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The influence of location, positioning, and seasonality on feeding behavior of the Sydney Oyster (Saccostrea glomerata) in New South Wales, Australia

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SIT Study Abroad

The influence of location, positioning, and seasonality on feeding behavior of the Sydney Oyster (*Saccostrea glomerata*) in New South Wales, Australia

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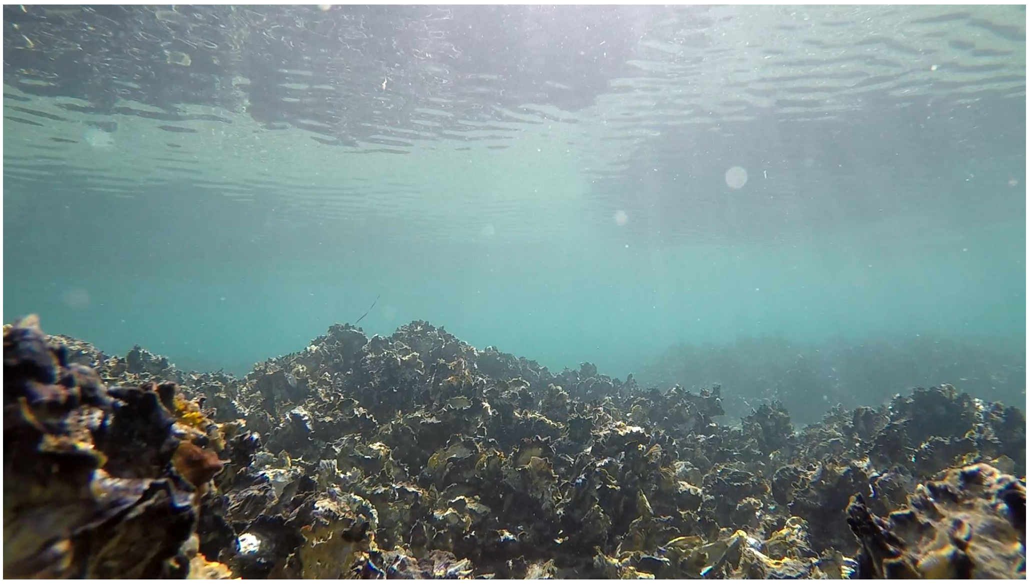

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Abstract

Oysters are hard shelled bivalves that aggregate over time to create structures in estuarine systems, known as oyster reefs. These reefs are important for the promotion of estuarine biodiversity by supporting many species of fish, invertebrates, and plants. They also act as a key contributor to water health by using active suspension feeding mechanisms and selective feeding to remove nutrients and water borne pollutants from estuarine systems. They have been touted as possible bio-remediators. They also effect rates of sedimentation in estuaries.

Oyster reefs have historically been threatened by anthropogenic influences such as overharvesting, destructive fishing practices, water pollution, CO_2 emissions and sediment runoff, prompting focus on efforts to restore and rehabilitate oyster reef ecosystems to restore their natural processes.

This study aims to investigate how location, positioning and seasonal variation affect selective feeding behavior of the Sydney Oyster *(Saccostrea glomerata)* in New South Wales, Australia. Video of oysters on the edge and centre of Port Hacking (n=39), and Towra Point (n=30), as well as the centre of Hunter River (n=7) were taken in order to observe feeding behavior in these locations. Observations of the length of time each oyster occupied 2 states, open or closed, were used to determine differences between oyster sites and locations. Data from Port Hacking was used to examine seasonal variation of oyster feeding behavior.

Oysters spent significantly more time feeding on the edge of a given reef, however this difference did not depend on whether an oyster was found on Port Hacking or Towra Point. This is likely due to the physiological differences between the reef edge and centre. Oysters located at Hunter River spent significantly less time actively feeding than oysters at Port Hacking and Towra Point. This is likely due to the physiological differences between the

sites, such as higher speed of water flow, and larger concentrations of suspended sediment at Hunter River.

There were significant differences in feeding behavior at Port Hacking based on month. The month of March experienced 7x more rain than April, and more than 2x the rain of August. These precipitation differences likely increased nutrient runoff to Port Hacking, increasing algal concentrations which would have decreased the amount of time oysters needed to spend actively feeding.

Acknowledgements

I would like to thank my supervisor, Ana Bugnot for her support and guidance throughout the course of this study. Thanks to the University of Sydney Coastal and Marine Science Laboratory for providing space and materials with which to conduct this project. As well as the Sydney Institute of Marine Science for supporting the Oyster Reef Restoration Projects in Sydney Harbor. Additional thanks to Katie Erickson and Janine Ledet for providing field work opportunities and advice.

