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 and benthic conditions in Macquarie Harbour. It follows on from the results reported in the IMAS report released in January 2017 which described the deterioration of benthic and water column conditions in Macquarie Harbour in spring 2016. This report presents the results and preliminary interpretation of oxygen monitoring data up until the end of March 2017, and a repeat survey of benthic communities in January/February 2017. This ongoing work forms part of a 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).

Dissolved oxygen conditions in the middle and bottom waters remained extremely low in late 2016 before a replenishment of oxygen was seen in the deep bottom waters at the Strahan monitoring site in early December 2016, with the effects being observed at the Table Head Central and Franklin monitoring sites soon after. The increase in bottom water DO levels at the Strahan and Franklin monitoring sites primarily occurred in waters below 30m with little change observed in DO levels between 20 and 30m depth. Although these observations are encouraging, and may help explain some of the benthic observations noted by the companies in March and April, it is important to recognise that an increase was observed in bottom water DO concentrations in early 2016 and concentrations still declined to extremely low levels six months later. DO levels in the middle of the water column remain low, and this mid-water region represents a much larger proportion of the total water volume in the harbour, thus there is still clearly capacity for the DO levels in bottom waters to decline.

Patterns in the abundance and number of species of benthic fauna in January 2017 remained largely unchanged from the October 2016 survey, with the exception of lease 3 where there was a further decline. Lease 5 in the north of the harbour was sampled for the first time and there were distinct differences in the fauna observed from each of the two transects. Faunal abundance and species numbers were greater on the shallower southeast transect compared to deeper transect that ran to the northwest. The lower abundances and species number appear to reflect a spatial difference in the footprint of the farm, with a greater level of organic enrichment from the lease extending to the NW. We were provided with some additional data from Aquenal, a consultancy which undertook biological assessment consistent with IMAS protocols at a sixth lease for comparison. This lease is located in the same region of the harbour as lease 3 and has a similar farming history. Results suggest that there was more fauna found on this lease (which we have called lease 6) compared to lease 3. The survey of lease 6 was conducted 2 months after lease 3. It was noted that a number of the individuals in the lease 6 samples were small, which may be indicative of recent recruitment. The next benthic survey for this study (FRDC 2016/067) is scheduled for May/June 2017 and will provide the additional data necessary to provide a better understanding of both the magnitude and extent of any potential recovery.

The benthic survey undertaken in January included a more comprehensive set of external sites to provide a better understanding of the broader benthic ecology of the harbour at this time. When this data is contrasted against the harbour wide surveys undertaken prior to the decline in fauna observed in spring 2016 it appears that the

greatest decline in abundance and species numbers has occurred in the deeper central region of the harbour, with relatively little change in the fauna in the shallower regions in the mid-harbour or to the north or south of the harbour. Although the abundance and diversity tends to suggest a depauperate community (akin to that observed pre-farming), when the functional nature of the fauna in this deeper central region is examined it is clear that it still reflects a community subject to organic enrichment. The next survey in May/June 2017 will further establish the magnitude and extent of potential recovery at both lease and external sites.

In this report we have also included some preliminary results and evaluation of the video assessments that were conducted in conjunction with the benthic sampling at all of the study sites for all 7 benthic surveys to date. This data demonstrates the association between the presence of *Beggiatoa* bacteria, Dorvilleid polychaetes and farming in the harbour. *Beggiatoa* was generally found around and extending from the cages, with 71 % of observations of *Beggiatoa* within 50m of the cage and 90% of observations within 100m.The surveys undertaken in October 2016 and January 2017 showed an increase in the prevalence of *Beggiatoa* around the leases relative to previous surveys. We have been advised that more recent surveys (submitted to EPA by companies in March and April) show a significant reduction in *Beggiatoa* around a number of the leases in March and April. This is consistent with the observed recharge of bottom water DO; as *Beggiatoa* occurs at the interface between anoxic/ oxic conditions it is to be expected that the levels of *Beggiatoa* might reduce when bottom water oxygen conditions improve.

It is important to keep in mind that DO levels appeared to be the major determinant of the deterioration in benthic condition witnessed in spring 2016, and while levels are currently higher, they are not dissimilar to the levels observed this time last year with mid water DO levels remaining low.

The information provided by this project will help inform both the operational management of farming activities and the long-term sustainable management of the harbour. Accordingly, additional update reports will be provided regularly throughout the project.

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 2017). 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 the 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

levels 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. The future of salmon farming in Macquarie Harbour depends on it being sustainable over the long term. A key challenge facing farmers and regulators is understanding and predicting the length of fallowing required for benthic recovery in this system specifically. This has major implications for future stocking plans in the harbour. It is clear that DO levels 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 levels 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) have recently funded 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 months. Work package 2 (WP2) will see the further development of the real time dissolved oxygen 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.

This report provides an update on benthic and water column conditions based on the latest observations (WP1 and WP2). *It is important to acknowledge that this is an 'interim' synopsis of benthic and water column conditions based on the latest observations from FRDC 2016-067. It is not an exhaustive and detailed presentation of all available environmental information for Macquarie Harbour. Whilst some comparisons have been made with previous sampling periods and data trends, the data have not been analysed statistically and all assessments and conclusions are preliminary – a full analysis will be undertaken in the final project report.*

WATER COLUMN CONDITION

In Ross & MacLeod (2017) 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 levels were extremely low throughout the harbour; 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 the 3 farm sites in 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 3). The contour plots produced from these strings[1] have been updated to include data up until the end of March 2017 (Figure 2). The yellow dashed line on the figure denotes approximately where the measurement period for the previous report (Ross & Macleod 2017) finished. At this point the very low DO levels were particularly evident, with DO at depths below 20m being less than 10, 15 and 20% saturation at Franklin, Strahan and Table Head Central respectively. Proximity to the influence of the ocean and the concurrent effects of bottom water residence time are likely to be important in determining the oxygen levels at the respective sites (i.e. sites further from the ocean are likely to have less bottom water exchange and the bottom water at those sites is likely to be resident in the system for a longer period of time). The DO levels remained low into November 2016. In early December there was a bottom water recharge, first seen in the deeper waters (>30m) at Strahan, soon after at Table Head Central, and then at Franklin in early January 2017. The increase in bottom water DO levels at Strahan and Franklin ostensibly occurred in waters greater than 30m with little change observed in DO concentrations between 20 and 30m depth. It is also important to note that the increase in bottom water DO concentrations in late 2016 and early 2017 is not dissimilar, and arguably may in fact be lower, than that observed over the same period in the previous year (Figure 2).

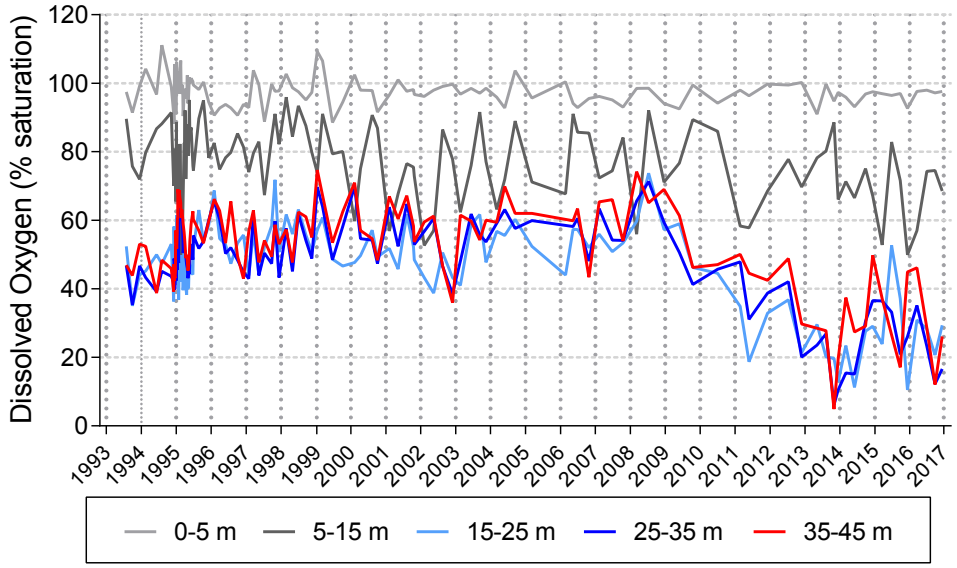

Figure 1 Long term trend in DO within a number of depth ranges at EPA site 12 (updated from MHDOWG 2014).

