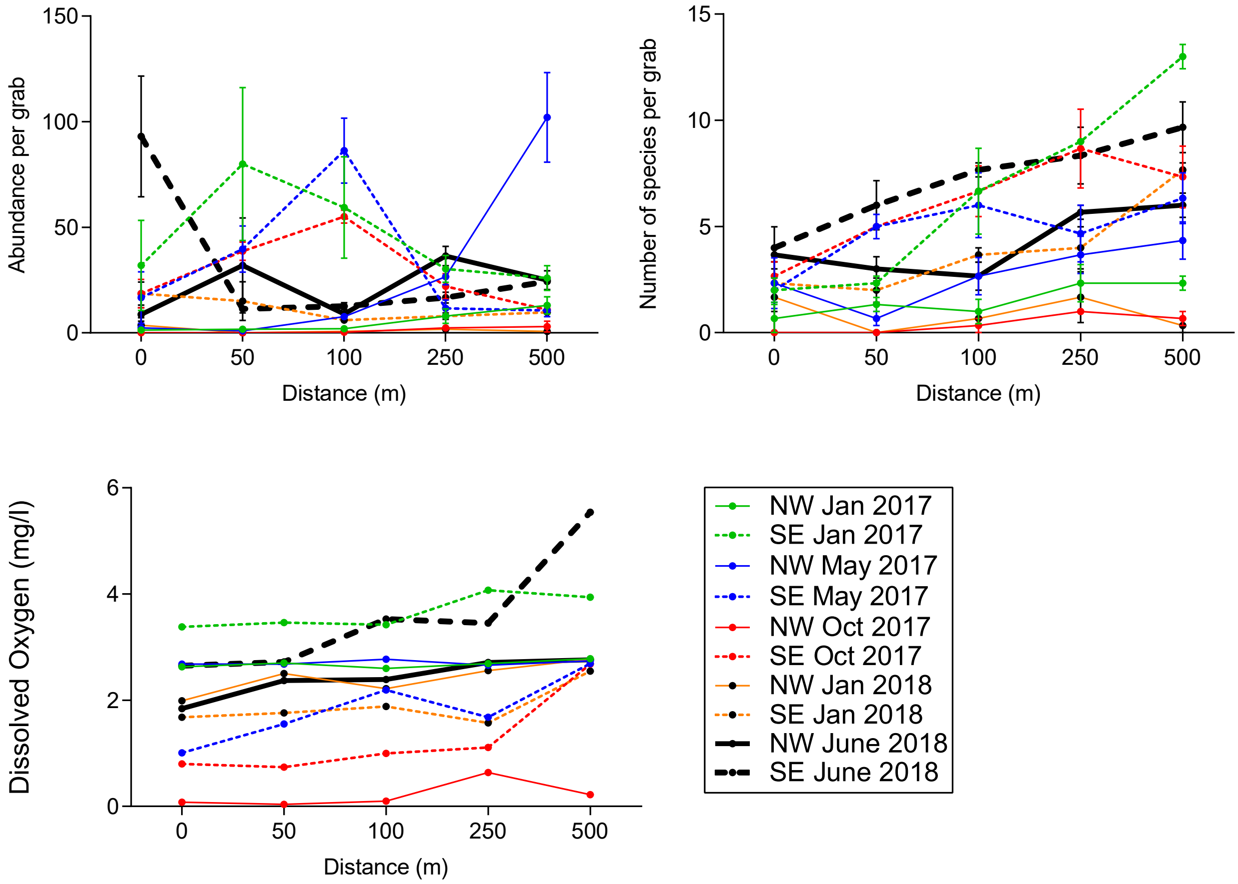

Figure 13 Plots of total infaunal (>1mm) abundance (per grab = ~ 0.0675m^2), number of species collected in grabs (n=3; middle panel) and the dissolved oxygen (mg/L) overlying the bottom (at 0, 50, 100, 250 and 500m from cages at lease 5 during the January, May, October 2017 and January and June 2018 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 several 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 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 14). 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 15).

