## Contents

<table>
<thead>
<tr>
<th>Section</th>
<th>Page</th>
</tr>
</thead>
<tbody>
<tr>
<td>Contents</td>
<td>1</td>
</tr>
<tr>
<td>Executive summary</td>
<td>2</td>
</tr>
<tr>
<td>Key findings</td>
<td>2</td>
</tr>
<tr>
<td>Current condition in the TWWHA</td>
<td>2</td>
</tr>
<tr>
<td>Impact of finfish aquaculture</td>
<td>3</td>
</tr>
<tr>
<td>1. Scope</td>
<td>4</td>
</tr>
<tr>
<td>2. Background</td>
<td>4</td>
</tr>
<tr>
<td>General environment and hydrology of Macquarie Harbour</td>
<td>4</td>
</tr>
<tr>
<td>Finfish aquaculture and monitoring in Macquarie Harbour</td>
<td>4</td>
</tr>
<tr>
<td>3. Water quality</td>
<td>6</td>
</tr>
<tr>
<td>Dissolved oxygen – current knowledge</td>
<td>6</td>
</tr>
<tr>
<td>Dissolved oxygen levels in the TWWHA</td>
<td>7</td>
</tr>
<tr>
<td>Nutrients</td>
<td>10</td>
</tr>
<tr>
<td>4. Benthic condition</td>
<td>12</td>
</tr>
<tr>
<td>Video surveys – external sites</td>
<td>12</td>
</tr>
<tr>
<td>Video surveys – lease impacts on TWWHA</td>
<td>12</td>
</tr>
<tr>
<td>Benthic infauna</td>
<td>14</td>
</tr>
<tr>
<td>5. Maugean Skate</td>
<td>16</td>
</tr>
<tr>
<td>6. References</td>
<td>17</td>
</tr>
</tbody>
</table>
Executive summary

Approximately one third of the area of Macquarie Harbour is located within the boundary of the Tasmanian Wilderness World Heritage Area (TWWHA). With the expansion of marine farming in Macquarie Harbour in recent years, there has been an increase in environmental monitoring as a consequence of marine farm licence requirements and additional targeted research studies initiated in response to an observed decline in dissolved oxygen concentrations in the water column and subsequent deteriorating benthic conditions.

This report provides a summary of recent monitoring of environmental condition in Macquarie Harbour within the TWWHA, and outlines research findings relevant to the TWWHA region. It has been prepared to support the decision making processes of the Director, Environment Protection Authority and to provide advice to the Minister for Parks, Environment and Heritage about impacts on the TWWHA.

Key findings

- There is evidence of deterioration in the environmental condition in Macquarie Harbour broadly, and also within the TWWHA region.
- It is clear that increased finfish aquaculture is likely to be one driver of dissolved oxygen decline in the Harbour, but that other drivers exist, including organic load from freshwater inputs.
- Within the TWWHA sites specifically, the deeper sites (39, 42 and 43) showed the greatest decline in in-fauna abundance and number of species in 2017 compared with early 2015 and 2016, but results in January/February 2017 showed little evidence of any marked change (improvement or deterioration) since October 2016. The shallower TWWHA sites (44 and 45) had did not show evidence of a decline between 2015/2016 and 2017.
- The Tassal “Franklin” lease (no. 266) was completely fallowed by 10 April 2017. Subsequent industry monitoring in March and April 2017 has indicated that the Beggiatoa spp. extent around this lease has contracted substantially and is now well outside of the TWWHA boundary.

Current condition in the TWWHA

There is evidence of deterioration in the environmental condition in Macquarie Harbour broadly, and also within the TWWHA region. The most likely cause of this deterioration is the protracted period of low levels of dissolved oxygen (DO) adjacent to the harbour floor, and in the midwater regions.

Ongoing water column monitoring has indicated that dissolved oxygen (DO) levels remain very low. Current DO concentrations in both the mid and bottom waters across the harbour and within the TWWHA are significantly lower than long-term averages.

The most recent monitoring of benthic condition has indicated that the number of sites in the TWWHA at which Beggiatoa spp. was observed has increased over the period January 2015 (zero of ten sites) to January 2017 (seven of ten sites). This is indicative of a low oxygen environment and a source of organic input; however, these observations do not indicate the source of the organic matter or the drivers of the environmental conditions which have led to the presence of Beggiatoa spp. at TWWHA sites. Recent industry monitoring in April 2017 indicates that the number of TWWHA sites with observed Beggiatoa spp. has reduced to two of nine sites, which may reflect the influence of DO renewal in bottom waters. This will be assessed again in May 2017.