[1] The existing strings are due to be refurbished and updated with the latest technology in early May 2017. Two additional delayed logger strings in the north and south of the harbour will be deployed at the same time.

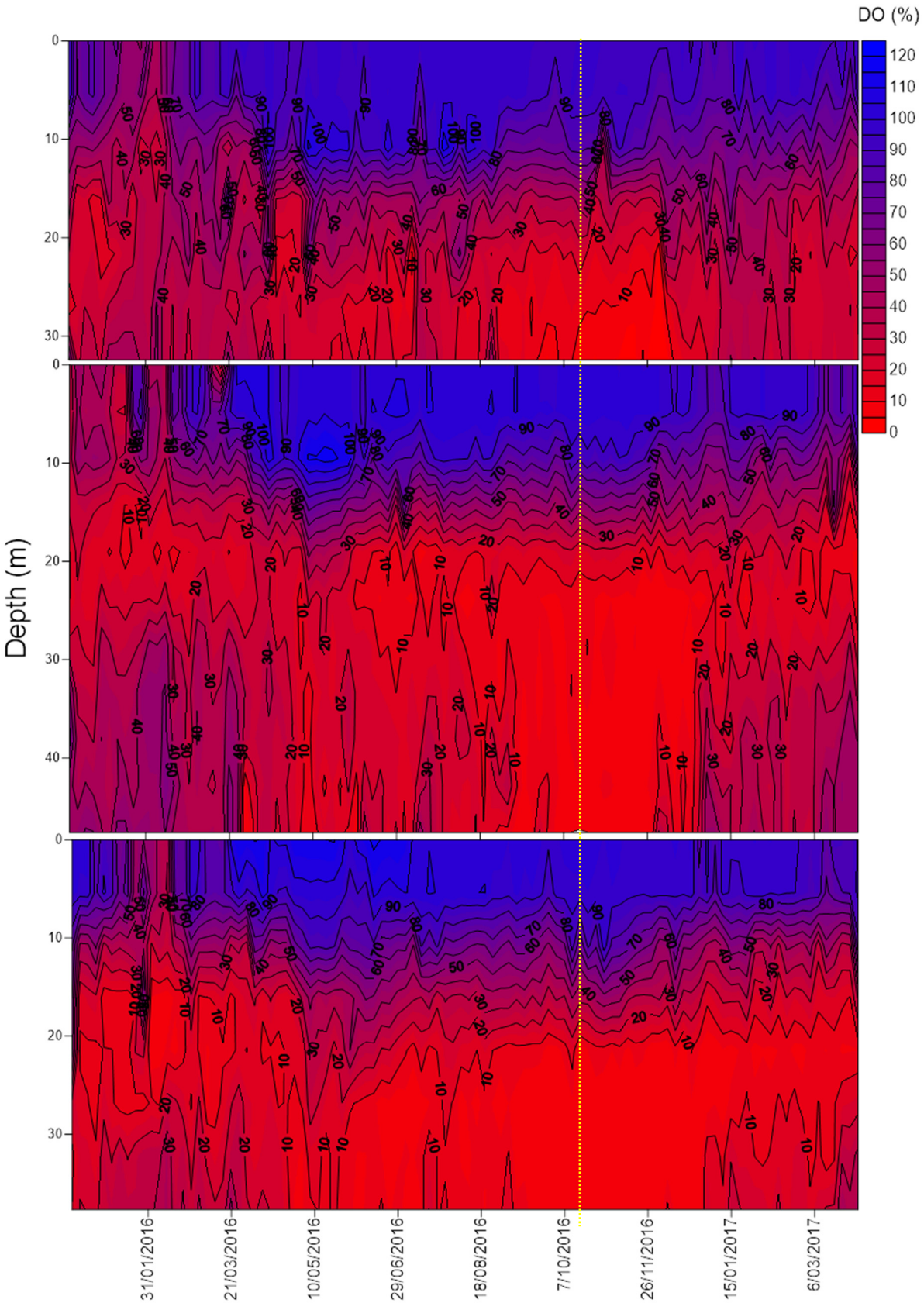

Figure 2 Contour plots showing DO profiles through the water column from the Sense-T environmental strings at Table Head Central (top panel), Strahan (middle panel) and Franklin (bottom panel) over the period from December 2015 to the end of March 2017. The yellow dashed line is approximately where the measurement period for the last report finished. It is important to keep in mind that the Sense-T project was about demonstrating the 'proof of concept' with the sensor deployment and although the data from the sensors has been periodically checked the new FRDC project (FRDC 2016-067) will involve a more rigorous QA/QC process. However, that said, the calibration checks and consistency with other independent data sets (EPA, Parks, Industry, CSIRO, IMAS) from the Harbour does provide a degree of confidence in the both the levels observed and the overall response patterns.

BENTHIC CONDITION

In early 2017, IMAS conducted a benthic survey of 5 leases and 24 Harbour wide external sites as part of FRDC 2016-067 (Figure 3, Table 1). This represents the 7th benthic survey conducted under consecutive FRDC projects (FRDC 2014-038, FRDC 2015-024, FRDC 2016-067) since the beginning of 2015. FRDC 2014-038 was undertaken when video footage identified an increase in abundance of Dorvilleid polychaetes and the presence of two Dorvilleid species; given that these species were used as indicators of enrichment it was felt that it was important to understand the distinction between the two species and whether their environmental responses were comparable. This study 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 2014-038; the Macquarie Harbour component of this study was completed in 2016. Consequently, FRDC 2016-067 was initiated to provide more specific information on benthic recovery and the effectiveness of fallowing. FRDC 2016-067 extended the benthic sampling to include an additional lease (lease 5) and more external sites[2]. We have also included data from one extra lease (shown as lease 6) in the results presented in this report. Lease 6 was sampled by Aquenal in March on behalf of Tassal. Tassal have agreed to share the data with the project. Although this lease was not sampled as part of the IMAS FRDC survey the same sampling design and protocols were used (i.e. triplicate benthic grabs at 0, 50, 100, 250 and 500m from the cage on each of 2 transects), and the compatibility of the data has been confirmed. This additional site provided a further data point (both in space and time) with which to assess the recovery process.