List of Figures and Tables

1. Introduction

Oysters are sessile invertebrates that live in coastal and estuarine waters. When healthy, oyster reefs provide significant economic benefits to local communities, Grabowski et al. (2012) found that the value of having healthy oyster reefs is worth an average of $17,072 per hectare of reef. This includes benefits from oyster harvesting, as well as ecosystem services provided from water filtration, habitat provision and prevention of coastal erosion. However, more than 80% of oyster reefs have been lost worldwide. In Australia alone, 99% of oyster reefs are "functionally extinct," meaning that existing oysters no longer provide significant ecological or economic benefits (Gillies et al. 2015). There are many factors that put oyster reefs at significant environmental risk, including overharvesting, destructive fishing practices, water pollution, estuary acidification, and sedimentation.

The process by which oysters are harvested involves the removal of the hard shells that future oysters use as substrate to attach to in the larval stage. It also reduces the number of reproductively viable adult oysters in a population, and therefore the number of oyster larvae in future generations. This has significant detrimental effects including lack of oyster recruitment, and shrinkage of existing oyster populations (Gillies et al. 2015). Loss of oyster reef is detrimental not only to the oysters themselves, but for the ecosystems in which they live. Oysters are commonly referred to as "ecosystem engineers." An ecosystem engineer is an organism that is able to modify the environment around it creating space, not only for conspecifics, but for many other organisms (Jones et al. 1996). Oyster larvae use existing hard surfaces as a substrate to anchor to. Over time, the aggregation of these oysters creates a complex habitat that provide resources to juvenile fish avoiding predation, substrate for algae to grow on, as well as food and shelter for sessile and motile invertebrates (Gillies et al. 2015). When oyster populations struggle, it affects the communities of fish and invertebrates that depend on them for food and shelter, as well as the fisheries that depend on those populations (Gillies et al. 2015).

Estuarine acidification also poses significant risks to the health of oysters. The effects of anthropogenic CO_2 emissions have long been studied in regard to the effect of ocean acidification on reef building corals, and more recently these effects on oysters and other shellfish have been noted. Estuaries, similar to oceans, act as CO_2 sinks and thusly, are negatively affected CO_2 related acidification that reduces waterborne concentrations of calcium carbonate that hard shelled invertebrates depend on to create their shells (Miller et al. 2009)

Oysters have been shown to significantly reduce concentrations of nitrogen, phosphorus and other pollutants in the water column and can increase visibility and decrease turbidity due to filtration. They are commonly used in the aquaculture industry as natural water waste treaters and have been shown to reduce the concentrations of anthropogenic waste in estuaries. Oyster filtration services also play an important role in the nutrient cycling and sedimentation processes that occur on oyster reefs. Digested and rejected particulate matter is excreted by oyster, contributing to sedimentation on the estuary floor (Gifford et al. 2007).

Recent years have seen increases in awareness of oyster reef ecosystems, and with that, an increase in oyster reef restoration projects, with varying degrees of success. The eastern United States has seen many active oyster related restoration project during the past 30 years, however these efforts have mainly been focused on prevention of further habitat degradation rather than rebuilding of habitat to restore sustainable populations and ecosystem services (Grabrowski and Peterson 2007). Ongoing research projects implemented by the Sydney Institute of Marine Science and Nature Conservancy- Australia in New South Wales (NSW) have been focused on gaining holistic knowledge of oyster reefs in NSW in order inform future restoration attempts, as well as identify suitable areas for restoration, and raise awareness of issues affecting oyster reefs (Gillies et al. 2015, 2018). The two most common reef creating oyster species in NSW are the Sydney Oyster (*Saccostrea glomerata)* and Pacific Oyster (*Crassostrea gigas)*, however *C. gigas* was introduced to Australian waters in 1947 for aquacultural purposes in response to the collapse of native oyster fisheries.

A significant area of oyster reef research that has not been examined in NSW is how the feeding behaviour of *S. glomerata* is affected by location and positioning.

Many species of oysters, including *C. gigas* and *S. glomerata* exhibit selective feeding behavior, meaning they actively choose when to feed and what to feed on. There are 3 mechanisms by which oysters select food: gill retentive, pre-ingestive, and post-ingestive selection. Gill retentive selection occurs when oysters beat their internal cilia creating a water current that sucks particulate matter inside. Some particulates stick to the mucus membrane of the oyster gill. Typically the size of the particle is the determining factor as to whether it is retained (Galimany et al. 2017). During pre-ingestive selection, oysters discriminate between particles based on factors such as species of algae or plankton, or whether they are organic or inorganic (Cognie et al. 2001). Post-ingestive discrimination, otherwise known as differential absorption, is determined by the efficiency of oyster digestion and nutritional value of ingested food (Cognie et al. 2001, Bayne and Svensson 2006)..