Faunal abundance and species numbers at the majority of the external sites in the June 2018 survey were within the range that had been recorded historically, consistent with observations in recent surveys. Faunal abundances at four of the southernmost external sites (39, 42, 43 and 44) remain low relative to that observed prior to the original decline from spring 2016 – early 2017, but there has been an increase at two of these sites across recent surveys.

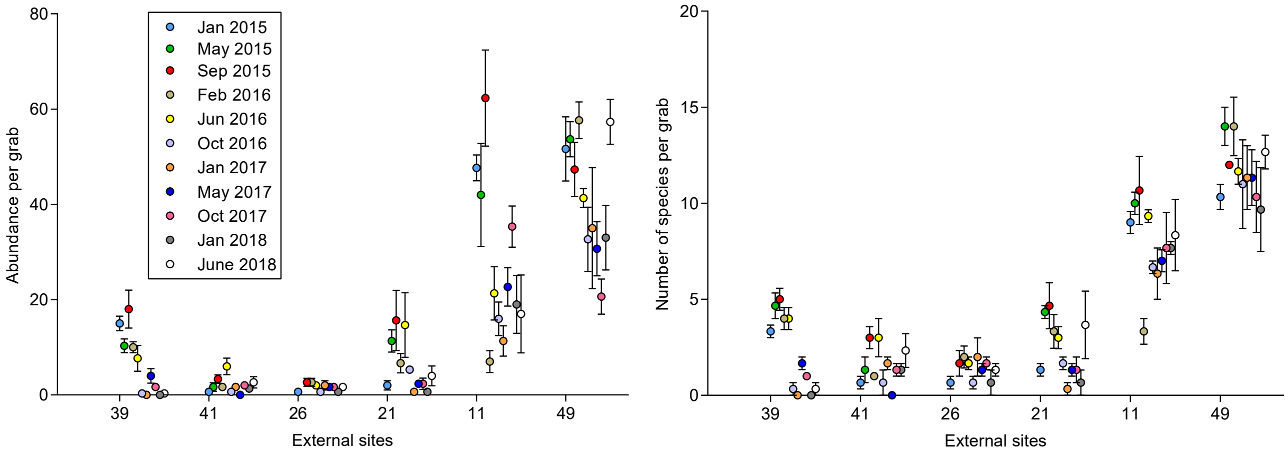

Figure 14 Plots of total infaunal (>1mm) abundance (per grab = ~0.0675m²) and number of species collected in grabs (n=3) at 7 external sites in Macquarie Harbour from surveys between January 2015 and June 2018. The data for each site represents the mean (±SE) from three replicate grabs. Note that site 26 was not surveyed in May 2015.