In the last survey (October 2016) a major decline in the total abundance and number of species collected from the benthic fauna was observed both at the leases and at a number of the external sites. There has been no obvious change (i.e. neither improvement nor deterioration) in the total abundance or number of species collected from the benthic fauna at leases 1 or 4 since the October 2016 survey (Figure 4). There may have been a slight increase (2 species) in the number of

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

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

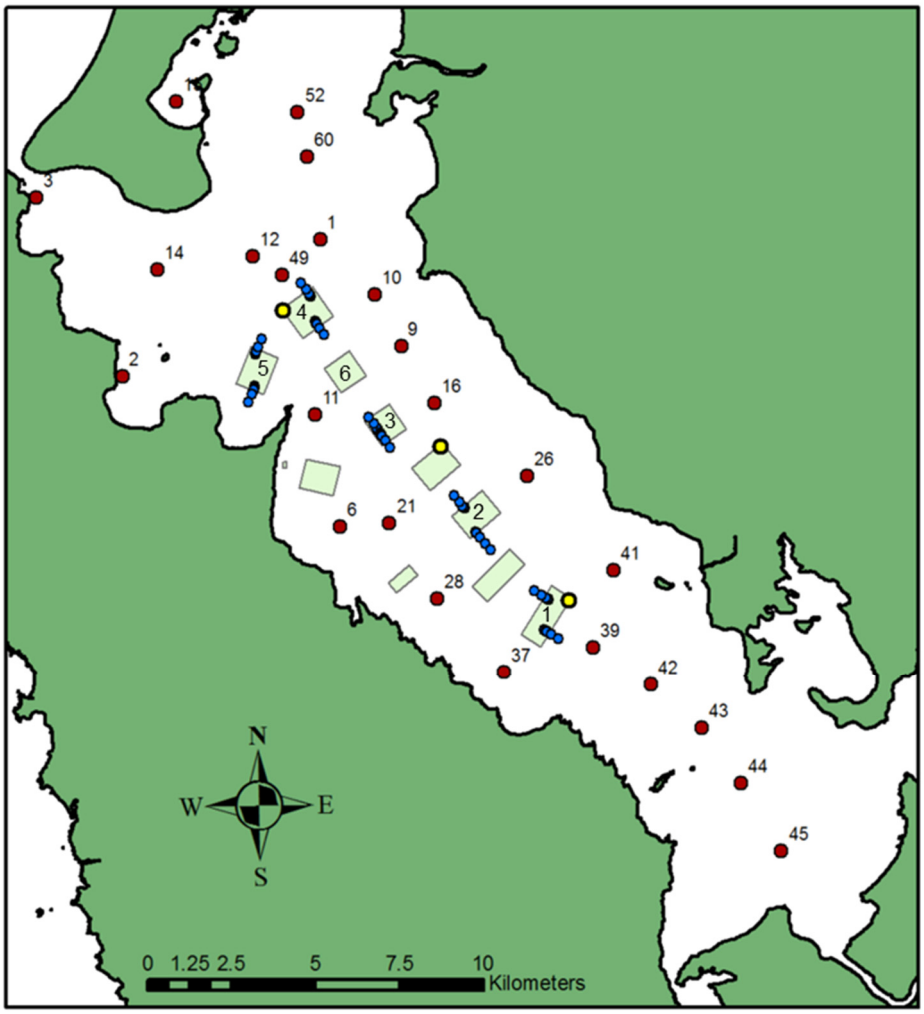

Figure 3 Maps showing external (red), lease (blue) and environmental string (yellow) sites. There are 2 transects from each of the study leases with five sites (at 0, 50, 100, 250 and 500m) on each transect.

species at the 250/500m sites for lease 2 but the overall abundance has not changed. At lease 3, there appears to have been a further decline in both the total abundance and number of species collected in the latest survey, interestingly this was most apparent at the 250 and 500m sites. At all 4 leases, the bottom water DO concentrations were higher in the January 2017 survey than in the previous survey in October 2016, with average concentrations across the transects of 0.9, 3.3, 2.3 and 1.9 mg l^{-1} at leases 1, 2, 3 and 4 respectively compared to 0.3, 0.5, 0.6 and 0.8 mg l^{-1} in October 2016.

At lease 5, there were clear differences between the two transects (Figure 5). The depth of each transect differed markedly at this lease; the NW transect starts at a depth of 30m next to the cage before reaching 34m at the 500m site, whilst the SE transect starts at 17m next to the cage and becoming slightly shallower (12m) at the 500m site. This may partly explain the large variability in faunal composition (abundance) between the two transects shown in figure 5. All of the sites on the deeper NW transect had markedly lower abundances and species numbers than those on the SE. Whilst this may in part be a function of the differences in depth it is known that the currents at this site tend to disperse more of the farm waste to the NW and the ecology of the species on the NW transect (diversity and abundance) is consistent with elevated levels of organic enrichment. The sites from 0 to 100m were relatively depauperate, typical of highly enriched sediments and the dorvilleid *Schistomeringos loveni* was the dominant species from 100-500m, reaching peak