Previous studies (Fritz et al. 1984, Lenihan 1999, Cognie et al. 2001) have examined growth rates and mortality of oysters in accordance with oyster location and food availability. Similarly, Bayne and Svensson (2006) examined the seasonal variation of food availability and oyster behaviour. However, no study has examined how location and positioning of an oyster effects their feeding behavior. This study aims to identify how physiological such as location and positioning of oysters might influence their feeding behavior.

Hypothesis: The amount of time an oyster spends feeding is determined by its positioning on the reef centre or edge. The amount of time an oyster spends feeding will also be influenced by its location. It is predicted that oysters on the edge of the reef will spend less time feeding, while oysters in the reef center will spend more time feeding. It is predicted that oysters on reefs with increased water flow and less sedimentation will spend more time feeding.

2. Methods

2.1 Field Sites

Three locations in New South Wales, Australia were selected for the study. Port Hacking, Towra Point, and Hunter River were chosen because they are some of the last natural oyster reefs left in the region.

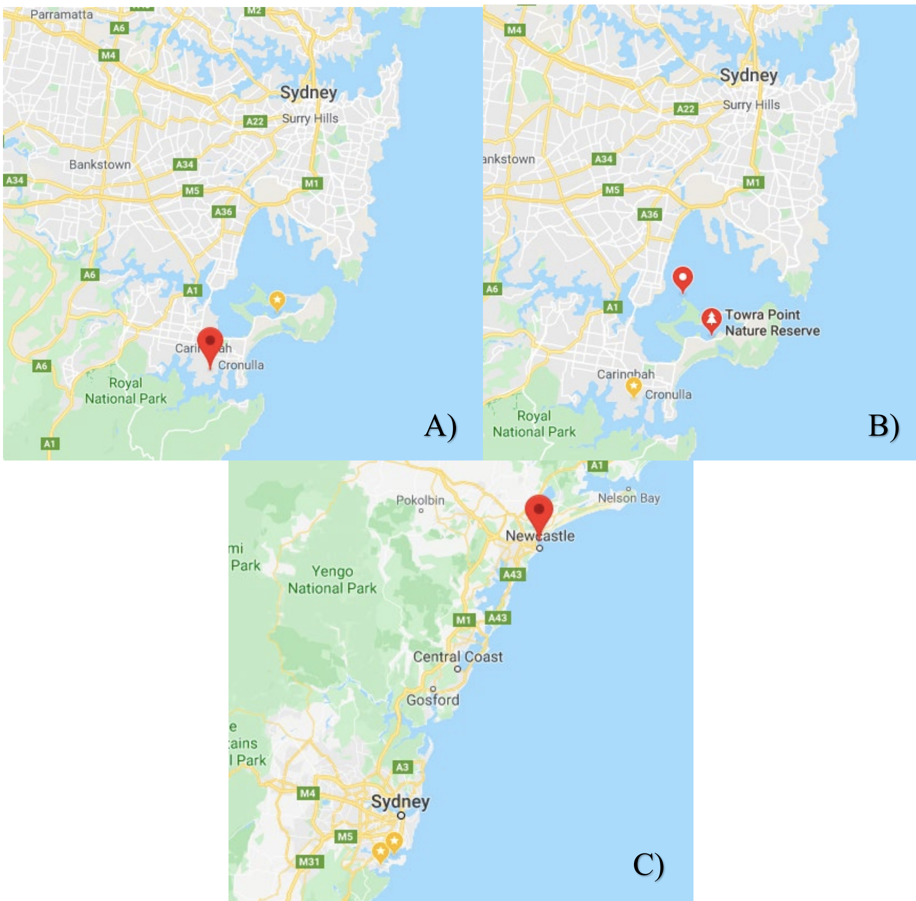

Figure 1. A) Port Hacking, NSW, Australia identified by marker. Sample site is approximately 30km away from Sydney B) Towra Point, NSW, Australia identified by location marker. Sample site is approximately 19.6km away from Sydney. C) Hunter River, NSW, Australia identified by marker. Sample site is approximately 171km away from Sydney.

2.2 Data Collection

In order to analyze oyster feeding behavior, GoPro cameras were placed on the edge and centre of oyster reefs in Port Hacking and Towra Point, between March and August 2019. Edge was defined as 20 cm along the edge of reefs. GoPro cameras were placed in Hunter River reefs in November 2018; however, all cameras were placed in the centre. All video was recorded at high tide (±1 hour). Video was recorded for one hour in each replicate, for a total of 76 hours of observed footage.