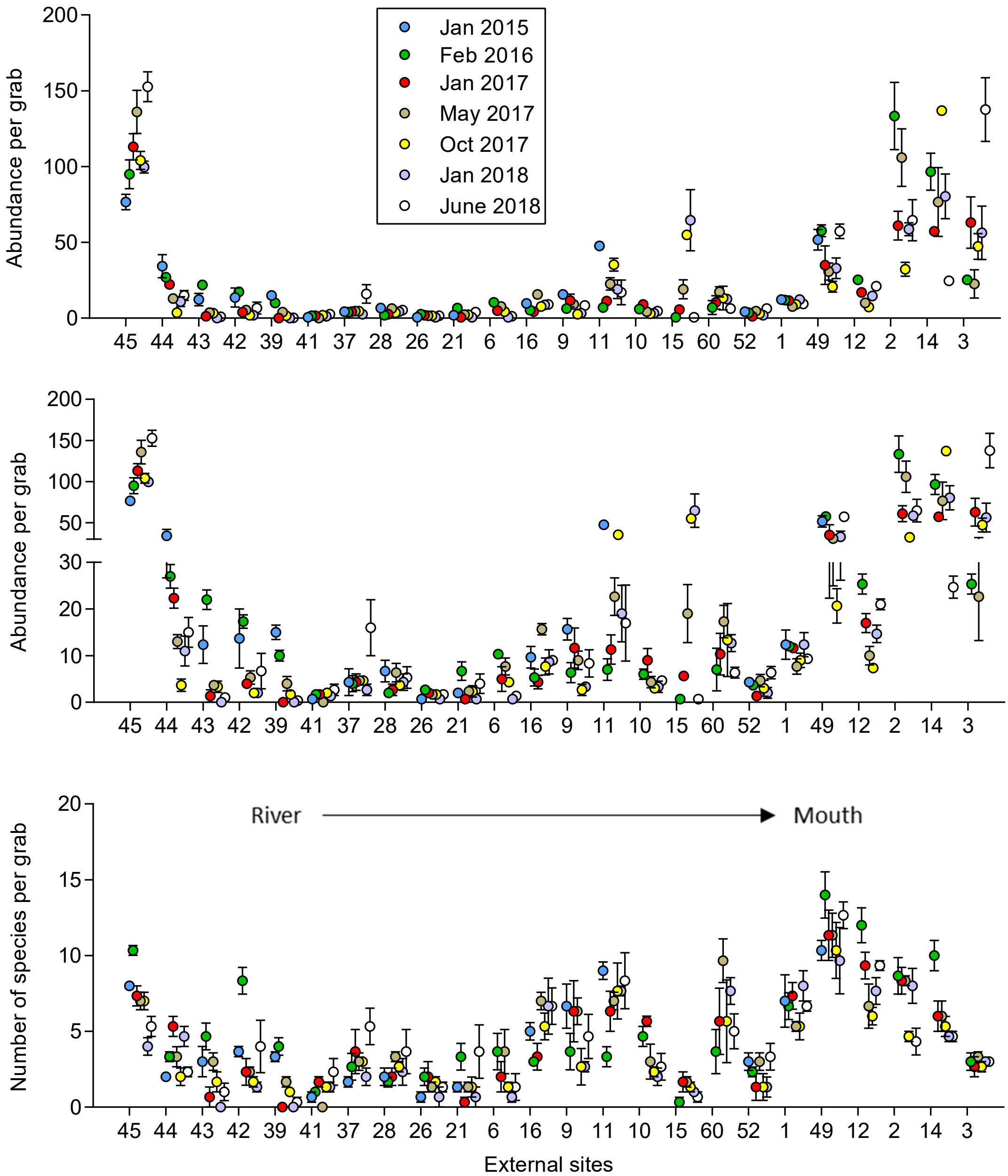

Figure 15 Plots of total infaunal (>1mm) abundance (per grab = ~0.0675m²; top 2 panels) and number of species collected in grabs (n=3; bottom panel) at 23 external sites in Macquarie Harbour from surveys in January 2015, February 2016, January 2017 and May 2017, September 2017, January 2018 and June 2018. 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[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.

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 video surveys were conducted in May 2018, a month earlier than the benthic faunal surveys, to coincide with compliance monitoring requirements. The May survey demonstrated that the presence of *Beggiatoa* remains low relative to that observed in in the October 2016 and January 2017 surveys (Table 4). 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), however, 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 results were similar in May with *Beggiatoa* observed on 21 of 51 lease dives, but in May there was a further reduction in the number of observations of *Beggiatoa* forming extensive mats and more observations of patches of *Beggiatoa* at lease sites relative to the most recent surveys. Most of the occurrences in June 2018, were on leases 3, 4 and 5 and all observations scored higher than patchy (thick patchy/thin mat) were within 50m of the cage (Figure 16). There was one observation of patchy *Beggiatoa* outside the lease boundaries at each of these leases. At the external sites, *Beggiatoa* was observed at 3 of the 28 sites in the May 2018 survey and in all cases as patchy (Figure 16).

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. In the May (58%) and January 2018 (56%) surveys dorvilleids were observed on fewer dives compared with two surveys prior in September (63%) and May 2017 (71%). Over this time there has also been a reduction in the observations of the more abundant categories (i.e. > 100 dorvilleids in a dive). In the May 2018 survey there were no observations at the external sites of >30 dorvilleids per dive (Figure 17). As described in previous

[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.

surveys, dorvilleids were more commonly observed at the external sites in the southern region of the harbour in the May 2018 survey.