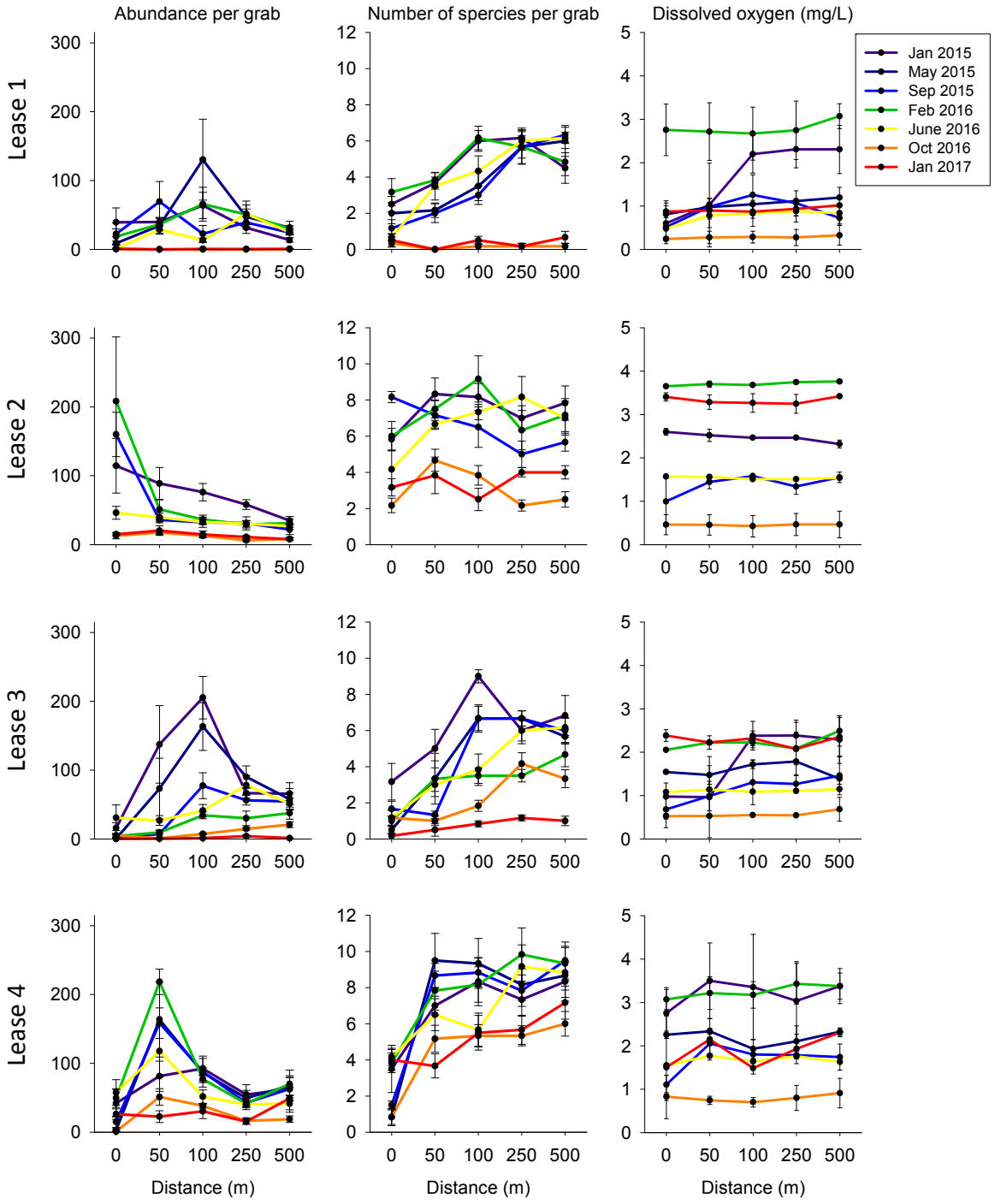

Figure 4 Plots of total infaunal (>1mm) abundance (per grab = ~ 0.0675m²), number of species collected in grabs (n=3) and the dissolved oxygen (mg/L) overlying the bottom at 0, 50, 100, 250 and 500m from cages at leases 1-4 in Macquarie Harbour from surveys between January 2015 and January 2017. The data for each lease represents the mean (±SE) from two transects that radiate out from cages on opposite sides of the lease. Lease 2 was not surveyed in May 2015. Only one transect was profiled in June 2016.

abundances at 250 and 500m. In contrast, on the shallower transect *S. loveni* was common closer to the cages (0-100m), with tube dwelling polychaetes (Spionids, Terebellids and Sabellids) dominating further from the lease at 250-500m. These polychaetes are sessile suspension feeders that are more sensitive to enrichment. Given the proximity of this lease to the ocean, bottom water DO concentrations were relatively high compared with the other leases, albeit lower on the deeper NW transect compared to the shallower SE transect.

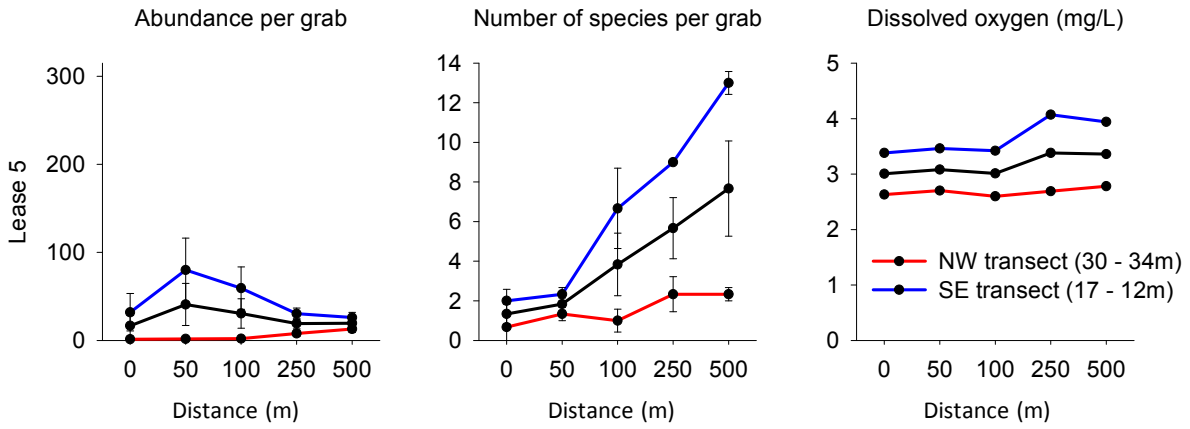

Figure 5 Plots of total infaunal (>1mm) abundance (per grab = ~ 0.0675m2), number of species collected in grabs (n=3) and the dissolved oxygen (mg/L) overlying the bottom at 0, 50, 100, 250 and 500m from cages at lease 5 in Macquarie Harbour during January 2017. The data shows the mean (±SE – black line) and North-western (red line) and South-eastern (blue line) transects

At lease 6 (the additional lease sampled by Aquenal) the abundance and number of species per grab at each of the transect positions followed a typical enrichment gradient; transitioning from a relatively depauperate community typical of highly enriched sediments close to the cages to one with higher faunal abundance and species numbers with distance from the cage i.e. at 250 to 500m (Figure 6). Although, faunal abundances are low relative to those observed on the other leases in the surveys before the spring 2016 survey. Lease 6, like lease 3, has been in operation for many years (>15 years), much longer than the other study leases. Leases 3 and 6 would appear to have had a similar production/ stocking history, and as such it may be useful to compare the environmental performance of these two leases to gain insight into deterioration/ recovery processes at long established farms. The current results would suggest that lease 6 is in a better condition than lease 3 in terms of faunal abundance and species numbers. Whilst this could be a function of differences in farming history and intensity over recent years (although the industry has suggested that this is in fact similar), it may also be a result of differences in proximity to the ocean, with lease 6 possibly having an advantage in terms of exposure to higher bottom water oxygen conditions by virtue of its location within the harbour.

However, it is also important to note the difference in sampling time, Lease 3 was sampled on the 17th of January whilst lease 6 was sampled on the 9th of March, almost 2 months later, and as such the benthic conditions and prevailing environmental conditions/ farming criteria will not be directly comparable (the lease is effectively 2 months further along in time). Two of the three most common taxa in the samples from lease 6 were the terebellid polychaete *Pista sp*. and the heart urchin *Echinocardium cordatum*. Many of the individuals were small, potentially juveniles and possibly indicative of a recent recruitment event. More recent data (mid-April) provided by Aquenal at survey sites within lease 1 and 3 has indicated an increase in faunal abundance at those sites (S Riley pers. comm.). The next survey for FRDC 2016-067 is scheduled for late May/June and will provide further information with which to assess the nature and scale of this benthic response. A summary report will be provided in August/September

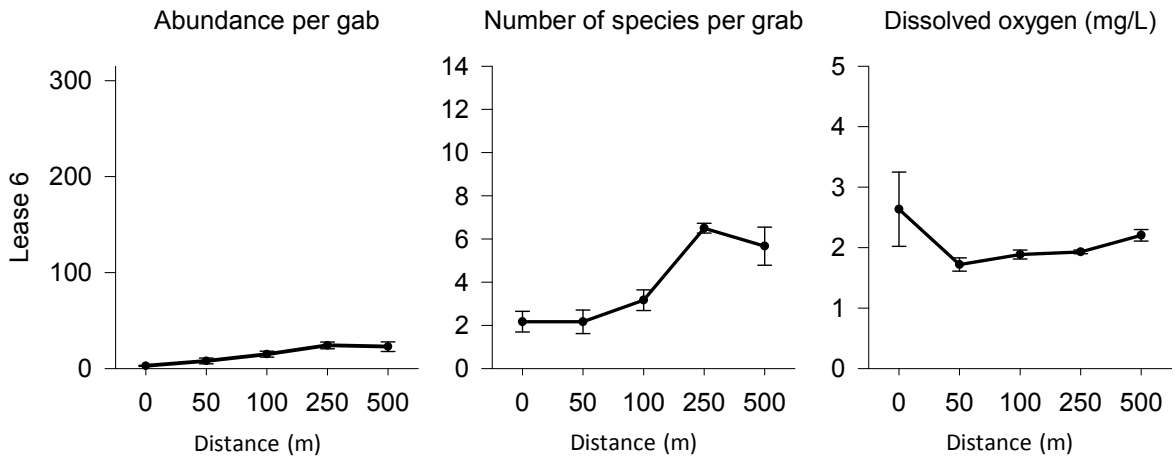

Figure 6 Plots of total infaunal (>1mm) abundance (per grab = ~ 0.0675m2), number of species collected in grabs (n=3) and the dissolved oxygen (mg/L) overlying the bottom at 0, 50, 100, 250 and 500m from cages at lease 6 in Macquarie Harbour in March 2017. Data collected and supplied by Aquenal on behalf of Tassal.