2.3 Video Analysis

Oysters that were visible in each video were noted, numbered, and observed for one hour. The state (open or closed) of each oyster at the beginning of observations was noted, as was the site (edge or centre) and Location (Port Hacking, Towra Point, or Hunter River). The time that any change in state occurred was also noted, as was the total length of time each oyster was open and closed during the observation. An oyster that was open was assumed to be feeding. A total of 76 oysters were observed, 39 of which were located at Port Hacking, 30 were located at Towra Point, and 7 were located at Hunter River.

2.4 Data Analysis

Average time open was used to determine feeding differences between oysters. Oyster feeding behavior data were analyzed using R Studio (R Core Team 2019). To analyze differences between oysters on the edge and crest a t-test was run. A 2-Way ANOVA was run to examine the relationship between oyster location and site on feeding behavior. A 1-Way ANOVA test was run to determine the relationship between oyster location and feeding behaviour. A 1-Way ANOVA test was run to determine the relationship between month and feeding behaviour.

3. Results

There was a significant difference between the time oysters fed at different sites within reefs (p=0.04). Oysters on the edge of reefs spent 82.7% of their time feeding, while those in the centre fed 71.8% of the time (Figure 2).

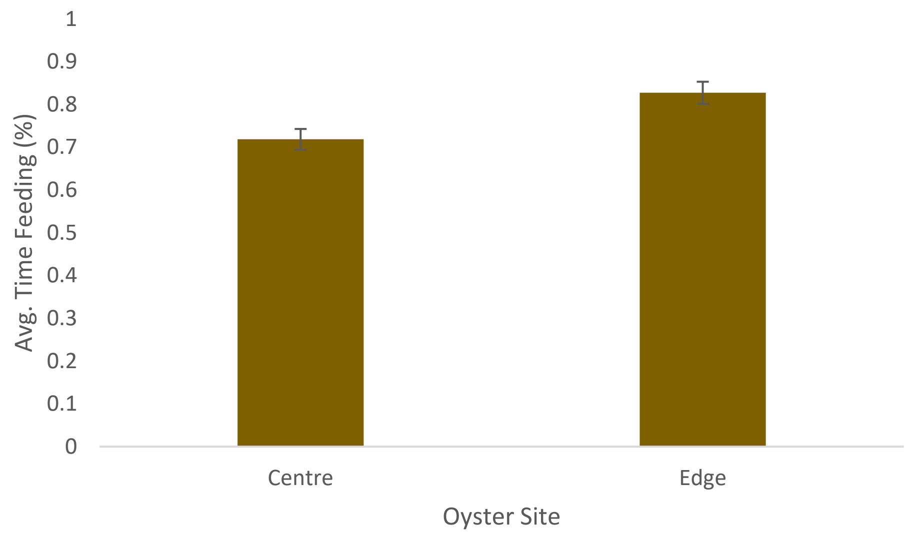

Figure 2. Average percent time an oyster spent feeding across all reef sites. Oysters located on the edge of reefs fed significantly more than oysters in the centre (t.test: df=74, p=0.04). Standard error (SE) bars show variation around the mean.

The percent time an oyster spent feeding on the edge and centre of a reef was not significantly related to the location it was observed (p=0.06, Figure 3). Oysters in the centre of Port Hacking spent 79.2% of their time feeding, which is not significantly different from oysters in the centre of Towra Point, which fed 73% of the time (p=0.06). Oysters on the edge of Port Hacking spent 89.5% of their time feeding. This is not significantly different from oysters on the edge of Towra Point, which spent 75.5% of their time feeding (p=0.06).