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. In May 2018, colonies were observed on 4 of 79 ROV dives and most often in close proximity to the cages and not at external sites. Thus, the broader distribution of dorvilleids seen in Figure 17 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%	
May-18	External	28	89%	11%				
	Lease	51	59%	33%	2%	6%		

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%

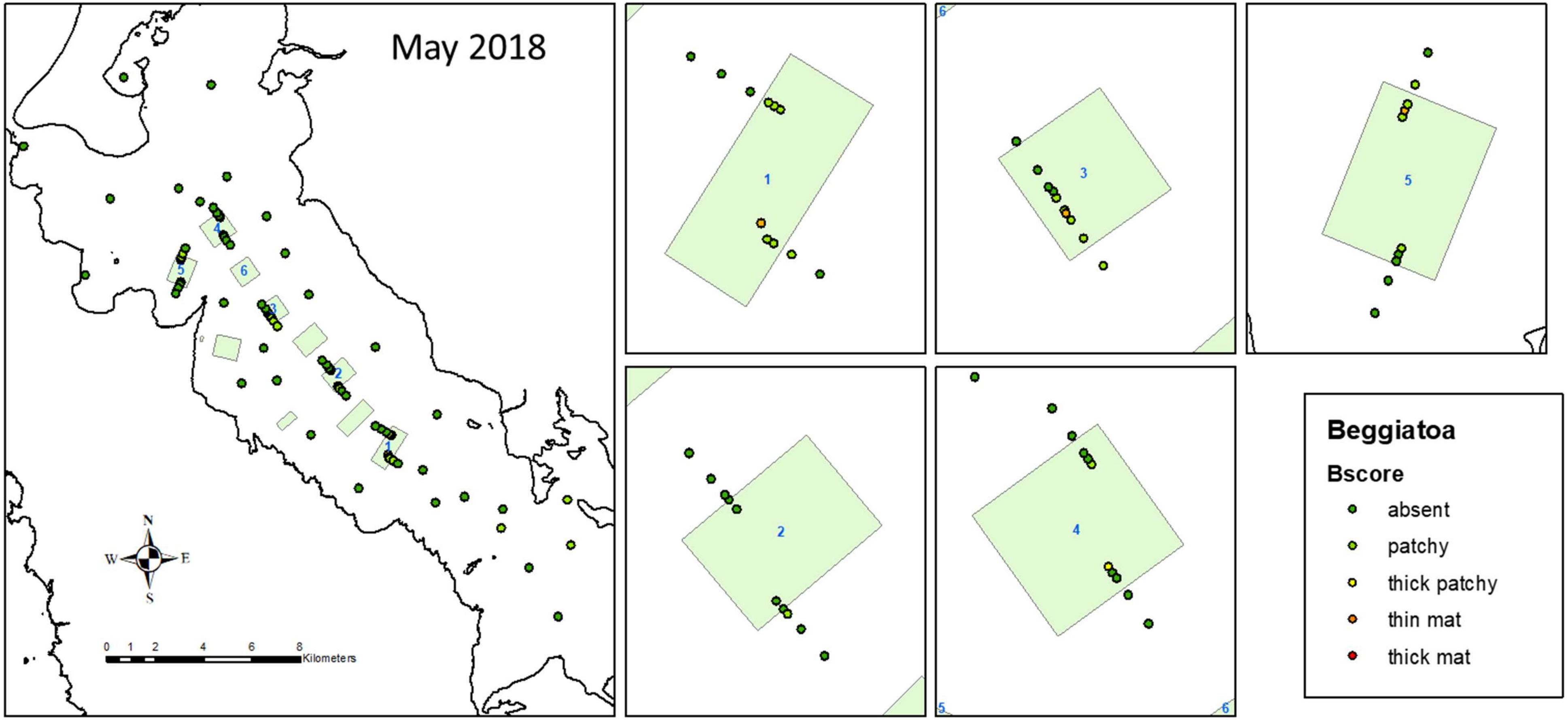

Figure 16 *Beggiatoa* score (severity) from ROV footage at study sites across the harbour on the left panel and shown in more detail for each of the study leases in the panels on the right.