Benthic infauna sampling conducted by IMAS has indicated a significant decline in the abundance and diversity of benthic species in October 2016 and January 2017 in the deep water sites within the TWWHA, when compared with early 2015/2016 surveys (Ross and MacLeod 2017a; 2017b). However, this decline was not apparent at the shallower sites within the TWWHA (Ross and MacLeod 2017b). These results provide an indication of the influence of bottom water oxygen concentrations on benthic response. Harbour wide surveys in January 2017 and more recent industry surveys have demonstrated potential early signs of benthic fauna recovery and recruitment further north in the Harbour.
The environmental health of Macquarie Harbour, in particular levels of DO in the bottom waters, is likely to represent a crucial factor in the future well-being of the Maugean Skate population. Low DO concentrations appear limiting for the skate and presumably their prey, however, further research is proposed to investigate how the endangered Maugean skate population is being impacted by the environmental conditions in Macquarie Harbour.

**Impact of finfish aquaculture**

Drivers of DO consumption in Macquarie Harbour are primarily related to processes which influence benthic and pelagic oxygen demand. Finfish aquaculture, as a source of organic load and ammonia, has been identified as one of a number of factors which may influence DO consumption and benthic condition in the harbour. Various research projects have identified the effects of finfish aquaculture at the lease (or near-lease) scale, including increased ammonia, increased pelagic oxygen demand (POD) rates and benthic responses such as reduced faunal abundance and diversity and increased *Beggiatoa* spp. However, marine farm leases are not located within the TWWHA, and the relative contribution of aquaculture to impacts at a harbour-wide scale (including the potential for impact in the TWWHA) has not been definitively determined.

It is clear that increased finfish aquaculture is likely to be one driver of DO decline in the Harbour, but that other drivers exist, including organic load from freshwater inputs. Recent industry research has suggested the influence of organic inputs from the Gordon River on DO consumption and presence of *Beggiatoa* spp. within the TWWHA is significant during certain periods. Regardless of attribution, DO levels have clear effects on benthic response, and the decline in DO has resulted in a broad-scale loss of benthic infauna across the deeper regions of the harbour, including in the TWWHA. Understanding the processes and relationships related to DO levels in the harbour, and its importance on benthic recovery, is the focus of ongoing research.

As noted above, the presence of *Beggiatoa* spp. at external monitoring sites within the TWWHA does not identify the source of the enrichment or the cause of the low DO environment. However, the January 2017 results of video monitoring from the Tassal “Franklin” lease (located approximately 1km outside of the TWWHA boundary) demonstrated *Beggiatoa* spp. extending from the lease to approximately 50m across the TWWHA boundary. This does appear to constitute a likely lease impact within the TWWHA at that particular location; however, based on current knowledge, it is not possible to extrapolate this impact to the other TWWHA sites, nor rule out other/additional sources of organic enrichment. This impact in January 2017 was observed after the EPA Director’s November 2016 direction to destock the Franklin lease, in response to observed impacts from the September 2016 survey (which did not extend into the TWWHA). The Franklin lease was completely fallowed by 10 April 2017. Subsequent industry monitoring in March and April 2017 has indicated that the *Beggiatoa* spp. extent around this lease has contracted substantially and is now well outside of the TWWHA boundary. This will be assessed again in May 2017.
1. Scope

On 15 March 2017, Minister Groom sought advice from the Environment Protection Authority (EPA) regarding impacts on the Tasmanian Wilderness World Heritage Area (TWWHA) from salmon farming in Macquarie Harbour, stating that serious environmental impacts inside the TWWHA were unacceptable (http://epa.tas.gov.au/pages/news.aspx?newsstory=3691).

This report provides a summary of the current monitoring and environmental condition of Macquarie Harbour specifically within the TWWHA. Over recent years, a large volume of research has been undertaken to understand the cause(s) of identified environmental trends in the harbour, and to investigate possible attribution. Aquaculture is one of several factors investigated. This report also aims to outline the findings of this research, where relevant to the TWWHA.

2. Background

General environment and hydrology of Macquarie Harbour

Macquarie Harbour, located on the west coast of Tasmania, has a total surface area of 276 km². The Tasmanian Wilderness World Heritage Area (TWWHA) encompasses approximately the southern third of the harbour (Figure 1). The harbour has a shallow, restricted entrance to the ocean and a long deep central basin with depths of 30-50m.

The main freshwater inflows to the Harbour are the Gordon River at the southern end and the King River at the northern end, with the yearly inflow volume of the Gordon being approximately 5 times that of the King River (Koehnken, 2001). Both the Gordon and King Rivers are regulated for hydro-electric power generation, with approximately 25% and 60% of the respective catchment areas being regulated. The hydrodynamics of the harbour are affected by freshwater inflow; the shallow oceanic sill; tide; wind; atmospheric pressure; and internal stratification and currents. The water quality of the King River is affected by low pH, high metal water due to the inflow of acid drainage from the Mt Lyell Copper Mine in Queenstown, which has resulted in a history of poor water quality events in Macquarie Harbour primarily related to large copper influxes in the north of the harbour (Koehnken, 2001). To monitor these environmental impacts, the EPA has conducted a water quality monitoring program in Macquarie Harbour since 1993. While the monitoring frequency has varied over this period, it provides a long term water quality dataset for the harbour (current EPA monitoring sites are shown in Figure 1). In late 2013, the EPA water quality monitoring program identified a decline in dissolved oxygen (DO) levels in the deeper waters of Macquarie Harbour, which started in around 2009.