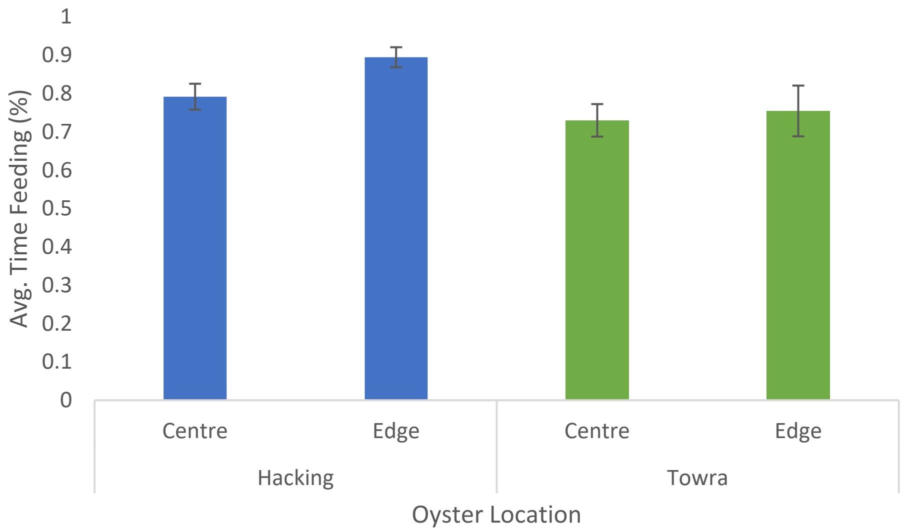

Figure 3. Average percent time an oyster spent feeding on the centre and edge of Port Hacking and Towra Point did not significantly differ (2-Way ANOVA: df=2,65, F=2.6, p=0.06). Standard error (SE) bars show variation around the mean.

The percent time an oyster spent feeding significantly depended on the location in which it was observed (Figure 4). Oysters at Port Hacking (83.1%) and Towra Point (74.1%) spent significantly more time feeding compared to Hunter River (43%, p<0.0001, p<0.001). The difference between Port Hacking and Towra Point was not significant (p=0.15).

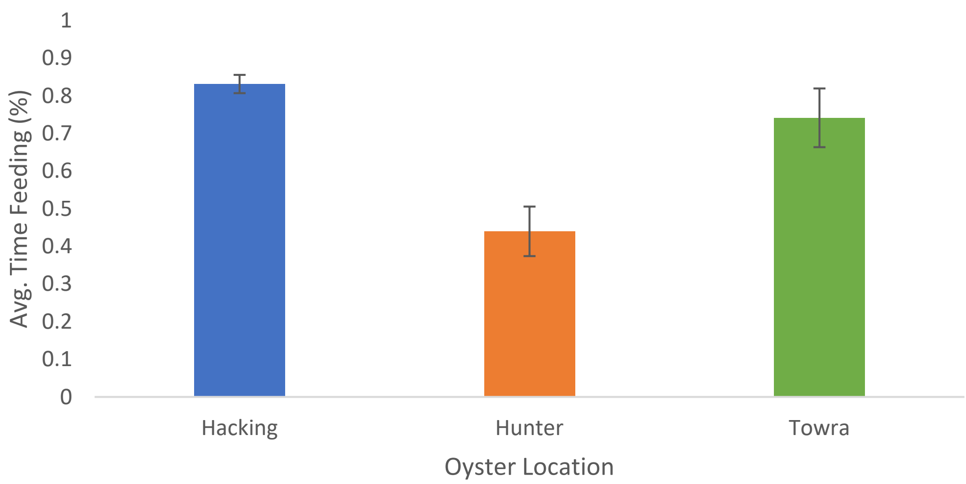

Figure 4. Comparison of Average Percent Time oysters were feeding across 3 locations: Port Hacking, Hunter River and Towra Point. Location of oyster significantly affected percent of time an oyster was open (ANOVA: df=2,73, F= 11.71, p<0.001). Oysters at Port Hacking spent significantly more time feeding than oysters at Hunter River (Tukey HSD, p<0.0001). Oysters at Towra Point spent significantly more time feeding than oysters at Hunter River (Tukey HSD, p<0.001). Average percent time oysters fed did not differ significantly between Port Hacking and Towra Point (Tukey HSD, p=0.15). Standard error (SE) bars show variation around the mean.

The percent of time an oyster spent feeding at Port Hacking significantly depended on the month in which it was observed (Figure 5, $p<0.0001$). Oysters spent significantly more time feeding in April (88.1%) than they did in March (67.3%, $p<0.001$). There were significant differences in feeding behaviour between March (63.7%) and August (87.0%; $p=0.01$). April and August did not differ significantly ($p=0.97$).