Harbour wide change

The surveys that have been repeated since January 2015 include a number of external sites to facilitate an assessment of harbour wide changes. These sites are at least 1km from the nearest lease and cover similar depth ranges and habitats. These sites allow comparison of benthic changes in the harbour as a whole alongside changes associated with farming and provide a means to assess temporal changes in benthic ecology. The results suggest that the greatest changes in faunal abundance and number of species at the external sites occurred at the southern end and in the middle of the harbour, i.e. similar to the pattern observed on lease. In the most recent survey, January 2017, there was little evidence of any marked change (either improvement or deterioration) since October 2016 (Figure 7).

The limited number and depth range of external sites sampled in previous surveys restricts our ability to evaluate and infer the potential for broadscale changes in the benthic ecology in other depth ranges and regions of the Harbour. To this end, in January 2017 we surveyed an additional 16 external sites (Figure 3) that overlap with sites sampled in the larger harbour wide surveys conducted at the start of 2015 and 2016.

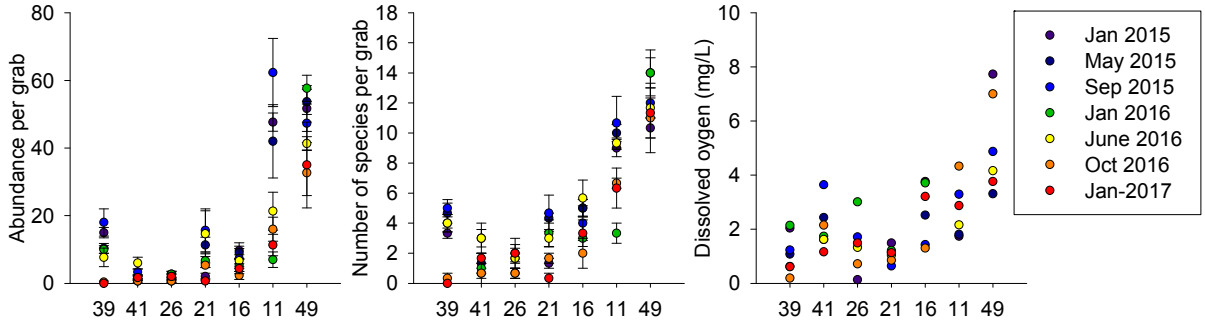

Figure 7 Plots of total infaunal (>1mm) abundance (per grab = ~0.0675m2), number of species collected in grabs (n=3) and DO in bottom waters at 7 external sites in Macquarie Harbour from surveys between January 2015 and January 2017. The data for each lease represents the mean (±SE) from three replicate grabs. Note that site 26 was not surveyed in May 2015.

An important feature of this data is the fact that the faunal abundance of the middle of the harbour would appear to be inherently lower than that of the shallower sites to the south in the WHA (44 & 45) and to the north i.e. those sites in closer proximity to the ocean (49, 12, 2, 14 & 3; Figure 8). Although the pattern in the number of species followed a broadly similar pattern, the distinction between the middle harbour sites and the shallower sites in the south and north was not as clear (Figure 8). Of the sites that were sampled in all 3 surveys, sites 39, 42 and 43 in the south of the harbour appear to show the greatest decline in both abundance and number of species in 2017 compared to 2015 and 2016. To provide further insight into the extent of faunal change within the harbour, data from the 500m lease sites has been included on a map of Macquarie Harbour (Figure 9 & 10). This highlights that that the greatest area of decline would appear to be towards the deeper centre of the harbour, with relatively little change occurring in the shallower regions around the margins of the harbour. This highlights that that the greatest area of decline would appear to be towards the deeper central region of the harbour (this includes the deeper sites 39, 42 and 43 in the south), with relatively little change occurring in the shallower regions around the margins of the harbour.

Comparing the benthic ecology of the harbour with our understanding of pre-farming conditions is complicated as there is limited comparable data for the harbour before farming commenced. Ross et al. (2016) described an increase in faunal abundance and a shift in community composition in recent years, this community shift was largely associated with species that respond well to increased levels of organic enrichment, notably tube building suspension feeders and surface deposit feeders. These changes were more pronounced in areas where there is farming. We have extended this comparison to include the January 2017 data[3] (Figure 11 & Figure 12). This again illustrates the importance of suspension feeders and surface deposit feeders such as the terebellid *Pista australis,* spionid *Pseudopolydora cf. paucibranchiata,* sabellid *Branchiomma sp.,* ampharetid *Samythella sp.*, and the dorvilleid *Schistomeringos loveni* in the temporal changes. However, in the 2017 survey the benthic community would seem to be less "dissimilar" to the pre-farming community than in the 2015 or 2016 surveys. This most likely reflects the decrease in faunal abundance at this time, which tends to make the community appear more closely aligned with the depauperate "natural" community in this system (Figure 12) and as such is likely an anomaly of the analysis rather than an improvement in conditions. The actual functional ecology of the species at these sites still suggests that the benthic community is consistent with what we might expect where there is organic enrichment.

[3] This comparison with baseline conditions was restricted to the northern region of the harbour where the baseline samples in the year 2000 were collected pre-farming. See Ross et al. (2016) for details on the sites used in this comparison.