Finfish aquaculture and monitoring in Macquarie Harbour

Finfish aquaculture began in Macquarie Harbour in the 1980s. Annual production remained under or around 2000 tonnes until 2005, when production began to steadily increase. Production reached ~9000 tonnes in 2011 and ~15,500 tonnes in 2015. The maximum standing monthly biomass for the Harbour reached ~20,000 tonnes in January 2015, and was ~16,000 tonnes in late 2016, under a biomass cap set for the Harbour of 21,500 tonnes. For the period 14 February to 30 April 2017 the biomass cap for the Harbour was reduced by the EPA to 14,000 tonnes, with a further determination to be made following this period. There are currently 10 operational marine farm leases in Macquarie Harbour, all located outside of the TWWHA boundary (see Figure 1). One lease has recently been destocked, which is discussed later in this document.

As part of the 2012 amendment to the Macquarie Harbour Marine Farming Development Plan and the subsequent expansion of marine farming in the harbour, water quality monitoring has been conducted on a monthly basis by consultants on behalf of Tassal, Petuna Aquaculture and Huon Aquaculture since October 2011 (see Figure 1 for current monitoring sites). This data confirmed the declining DO trend in the harbour. As a result, since late 2013 monitoring has been increased in the harbour and a significant amount of targeted research has been undertaken to investigate the factors influencing DO levels.
In line with marine farm licence conditions, all operational leases have undergone routine regulatory environmental video surveys in and around lease areas to assess benthic sediment for indicators of visual impact. In response to increasing observations of visual impact at marine farming lease compliance sites since around 2014, DPIPWE/EPA has increased the frequency and spatial extent of video monitoring required of marine farm operators, including the monitoring of harbour-wide “external” sites shown in Figure 1, some of which are located in the TWWHA. Other management responses have been implemented where required, and significant research into benthic effects in Macquarie Harbour is also ongoing.

As shown in Figure 1, the EPA collects or receives data on water quality and benthic condition at numerous monitoring locations within the TWWHA. Additional data related to environmental condition in Macquarie Harbour is also collected through numerous research projects conducted by IMAS, CSIRO, Sense-T, industry, consultants and other collaborators, and results from this research are also discussed in this report.

![Figure 1. Macquarie Harbour relative to the TWWHA (see inset, shaded purple) and the location of the TWWHA boundary within the Harbour. Marine farm lease boundaries and location of current monitoring sites (where data is either collected by EPA or reported to EPA/DPIPWE by industry) are also shown. Note that there are additional monitoring sites in Macquarie Harbour not shown here – these include research/monitoring sites used by other projects/agencies (e.g. IMAS, CSIRO, PWS, aquaculture operators) or historical monitoring sites (e.g. EPA Mt Lyell Remediation water quality sites, additional marine farming baseline/control sites etc).](image-url)
3. Water quality

Dissolved oxygen – current knowledge

It is typical to find lower dissolved oxygen levels at depth in stratified systems such as Macquarie Harbour, which have deep central basins and limited exchange with oceanic waters. However as stated above, long term EPA monitoring suggests that DO levels in mid-bottom waters of Macquarie Harbour have declined significantly since around 2009, including in the TWWHA (Figure 2). While the data shows variability, as well as a substantial recharge of bottom waters in mid-2014 (particularly in the northern part of the harbour), DO levels are clearly below the long term levels recorded from 1993-2009. Since this decline was identified in late 2013, data from several other monitoring programs and research projects have confirmed these very low levels in deep waters of the Harbour.

The timing of this decline has coincided with the expansion of finfish aquaculture in Macquarie Harbour. Subsequently, numerous research studies have been undertaken to investigate the potential drivers and key influences on dissolved oxygen levels in the harbour. These drivers broadly fall into two categories: processes associated with DO consumption; and processes associated with DO renewal (Ross and MacLeod, 2017a). Drivers of DO renewal are mainly physical processes associated with (i) vertical mixing and (ii) oceanic “recharge”. These processes are influenced by river discharge into the harbour and other environmental variables including wind, tide and atmospheric pressure. Understanding how these physical processes interact to influence oxygen drawdown and recharge is the subject of ongoing collaborative research led by IMAS and CSIRO, using sensor technology to collect high-quality, high-frequency real-time data on environmental conditions including DO, and continuing the development and calibration of the CSIRO Near Real Time Hydrodynamic and Oxygen Transport Model for the Harbour.