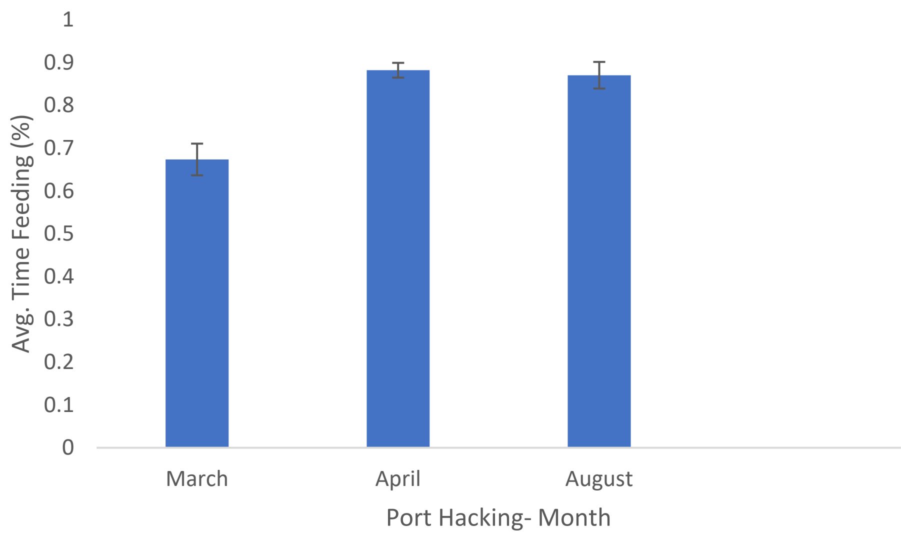

Figure 5. Comparison of average percent time oysters fed across 3 months at Port Hacking, NSW. The percent of time an oyster spent feeding depended significantly on the month in which it was observed (ANOVA: df=2,36, $F=9.1$, $p<0.001$). Oysters spent significantly more time feeding in April and August than they did in March (Tukey HSD: $p<0.001$, $p=0.01$). Feeding behavior did not differ significantly between April and August (Tukey HSD: $p=0.97$) Standard error (SE) bars show variation around the mean.

March 2019 experienced 7 times more rainfall than April 2019. March 2019 experienced more than 2x the rainfall than August 2019 (Table 1). Data obtained from Australia Bureau of Meterology (2019).

Table 1. Total rainfall (mm) at Royal National Park during 3 months of the study.

Month	Total Rainfall (mm)
March	*204*
April	*27*
August	*89*

4. Discussion

4.1. Oyster Positioning and Location

Oysters positioned on the centre of a reef spend significantly less time feeding than oysters on the edge (Figure 2). This is contrary to the initial prediction of this study. However, our findings are consistent with Lenihan (1999) who found the centre of a reef was subjected to faster water flow speed, higher food quality, and lower sedimentation. Higher quality of food implies that oysters are able to be more selective about the amount of time they spend feeding, as well as what they eat (Galimany et al. 2017).

The time an oyster spent feeding on the edge or centre of a reef was not significantly related to whether that oyster was found at Port Hacking or Towra Point (Figure 3). Oysters located in Hunter River spent significantly less time feeding than oysters in Port Hacking and Towra Point (Figure 4). This is consistent with the initial prediction of this study. These differences can be explained by the physiological differences of the sites themselves. Previous studies have shown that sediment depositions in Hunter River are four times greater than those of Port Hacking (Peebles *Unpublished Data*). Studies have also shown that faster flowing bodies of water, such as the Hunter River, typically carry larger sediment loads, whereas slower moving bodies of water, such as Port Hacking and Towra Point carry less suspended sediment (Peebles *Unpublished Data*, Milliman et al. 1985). The prevalence of slow-moving estuarine currents has been shown to decrease food availability (Lenihan 1999). This is one possible explanation of increased feeding times for oysters in the slow flowing areas of Port Hacking and Towra Point because increased time spent feeding would yield greater feeding success and would also explain the lack of significant differences between the edge and centre of Towra Point and Port Hacking (Figure 3). Areas with faster water flow have increased food availability, implying that oysters in these areas can be more selective about the time they spend feeding. Similarly, the nutritional value of suspended particles in high flow areas has been shown to be higher than in areas with slower flow rates, increasing the absorption efficiency of oysters (Lenihan 1999). This is supported by previous studies (Cognie et al. 2001, Galimany et al. 2017) which found that selectively feeding oysters regulate their internal water flow to select certain edible particles, while disregarding others.

However, it is also worth noting that sedimentation on oyster reefs can increase mortality, and it is therefore possible that the oysters at Hunter river are feeding less due to an inability to effectively filter high levels of silt (Cognie et al. 2001, Burdige 2011, Heery et al. 2017). This is an important distinction to focus on in future studies, because oysters have been touted as effective bio-remediators of polluted water, however our data suggest possible limitations on their effectiveness.