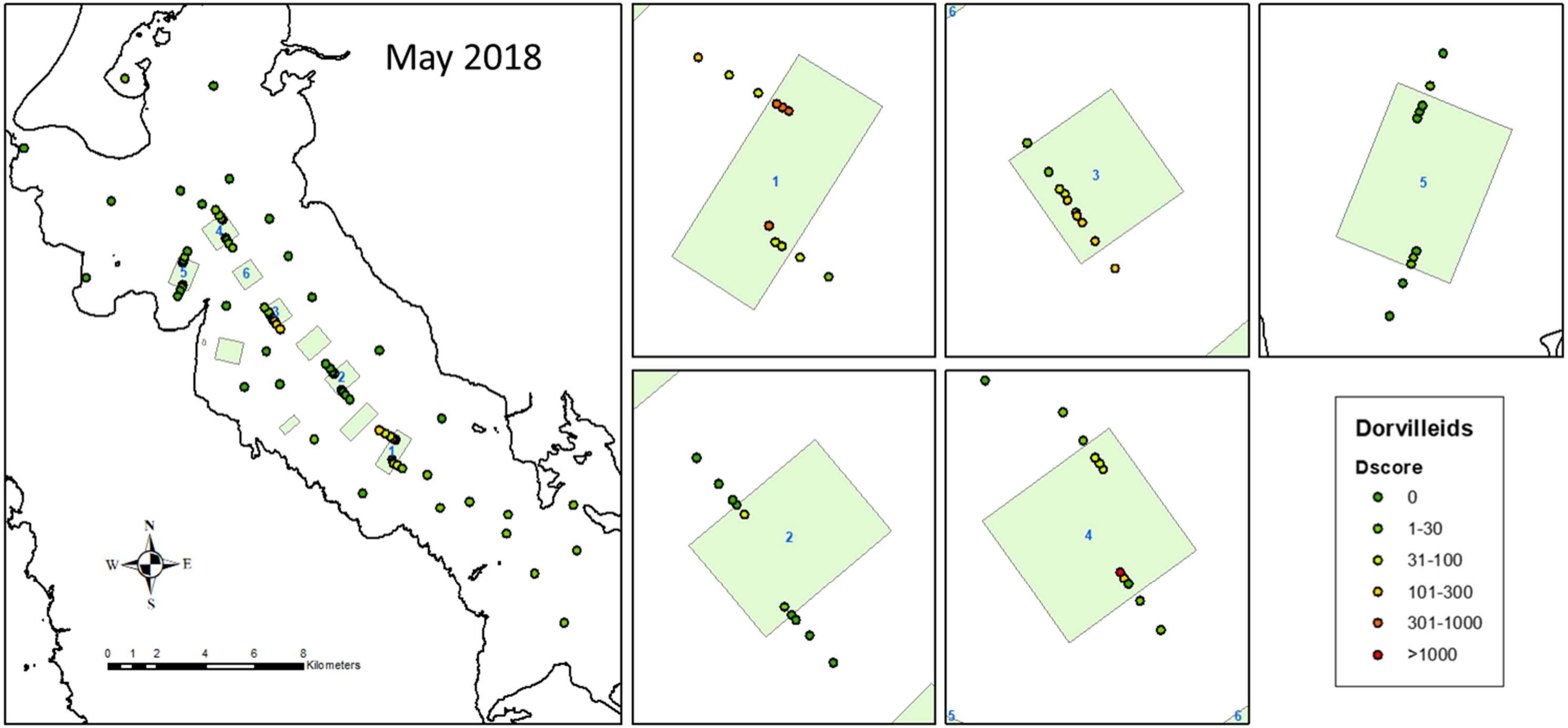

Figure 17 *Dorvilleid* score based on counts from ROV footage at study sites across the harbour on the left panel and shown in more detail for each of the study leases in the panels on the right.

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