Understanding and quantifying the drivers of oxygen consumption in the harbour has also proven complex. Research studies have investigated biological oxygen demand in the harbour, from both benthic and pelagic sources, and attempted to characterise the contribution of various organic carbon inputs, including fish
farming and river discharge. It has been estimated that aquaculture may be responsible for 3-12% of the benthic oxygen demand (BOD) for sediments >15m in Macquarie Harbour (MHDOWG, 2014). Initial estimates of pelagic BOD (the consumption of oxygen in the water column) is that while spatially variable, it may be at least 2 times that of benthic respiration (Revill et al., 2016). Pelagic oxygen demand (POD) can occur via microbial aerobic respiration (where DO is consumed as microbes break down organic matter) and nitrification (where DO is consumed to convert ammonia to nitrate) (Maxey et al., 2016). Finfish aquaculture is known to be a source of organic matter (feed and faeces) and ammonia in the water column leading to POD. However, the processes influencing POD are complex and there are other sources of organic matter and drivers of POD in Macquarie Harbour.

Maxey et al. (2016) found that POD rates in the Harbour were highest around farm leases below the halocline and increased with depth and also observed that nitrification rates increased with depth. However, the follow-up study (Maxey et al. 2017) identified that organic input entering Macquarie Harbour from the King and Gordon Rivers is also a significant driver of POD and can exceed the contribution of fish farms depending on seasonal conditions.

Ross et al. (2016) identified that the prevalence of nitrifying bacteria and archaeb (organisms which produce organic matter via a chemical process which converts ammonia to nitrate and consumes oxygen) in Macquarie Harbour may be another significant source of carbon, and an influence on nitrogen cycling and oxygen dynamics, in the water column. Further research is required to better understand the processes and relationships contributing to pelagic DO drawdown in Macquarie Harbour.

**Dissolved oxygen levels in the TWWHA**

With regard to the current status of dissolved oxygen levels in Macquarie Harbour, and the potential effects in the TWWHA, the January 2017 IMAS synopsis of Environmental Research in Macquarie Harbour (Ross and MacLeod, 2017a) states:

“DO levels are now extremely low throughout the Harbour, but most notably in the southern part of the Harbour. All of the independent data sets (industry, EPA, Sense-T, Parks, IMAS and CSIRO) are providing the same picture; DO levels in bottom waters are now worryingly low.

.. The levels of DO now observed in bottom waters throughout the Harbour present a significant potential risk to the ecology of the Harbour”.

In a Progress Report received by EPA in late April 2017 to provide an update of the most recent research, Ross and MacLeod (2017b) noted that while some replenishment of DO was observed in the deep bottom waters of the central basin of the Harbour over summer 2016/2017, this increase occurred primarily in waters below 30m, with little change observed between 20-30m depth. It is noted that while the deep water replenishment is encouraging and may contribute to some benthic recovery, a similar increase has been observed in previous summers (including 2016), with concentrations still declining to extremely low levels 6 months later. Ross and MacLeod (2017b) also point out that the mid-water column, where DO levels remained low, represents a much larger proportion of the total water in the Harbour, and as such there is clearly capacity for DO levels to continue to decline.

Based on the most recent monitoring by EPA in March 2017, DO levels are still very low in the TWWHA region. EPA monitoring on 8 March 2017 recorded extremely low DO levels in the water column at several sites in the TWWHA (i.e. recorded concentrations of 0 mg/L at depths of ~15-30m dependent on site). Shallower sites furthest south in the Harbour (MH34 and WHA4; see Figure 1 for locations) had no detectable DO at 19 metres and 14 metres respectively, while sites around the TWWHA boundary and further north showed some signs of deep-water recharge (Figure 3).
Figure 3. Dissolved Oxygen profiles moving southeast through Macquarie Harbour – March 2017

Site MH34, in the south eastern end of Macquarie Harbour and within the TWWHA, is approximately 7km from the nearest marine farm lease (Lease No. 266). Figure 4 shows the MH34 quarterly dissolved oxygen profiles for the period March 2016 to March 2017 against a long-term statistical representation of the data from 2000-2010. The recent profiles show that a significant decline in DO below 10m has occurred when compared to the DO range over the 2000-2010 period. Dissolved oxygen levels below 15m at this site have been consistently lower in 2016/2017 than the long-term 20th percentile value, which represents a significant decline.

Figure 4. Dissolved oxygen profiles at EPA site MH34; quarterly profiles for the period March 2016-March 2017, and a statistical output for the long term data 2000 to 2010; the median is red and the 20th and 80th percentiles are displayed by the boundaries of the blue polygon. Zero DO results are indicative of measured DO concentrations less than the sensitivity range of probe.

Figure 5 shows the continuous logger string data from the site on the TWWHA boundary. Recharge events are evident at this site over January/February 2017, with increases in DO (and subsequent declines) at 35m depth. A sustained small increase in DO ranging from 1-2.5mg/L above the anoxic level of approximately 0.5
mg/L did occur over this period before returning to less than 1 mg/L in March 2017. The current levels are considerably less than the long term (2000 – 2010) average of 4 mg/L at 35 m. Note that despite the recharge at the logger string location in January/February 2017, DO levels at site MH34 further south (Figure 4) were lower in March 2017 than in December 2016. This demonstrates that the oxygen renewal of the recharge events did not penetrate as far south as MH34 (or did not last long if it did), which may reflect physical processes as well as the ongoing DO consumption in the water column.