4.2.Temporal Differences

Oysters in Port Hacking spent significantly more time feeding in July and August than they did in March (Figure 5). This difference can be linked to the seasonal variation in rainfall in the Port Hacking catchment, and therefore the nutrient and algal availability in the water during these times. Rainfall variation has been linked to increased runoff of nitrogen, phosphorus and other nutrients commonly linked to higher algae concentrations (Ahn et al. 2002). Royal National Park, located about 6km away from Port Hacking, would have experienced similar rainfall patterns previous to behavioral data collection. March 2019 saw 204.0mm total rainfall, compared to April and August which had 27.0mm and 89.0mm rainfall respectively (Australia Bureau of Meterology 2019, Table 1, Appendix i). This data implies that Port Hacking would have experienced higher availability of algae in March of 2019 than in April or August, which can explain the variation we see in oyster feeding behaviour. Oysters in March spent 67.3% of their time feeding, compared to 88.7% in April and 87.0% August. This is consistent with Bayne and Svensson (2006), who found that feeding behaviour of *S. glomerata* varies depending on quality and availability of food. When food is more available, oysters are able to be more selective about what they eat, and therefore the percent of time they spend feeding varies. Similarly, when food is less available, oysters will spend more time actively feeding because there are less inherent opportunities for food acquisition.

5. Conclusion

Understanding oyster feeding behavior and the variables that effect it is extremely important for informing future oyster reef restoration attempts. By understanding the factors that influence oyster feeding, we can selectively choose sites on which to focus restoration attempts. For example, a site known for high variability in food availability dependent on the season or precipitation can influence the time of year that restoration initiatives are implemented. Similarly, if particular sections of reef, or reef locations are known to be affected differently by estuarine processes such as sedimentation, then that would also influence the implementation of restoration projects.

Future studies on selective feeding behaviour of oysters in NSW are necessary to further understand the natural processes that occur in these ecosystems, and the ways in which they influence oyster behavior. Firstly, it is important to determine whether bioremediation and water filtration capabilities of oysters are limited via food availability or rates of sedimentation. Secondly, it would be beneficial to compare bioremediation efficacy and differential feeding behaviors of the two most common reef creating oysters in NSW: *S. glomerata* and *C. gigas*. This comparison would give beneficial insights into the various behaviors of different oyster species, which could inform the species focused on during restoration attempts. Similarly, examining whether the presence of *C. gigas* in NSW estuaries increases competition for available resources, and increased spatial competition would be useful to inform the long-term effects of bivalve introduction for aquaculture. It would also be wise for future studies to examine the seasonal variability of water pH to determine its effect on oyster larval recruitment, mortality, growth rates, and feeding behaviour.

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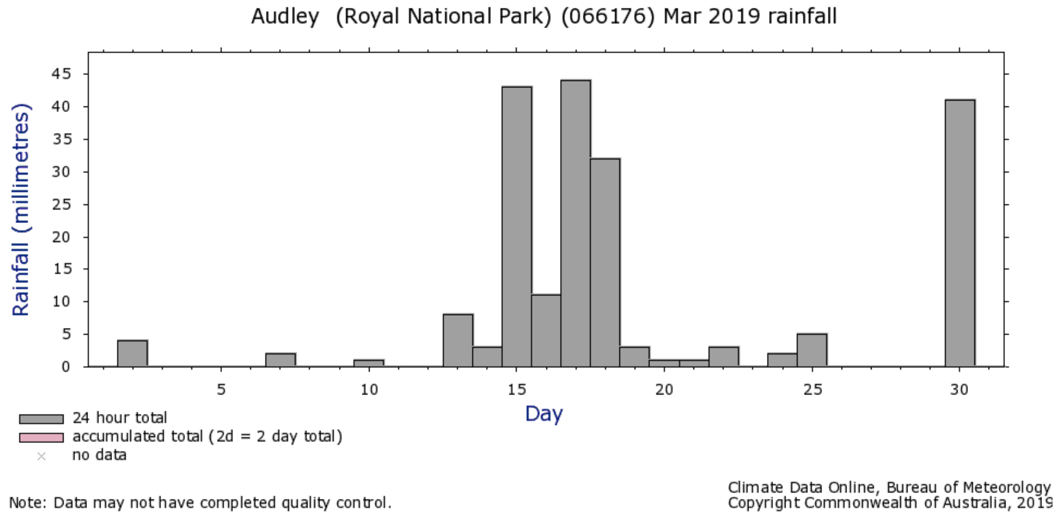
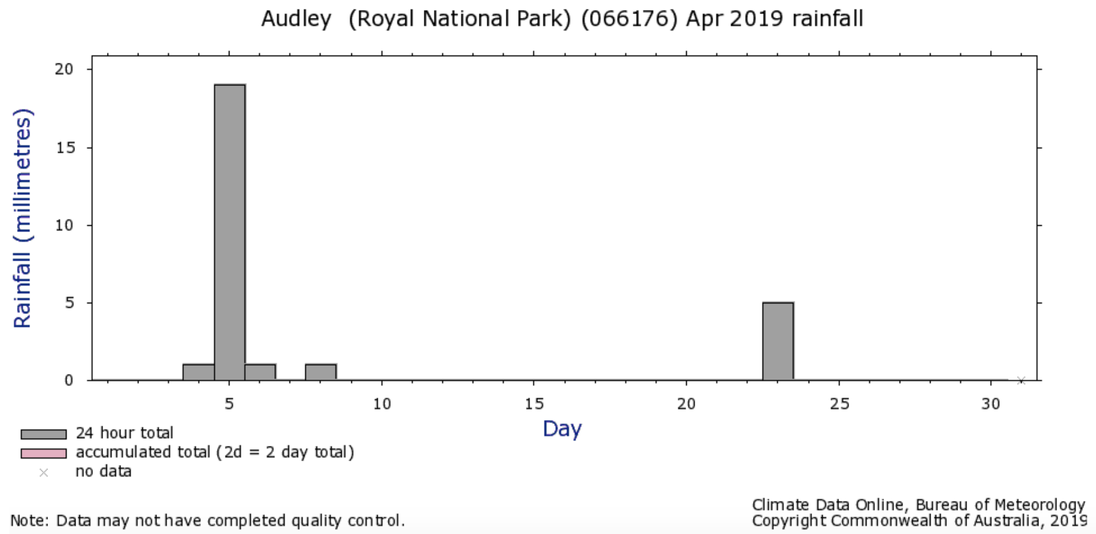
Appendix