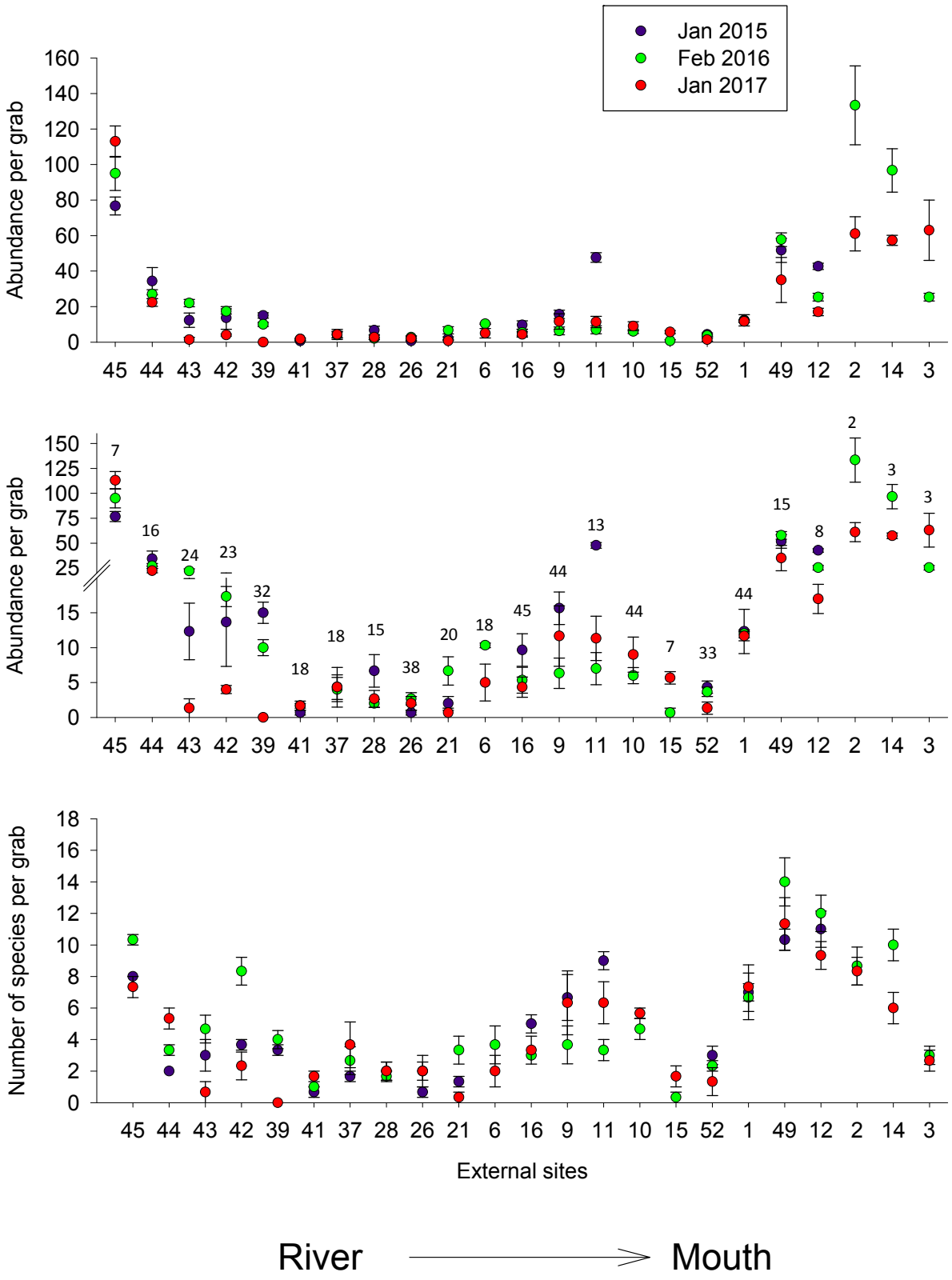

Figure 8 Plots of total infaunal (>1mm) abundance (per grab = ~0.0675m²; top 2 panels) and number of species collected in grabs (n=3; bottom panel) at 23 external sites in Macquarie Harbour from surveys in January 2015, February 2016 and January 2017. In the middle panel the axis is split to better show differences between surveys at the sites with lower abundances; the depth of each sites is also shown in this panel. 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.

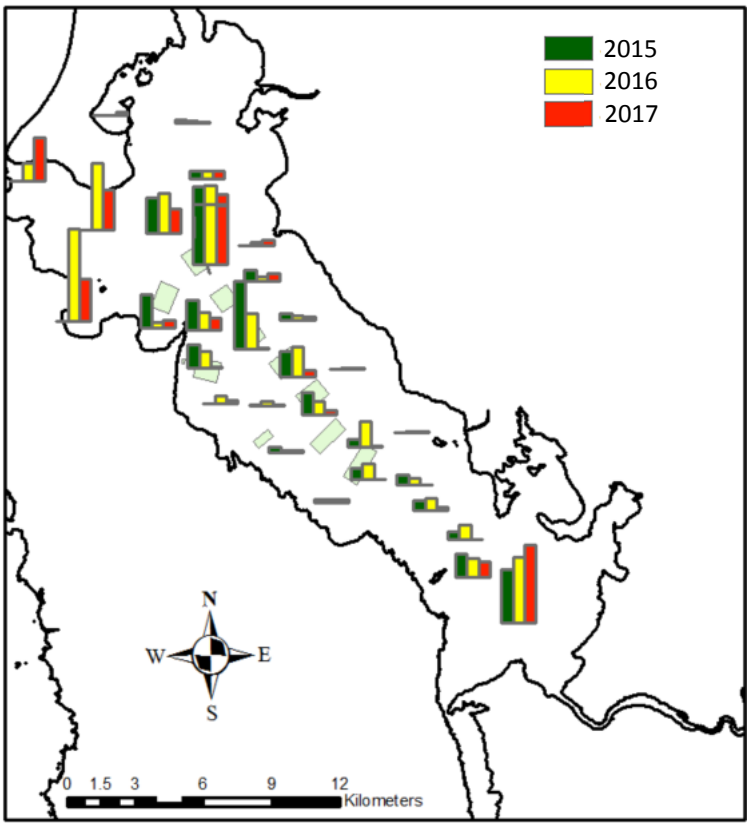

Figure 9 Map showing the relative abundance of fauna across surveys (Jan 15 - green, Feb 16 - yellow & Jan 17 - red) in bar charts at each of the external and 500m lease sites.

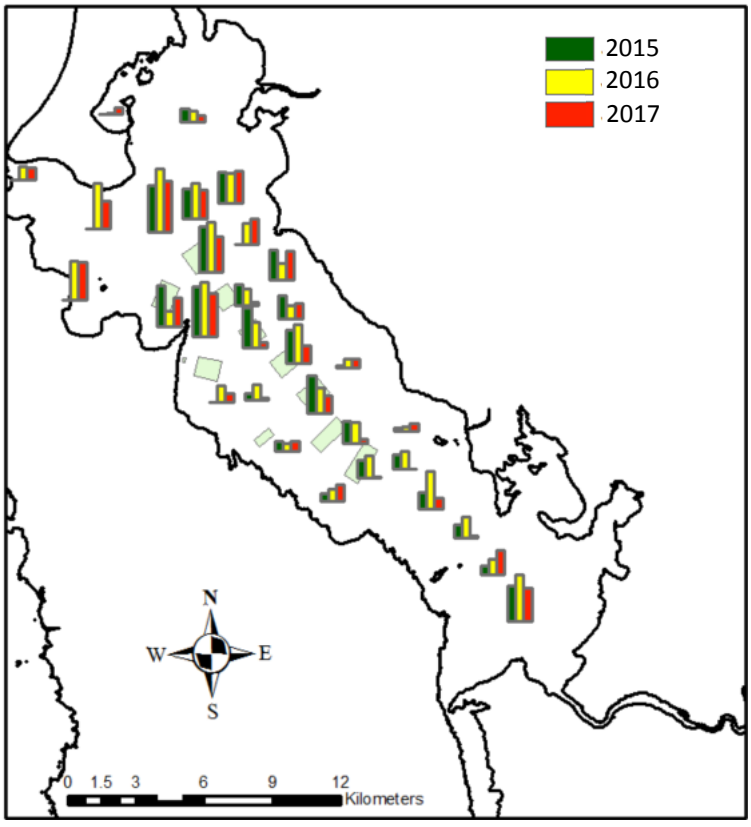

Figure 10 Map showing the relative number of species across surveys (Jan 15 - green, Feb 16 - yellow & Jan 17 - red) in bar charts at each of the external and 500m lease sites.