Figure 5. Continuous logger string data at WHA boundary Dec 2016-March 2017

As part of research into the biology and ecology of the endangered Maugean Skate in Macquarie Harbour, IMAS also maintains two continuous dissolved oxygen loggers within the TWWHA, at Rum Point and Kelly’s Basin which are located on opposite sides of the southern end of the harbour. Confirming the observations of other monitoring programs, researchers have advised that these loggers have continued to record very low DO levels within mid-bottom water of the TWWHA over the last 12 months.

Monthly water quality monitoring conducted by industry, which includes DO as well as a range of other physico-chemical and nutrient parameters, also indicates persisting low DO levels in bottom waters of the TWWHA part of the harbour (see Figure 6 below for industry site WH2, which is located within the TWWHA close to the EPA logger site; note: this is different to EPA site WH2).

Levels recorded on 18 March 2017 were not as low as those recorded nearby by EPA 10 days previously, however there appears to be a decline in the surface and mid-waters down to ~20m, with some recharge in the deeper part of the water column at this site. Most recent April data shows evidence of renewal higher in the water column. Note that a comparison of these datasets indicates that while the long-term trend is consistent, there is substantial short-term variability. This highlights the need for the high-frequency real-time sensors and a high quality, calibrated hydrodynamic model to improve our understanding of the detailed dynamics of DO patterns in the harbour, and how these patterns influence ecological responses.
While there was evidence over the 2016/2017 Summer of an increase in bottom water DO, mid-water levels remain extremely low compared with long-term averages, particularly in the southern end of the harbour. Increases in bottom water DO observed in early 2016 are similar to those observed in early 2017, and yet concentrations declined to very low levels by Spring 2016, which indicates there is a clear capacity for DO levels to decline again in 2017.

**Nutrients**

A review of long-term nutrient monitoring across Macquarie Harbour, including in the TWWHA, is the subject of a separate EPA report (*Macquarie Harbour Nutrient Review*, Draft, May 2017). Observations from this report, relevant to the TWWHA, are outlined below.

Across the WHA sites, median values of NOx (nitrite and nitrate) over the 2012-2016 period were significantly higher than median values at similar sites over the 1995-1997 period in both surface and bottom waters. Across the spatial extent of the Harbour, NOx ranges were similar in surface waters, but for bottom waters were highest at the deeper sites in both the WHA and northern part of the Harbour when compared with shallower sites in both the Gordon River and in Kelly Channel (Kelly Channel is located near exit of the harbour to the ocean, as opposed to Kelly’s Basin which is in the WHA region). Note that the “bottom water” depths of the Gordon River and Kelly Channel sites are comparatively shallower than the bottom waters of the more central sites, and the lower NOx values at these shallower sites may reflect the more well-mixed water column at these locations. For deeper sites, the higher NOx values at depth (compared with surface) reflect the release of nitrate in bottom waters as a result of the breakdown of organic matter and nitrogen cycling processes. Historical harbour values (1995-1997) and current riverine and Kelly Channel derived NOx values are similar in magnitude while NOx values for the bottom waters in the harbour proper are an order of magnitude greater. This suggests that elevated NOx observed in the central harbour region may be entering the harbour from sources within the harbour in addition to those entering from either the Gordon River or marine waters (via the Kelly Channel).

Over the 2012-2016 period, increases in NOx values were evident in the WHA and to a lesser extent in the North Harbour transects. This would suggest generation of nitrate, movement of elevated NOx, and possible retention towards the southern region of the harbour. Bottom water NOx results over this period demonstrated a gradual increase at the WHA and North Harbour sites as well as the Gordon River site. Higher NOx levels in bottom waters at the Gordon River were related to salt water intrusion from the harbour and correlated with increased salinity at this location.
All results of ammonia and ammonium monitoring in the harbour are below guideline values considered likely to cause toxic effects. At WHA and central harbour sites, the median ammonia and ammonium levels in bottom waters were approximately half of those in the surface waters. This is reflective of the nitrogen cycle, i.e. planktonic uptake and breakdown with bacterial nitrifiers converting ammonia to nitrate under oxic conditions, particulate organic nitrogen being formed, and nitrate converted to nitrogen gas or remineralized under anoxic conditions.

Total phosphorus (TP) and dissolved reactive phosphorus (DRP) values for surface waters were similar across all areas of the harbour. For bottom waters, both total phosphorus and dissolved reactive phosphorus concentrations are highest in the harbour (WHA and North Harbour sites) and lowest in the riverine waters of the Gordon. When compared with historical values, there has been a harbour wide increase in DRP with the most significant elevation in DRP occurring in the bottom waters in both the Northern Harbour and WHA sites.
4. Benthic condition

Video surveys – external sites

Since January 2015, 20 ‘control’ sites (external to lease areas) around Macquarie Harbour have had video monitoring surveys undertaken on a 4-monthly basis, to support harbour-wide research into low DO levels and benthic condition. Ten of these sites are located within the TWWHA (see Figure 1). The presence of the bacteria Beggiatoa spp. on the benthic sediment surface is one of the key parameters reported via video monitoring.