i. Port Hacking Rainfall Data




Audley (Royal National Park) (066176) Apr 2019 rainfall
Rainfall (millimetres)
0
5
10
15
20
5
10
15
20
25
30
Day
24 hour total
accumulated total (2d = 2 day total)
no data
Note: Data may not have completed quality control.
Climate Data Online, Bureau of Meteorology
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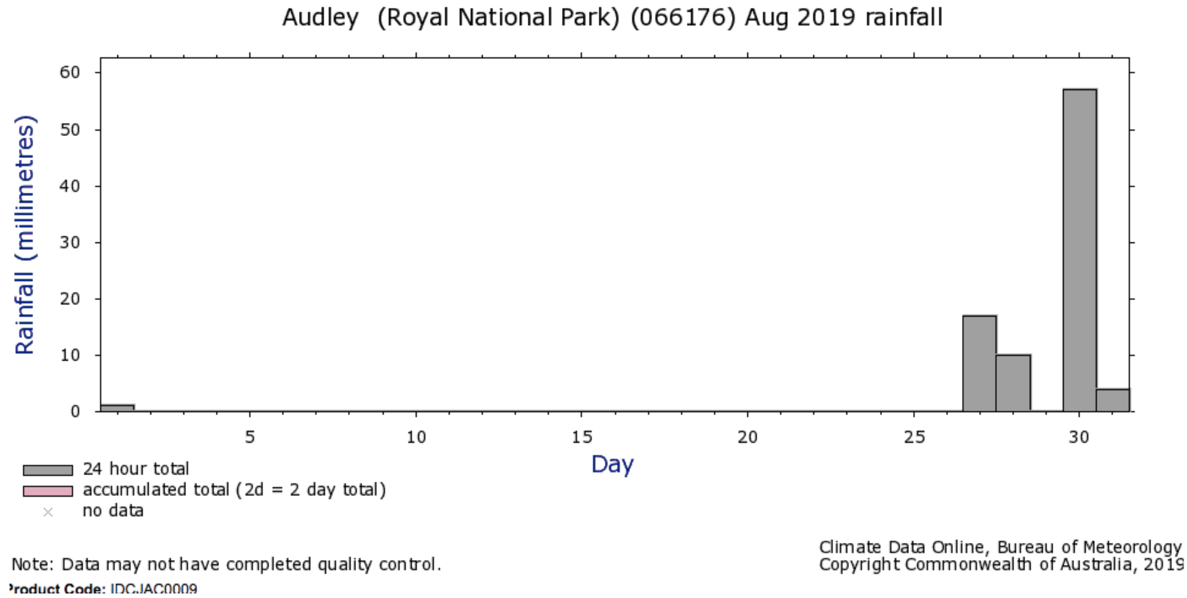
Audley (Royal National Park) (066176) Aug 2019 rainfall
Rainfall (millimetres)
0
10
20
30
40
50
60
5
10
15
20
25
30
Day
24 hour total
accumulated total (2d = 2 day total)
no data
Note: Data may not have completed quality control.
Climate Data Online, Bureau of Meteorology
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