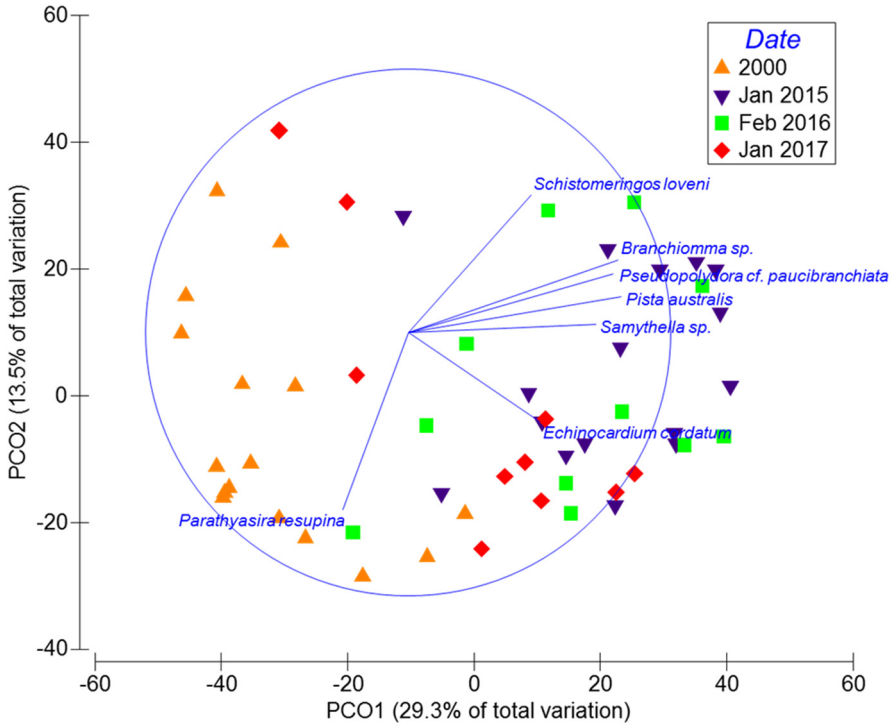

Figure 11 Principal Coordinate analysis comparing benthic communities from grab samples collected in the pre-farming baseline survey in 2000 in the northern region of the harbour with samples collected in the same region after farming in January 2015, February 2016 and January 2017. Species shown on the vectors have >0.4 correlation. See Ross et al. (2016) for details on the sites used in this comparison.

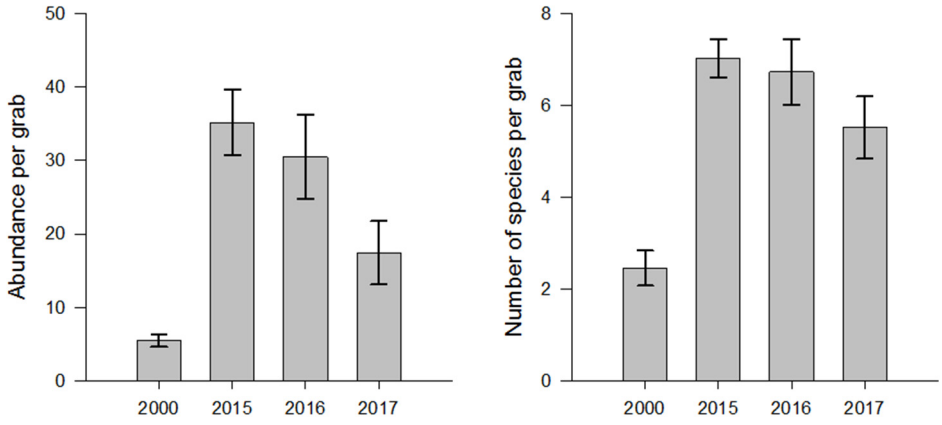

Figure 12 Mean total abundance and number of species per grab sample collected in the pre-farming baseline survey in 2000 in the northern region of the harbour with samples collected in the same region after farming in January 2015, February 2016 and January 2017. See Ross et al. (2016) for details on the sites used in this comparison.

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

[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 staff.

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 results of the first 7 surveys are shown here to provide further insight into the temporal changes in benthic condition and in particular the response of *Beggiatoa* cover and Dorvilleid abundance (as established indicators of organic enrichment).

Table 2 Scoring categories of *Beggiatoa* cover for video assessment

Beggiatoa cover
absent
patchy
thick patches
thin mat
thick mat
streaming

Table 3 Scoring categories of Dorvilleid abundance for video assessment

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

Of the 320 ROV dives conducted at lease sites across the 7 surveys, *Beggiatoa* was observed on 111 dives (~35%). Of the dives when it was present it was typically observed as patchy (~46% of observations). It was observed as a thin mat approximately 30% of the time, as a thick mat approximately 23% of the time and as streaming only on relatively rare occasions (~2%). With respect to distance from the cage, 45% of *Beggiatoa* observations were at the cages/ 0m, 71% within 50m and 90% within 100m. It is important to note here that these are distances from the cage and not from lease compliance points. As a reference, 35m from the lease (which is the standard compliance point for regulation) generally sits between the 100 and 250m sites on our study transects (as the cages are not located on the lease boundary).

At the external sites surveyed in this study, *Beggiatoa* has only been observed on 21 (15%) of 143 dives, and was reported as patchy in all but one instance (thin mat). The majority of instances where *Beggiatoa* has been observed at external sites have been in the south of the Harbour in the WHA (Figure 13). In the October 2016 survey *Beggiatoa* was more prevalent at both lease and external sites (Table 4), this is consistent with the outcomes of the September 2016 compliance surveys (EPA pers. comm.). In the January 2017 survey there does not appear to have been any major improvement, in fact *Beggiatoa* was present on a greater proportion of lease dives at this time. We understand that more recent company data, submitted to the EPA, has shown a significant contraction of *Beggiatoa* around leases in March and April (EPA pers. comm.). The increase in bottom water DO concentrations over this period would certainly provide the conditions for improvements in the *Beggiatoa* status and is likely to be a key driver behind the patterns seen in Figure 13.

The ROV footage also appears to show the association between the presence of Dorvilleids and farming (Figure 14, Table 5). The distribution of Dorvilleids typically extends further from the cages than *Beggiatoa* and Dorvilleids are more commonly observed at external sites. Of the 320 ROV dives, Dorvilleids were observed on 72% of lease dives and 40% of external dives. Dorvilleids were more commonly observed in the southern region of the Harbour, although in February 2016 they were observed at external sites throughout the middle and northern reaches of the harbour. Ross et al. (2016) noted that the broader distribution is largely associated with the Dorvilleid *Schistomeringos loveni* which appears to be less tolerant of highly enriched sediments than the colony forming Dorvilleid *Ophryotrocha shieldsi* that is typically found closely associated with stocked cages. Consequently, this needs to be taken into account when analysing Dorvilleid distribution from ROV footage in Macquarie Harbour. A more detailed analysis, interpretation and recommendations regarding ROV usage will be provided in the final report for FRDC project 2015-024.