Beggiatoa spp. is a naturally occurring organism, present in circumstances of low dissolved oxygen where it breaks down (feeds on) decaying plant and animal material. The presence of Beggiatoa spp. can therefore be used as an indicator of a low oxygen environment. Beggiatoa spp. was first observed at 2 control sites in the TWWHA in September 2015 (Table 1). It’s distribution within the TWWHA appears to have expanded since that time, being observed at 7 of the 10 TWWHA monitoring sites in the most recent January 2017 surveys. Generally, the observations have been of faint, patchy Beggiatoa spp. at these sites, with a thin mat observed at site 45, closest to the Gordon River, in January 2017. The presence of Beggiatoa spp. in the TWWHA reflects a decreasing oxygen environment, as evidenced by the water quality data, and the presence of an organic load. However, these observations do not indicate the source of the organic matter or the drivers of the environmental conditions which have led to Beggiatoa spp. presence, nor a complete picture of potential impacts.

Table 1. Observations of Beggiatoa spp. from 4 monthly video survey monitoring at TWWHA sites. Blank cells indicate Beggiatoa spp. was not observed for this site/survey date.

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Video surveys – lease impacts on TWWHA

Within Marine Farm licence conditions, the presence of Beggiatoa spp. observed at compliance sites (35m from the lease boundary) via video monitoring may be used as an indicator of visual impact for compliance assessment purposes, and triggers a management response. Several leases within Macquarie Harbour are currently subject to a range of management responses due to the presence of Beggiatoa spp. at lease compliance sites; the specific results of compliance monitoring at marine farm leases in Macquarie Harbour are not presented in this report, but are made available on the EPA website once assessed. However, it is relevant to the discussion of the TWWHA to note that one lease, MF266 which is closest to the TWWHA (approximately 1 km northwest of the boundary), has recently been destocked by Tassal following the direction of the EPA in November 2017. Destocking began in January 2017 and was complete by 10 April 2017. This was a management response implemented following the September 2016 compliance survey due to the ongoing presence and expanding extent of Beggiatoa spp. at and beyond 35m from the lease boundary.
The EPA also took into account IMAS benthic infauna research results within the vicinity of this lease (outlined below). As part of compliance monitoring surveys, where *Beggiatoa* spp. is detected at a 35m compliance point, the company is required to map the outer extent of *Beggiatoa* spp. around the lease. In the September 2016 survey, the furthest extent of *Beggiatoa* spp. along the south eastern boundary of the lease (the boundary closest to the TWWHA) was reported as approximately 285m from the lease, roughly 700m outside of the TWWHA boundary. The January 2017 survey was conducted in late January and early February 2017 (extension due to weather), and reported in draft form to EPA on 17 March, followed by an updated draft on 7 April 2017. The January 2017 “extent mapping” survey results showed that the outer extent of *Beggiatoa* spp. from the south eastern lease boundary had extended to approximately 1035m in at least one location, and had crossed the TWWHA boundary by approximately 50m.

From November 2016, along with the direction to destock, EPA has required Tassal to monitor and map the extent of *Beggiatoa* spp. around MF266 on a 2-monthly basis. Tassal provided the results of *Beggiatoa* spp. extent mapping conducted in March 2017 in the updated draft report submitted in April 2017, which indicated that the extent of *Beggiatoa* spp. from the south eastern lease boundary had retracted to a maximum of approximately 735m from the south eastern lease boundary, and was no longer extending into the TWWHA region. The March 2017 results provide an early snapshot of benthic condition following the implementation of the management response to destock MF266.

*Beggiatoa* spp. occurs at the interface between anoxic and oxic conditions. While it can be expected that *Beggiatoa* spp. might reduce when oxygen conditions improve (Ross and MacLeod, 2017b), it may also be reduced in persistently anoxic conditions. It is likely that bottom water DO recharge events in early 2017 contributed to the reduction of *Beggiatoa* spp. around MF266 in March 2017.

On 24 April Tassal provided results of a voluntary April 2017 *Beggiatoa* spp. extent mapping survey to the EPA, indicating that there had been a significant further contraction of the *Beggiatoa* spp. “footprint” around lease 266. Tassal’s submission indicated that the *Beggiatoa* spp. extent for the lease was much closer to the lease boundary, and well outside of the TWWHA region.

The next compliance survey, due in May 2017, will enable the EPA to assess this formally. The EPA has also directed Tassal to conduct a comprehensive “post-harvest” survey - including video monitoring, sediment chemistry and benthic infauna sampling. This will be conducted in May 2017 to provide a “baseline” of benthic condition, from which repeat surveys will be required to closely track remediation and recovery at this lease. Ongoing research work led by IMAS and CSIRO will also inform this recovery monitoring. MF266 will not be restocked until the EPA is satisfied that the benthic environment has adequately recovered.

As noted above, patches of *Beggiatoa* spp. have been detected at various external monitoring sites within the TWWHA since September 2015, up to 12kms from the MF266 lease. While *Beggiatoa* spp. is indicative of organic enrichment and a low oxygen environment, the presence of *Beggiatoa* spp. alone at these external sites does not identify the source of the enrichment or the cause of the low DO environment. It is worth noting that the appearance of *Beggiatoa* spp. at TWWHA sites is generally patchy and does not have the same appearance or coverage as the *Beggiatoa* within leases. However, the January 2017 results of extent mapping from MF266, which show a “footprint” of *Beggiatoa* spp. extending from the lease to approximately 50m across the TWWHA boundary, do appear to demonstrate a likely lease impact within the TWWHA at that particular location. Based on current knowledge at this stage, it is not possible to extrapolate this impact to the other TWWHA sites, nor rule out other/additional sources of organic enrichment.

Tassal believes that organic loading from the Gordon River is an important influence on the presence of *Beggiatoa* spp. and low dissolved oxygen levels in the TWWHA. The following text is extracted from the Tassal MF266 compliance reports for the September 2016 and January 2017 surveys (the Tassal “Franklin” lease is MF266):

“It is now known from recent industry research that the largest pelagic oxygen consumption is in the World Heritage Area (WHA) region of the Harbour. This area is subjected to the largest organic loading as particulates drop out of the riverine fresh waters and settle on the benthos. Tassal manages WHA monitoring points for industry and films these locations every four months. There are some areas within this region of the system that regularly have showed
the presence of Beggiatoa indicating that they are depositional areas for organics flowing down the river systems. The volume of this organic matter (leaves etc.) has been observed in the last year as approximately 50cm deep down both sides of this section of the Harbour. These areas are upstream from the impacts from farming and are ranging from between 7-12km from the Franklin lease.”

A report outlining this research (Maxey et al., 2017) describes research which was carried out in December 2016 and February 2017, following on from previous work investigating POD in the Harbour. The most recent results suggest that organic inputs from the Gordon and King Rivers have been underestimated as a major driver of pelagic oxygen demand (POD) in Macquarie Harbour, and that this may vary significantly from season to season. The report states that while salmon farming influences on POD may be significant, under some circumstances (e.g. periods of high river discharge) riverine sources of organic material into the system may drive rates of POD which can “rival, and sometimes exceed” those measured under farm cages. This work is ongoing.

Benthic infauna

Since mid-2013, routine monitoring of benthic condition around Macquarie Harbour demonstrated an increase in the abundance and distribution of opportunistic polychaetes (Dorvilleids) on the sediment surface in and around marine farming leases. Surveys of external monitoring sites from late 2014 onwards has also found Dorvilleids at various sites within the TWWHA. Opportunistic polychaetes are commonly associated with increasing organic enrichment, however due to the limited understanding of their ecology and response in Macquarie Harbour, their use as an indicator species to monitor impact related to marine farms was put on hold pending the results of targeted IMAS research (FRDC 2014/038: Understanding Dorvilleid ecology in Macquarie Harbour and their response to organic enrichment and FRDC 2015/024 Managing ecosystem interactions across differing environments: building flexibility and risk assurance into environmental management strategies which is ongoing until 2018). As part of these research projects, benthic infauna sampling (of all species, not just Dorvillleids) has been conducted at 4 leases and at a number of external sites, including the TWWHA sites 39 and 41, since January 2015.

The results of the October 2016 survey (the sixth survey) showed a significant reduction in the total abundance and number of benthic infauna species collected at the leases and at external sites. Of the external sites, the greatest decline was at the sites in the southern end of the harbour (TWWHA). When compared with surveys 1-5, in October 2016 (survey 6) there was a 97% reduction in abundance and 92% reduction in number of species at site 39; at site 41 there was a 75% and 63% reduction in abundance and species numbers respectively (Ross and MacLeod, 2017a). Researchers noted the concurrent very low DO levels and increased Beggiatoa spp. extent in the harbour recorded via regulatory industry surveys and other monitoring undertaken around this time. It was identified that very small changes in DO, especially when levels are already very low, can have a major effect on the ecological response.

An early effect of organic enrichment of the benthic zone might be a change in benthic macrofauna community composition, marked by a shift towards opportunistic species. A more severe response to a deteriorating benthic environment would be a reduction in total benthic fauna, both abundance and species diversity. A consequence of the DO decline in Macquarie Harbour has been a significant decline in the abundance and diversity of benthic infauna in existing hypoxic zones, including in the TWWHA. These conditions represent a risk to the ecological processes within the harbour, particularly to sensitive species where aspects of their life history or behaviour might result in them being exposed to the bottom waters (Ross and MacLeod, 2017a). In addition, Ross and MacLeod (2017a) point out that the loss of benthic infauna is also likely to affect the functional processes underpinning organic matter processing and sediment recovery. This in turn has negative implications for the sustainability of aquaculture, through reduced benthic processing of organic waste from salmon pens, reducing the carrying capacity of the sediments and delaying sediment recovery.