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%	28%				
	Lease	42	52%	14%	7%	10%	17%	
Jan-17	External	28	75%	21%		4%		
	Lease	51	43%	25%		12%	16%	4%

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%

NOTE: the circles indicating *Beggiatoa* relate to the *Beggiatoa* score (severity) at the sampling site and not the spatial coverage of *Beggiatoa*

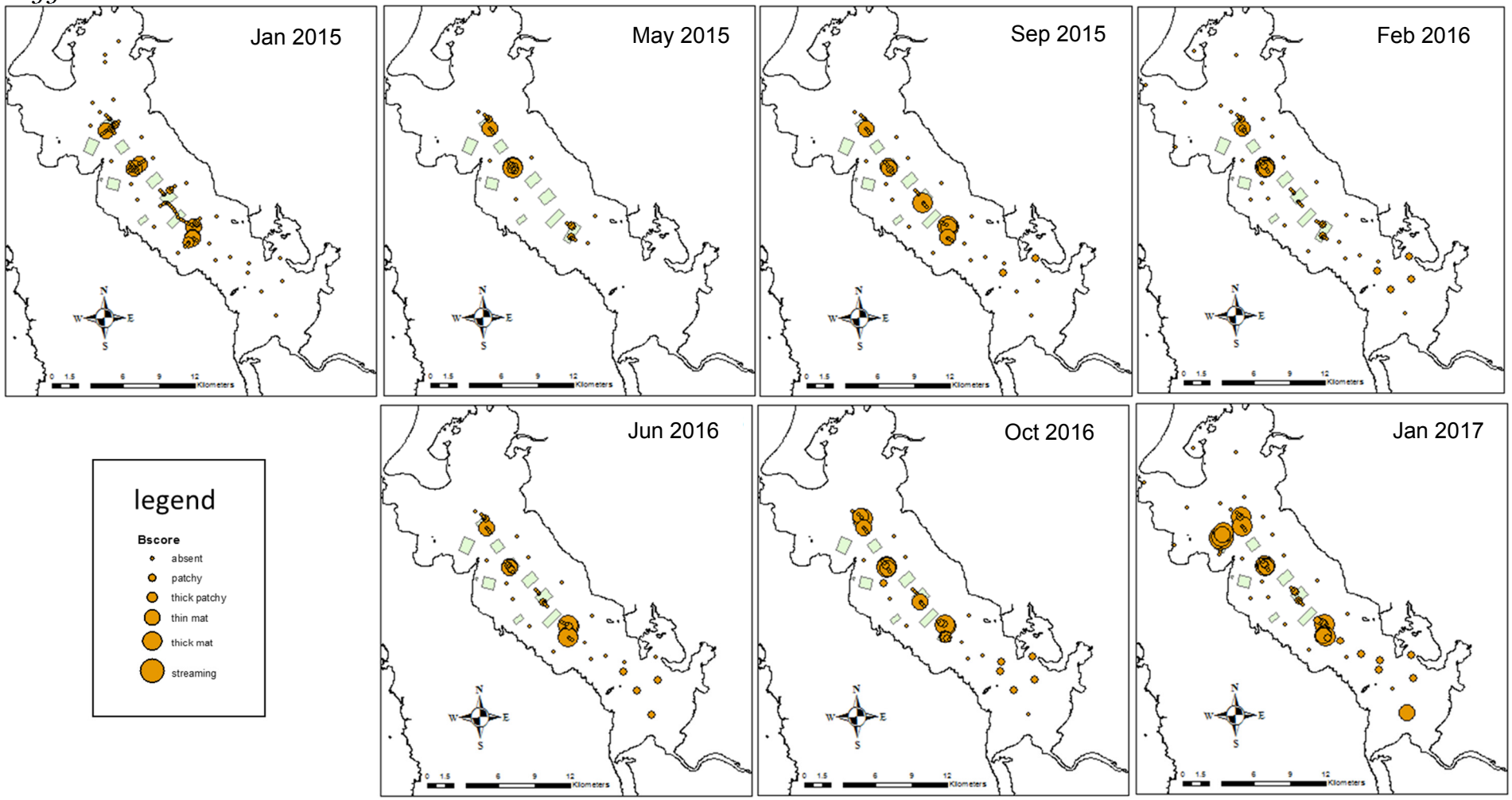

Figure 13 *Beggiatoa* cover from ROV footage at study sites shown on the above maps for each of the surveys. Please, note that only the sites surveyed are shown and this varied between surveys.

NOTE: the circles indicating Dorvilleids relate to the Dorvilleid score (count) at the sampling site and not the spatial coverage of Dorvilleids

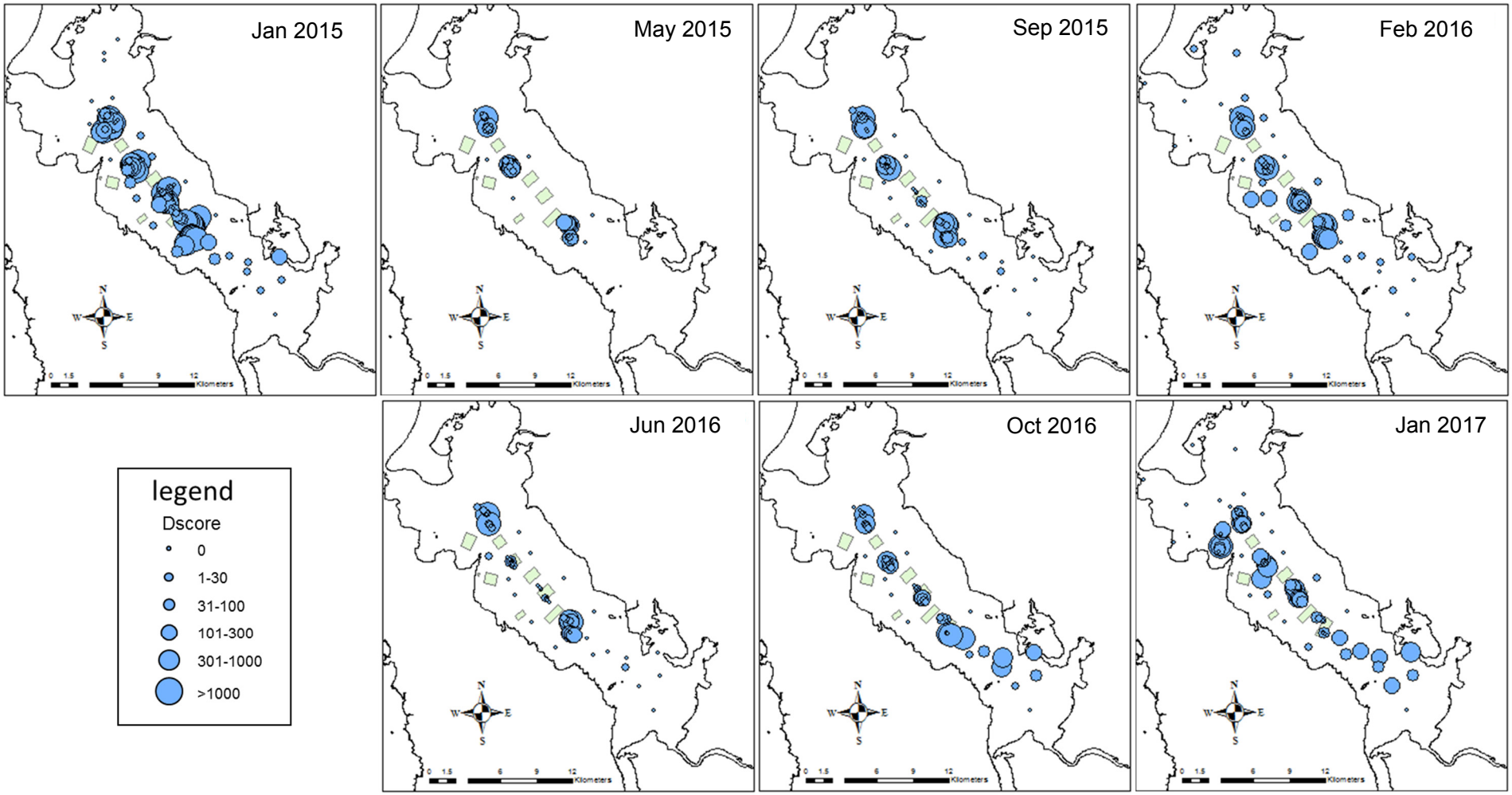

Figure 14 Counts of Dorvilleids from ROV footage at study sites shown on the above maps for each of the surveys. Please, note that only the sites surveyed are shown and this varied between surveys.

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