The preliminary results of benthic infauna surveys conducted in January/February 2017 (survey 7) were provided to EPA in late April 2017 (Ross and MacLeod, 2017b). Patterns of abundance and species diversity were generally similar to the October 2016 survey (with a decline at a lease in the central north of the Harbour). The authors referenced more recent industry sampling in the central north of the harbour which
provided indications of faunal recruitment and potentially signs of preliminary benthic recovery at these lease sites. The January/February 2017 survey included a larger number of external sites to provide a better understanding of effects on the broader benthic ecology of the harbour. This showed that the greatest decline in fauna occurred in the deep central basin of the Harbour, with relatively little change in the fauna in the shallower regions of the mid-harbour or to the north or south (Ross and MacLeod, 2017b).

For the TWWHA sites specifically, the deeper sites (39, 42 and 43) showed the greatest decline in abundance and number of species in 2017 compared with early 2015 and 2016, but results in January/February 2017 showed little evidence of any marked change (improvement or deterioration) since October 2016. The shallower TWWHA sites (44 and 45) had did not show evidence of a decline between 2015/2016 and 2017.

Based on the recent monitoring across the whole harbour, including industry monitoring, Ross and MacLeod (2017b) point to encouraging signs: higher bottom DO levels; the decline of fauna appearing to be restricted to the deeper central basin; recent *Beggiatoa* spp. retraction; and possible early signs of benthic recovery. However, it is emphasised that DO levels appeared to be the primary driver of the deterioration in benthic condition observed in October 2016, and that while early 2017 levels increased in deep water, they are similar to levels in early 2016 (which subsequently declined), and mid-water levels remain very low. As such, there is capacity for benthic condition to deteriorate if DO levels do not improve during 2017. This research is ongoing as part of the recently funded FRDC 2016-067: *Understanding oxygen dynamics and the importance for benthic recovery in Macquarie Harbour*. 
5. Maugean Skate

The endangered Maugean Skate (Zearaja maugeana) is known from only two estuarine systems located on the west coast of Tasmania, Macquarie Harbour and Bathurst Harbour. FRDC project 2013/008 investigated the habitat utilisation, and population status of the Maugean Skate, and implications for fishing and aquaculture operations in Macquarie Harbour (Bell et al., 2016). Key findings of this study, relevant to the environmental conditions discussed in this report, included:

- Maugean Skate spent the 85% of their time at 6–12 m depth, although they were detected from 0.6 m to >55 m, indicating they are not restricted to their preferred depth range.
- Skate depth utilisation appears to be dictated by water chemistry with shallow waters having low salinity and high temperature variability, whereas deeper waters are stable in terms of temperature and salinity but have low concentrations of dissolved oxygen (DO) (<20%).
- Low DO concentrations appear limiting for the skate and presumably their prey. Waters in their preferred depth range generally retained moderate dissolved oxygen concentrations (>30%).
- Maugean Skate have a restricted diet dominated by three groups of epibenthic crustaceans, namely crabs, carid shrimp and mysids. Fish represented a minor prey item. While there was no evidence of pellet feeding, this cannot be ruled out since sampling was conducted some distance away from the farm lease sites and skate tend to have small home ranges.

Bell et al. (2016) made the following points regarding implications for marine farm operations:

- Direct interactions between Maugean Skate and aquaculture operations appear to be limited. Based on the Maugean Skate’s preference for shallower depths, there is minimal overlap between core skate habitat and the marine farm lease sites.
- This study provided no evidence of feeding on fish pellet overfeed by the skate, although it is not possible to completely discount this occurring.
- The influence of bottom DO in determining suitable skate habitat is uncertain but it is highly likely that any reductions in bottom DO, regardless of cause, will negatively influence the area of core habitat (preferred depths).
- The environmental health of Macquarie Harbour, in particular levels of DO in the bottom waters, is likely to represent a crucial factor in the future well-being of the Maugean Skate population.

Following on from this study, IMAS now proposes to progress research to investigate how the endangered Maugean skate population is being impacted by the environmental conditions in Macquarie Harbour. This research will use acoustic DO tags to establish the DO levels experienced by the skate, particularly when in deeper waters, and examine any physiological costs associated with this. Based on some preliminary observations that Maugean skate may select waters deeper than 20m to lay egg capsules, this research will also establish the distribution of skate eggs within Macquarie Harbour, particularly in relation to depth and DO. By examining the relationship between environmental conditions and the survival and viability of Maugean skate eggs, the project will seek to assess the potential implications of declining DO levels in Macquarie Harbour on the recruitment and future viability of the Maugean skate population.
6. References


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