Department of Transport

Two Rocks Southern Beaches

Summer Wrack Clearing Events – Technical Report 2020

Two Rocks Summer Wrack Clearing Events – Technical Report 2020

Prepared for: Department of Transport

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Version control

Version No.	Date	Prepared by	Revision or issue description	Issued to
A	24/04/2020	TS	First draft issued for review	FL
B	17/07/2020	TS	Major updates and added analyses	FL
C	10/08/2020	TS	New events and figures added	FL, RE
0	13/08/2020	TS	Final version accepted	FL, RE

Amendment record

This guidelines document is reviewed to ensure its continuing relevance to the systems and process that it describes. A record of contextual revisions is listed in the following table.

Page No.	Context	Revision	Date

Cover photographs: Oblique aerial photograph of Two Rocks taken in summer on 2/12/2013 by T. Stead. Ground photograph taken in summer on 24/12/2018 via fixed monitoring camera.

Contents

Executive summary

Excess wrack accumulation at Two Rocks southern beaches has been a contentious issue since the marina was constructed in 1974. Upon assuming operational management of the facility in 2014, the Department of Transport (DoT) undertook various coastal monitoring regimes to assist future marina planning. This includes a two-year photo monitoring record at the beach immediately south of the marina, plus concurrent collection of nearshore water level, wave, and current data. Data collection, completed in 2019, was simultaneously shared with City of Wanneroo.

Collected data were analysed to better understand dynamic wrack accumulation patterns at the crescent bay south of Two Rocks marina. It was found that small, short-lived wrack accumulations occur between April and October, with more voluminous and long-lived wrack accumulations observed between November and March.

A goal of this report was to identify when wrack was cleared off the beach between November and March from photo monitoring between 2017 to 2019. Joint wind, wave, and camera data analyses indicate that three types of wrack clearing event occurred: a ‘Seabreeze’ event, a ‘Storm’ event, and an ‘Offshore’ event. All event types demonstrated rising tides (often a spring tide), high wave heights, and wind-driven currents. A Seabreeze event entailed sea breeze winds, likely transporting wrack away to the north. A Storm event involved stormy winds and offshore currents to the south. An Offshore event entailed persistent easterlies and offshore currents to the west. However, it was found that wrack accumulations can return rapidly following any type of clearing event. Furthermore, metocean conditions common to most wrack clearing events also occurred at other times, yet did not always lead to significant wrack clearing.

Three different mechanisms are proposed within this report to explain how wrack returns to the beaches at the crescent bay south of Two Rocks marina after a wrack clearing event. These possibilities add significant uncertainty to wrack management efforts.

Short-term wrack management options may vary in effectiveness. Manually pushing wrack offshore during a wrack clearing event has been proposed in the past, and might accelerate natural wrack removal requiring less management effort, though the inconsistent nature of wrack clearing events introduces uncertainty towards the effectiveness of this strategy A second wrack management method involves pushing beach wrack onto the dunes behind the beach and letting it dry. This method would require more management effort, where dried wrack is pushed back into the ocean in winter. It is considered that reconfiguration of the southern marina breakwater presents the most effective solution in the long term. Additional studies to define wrack sources and transport pathways may also assist long-term wrack management at Two Rocks.

Promising date windows with suitable water levels were forecast if offshore wrack pushing is to be trialled in 2020/21. These appear to be mid-December 2020 and mid-January 2021. Wrack pushing should then be timed when wave heights are considerably high (e.g. Rottnest Hs >2m), and forecast winds are either during a strong sea breeze lasting beyond sunset, a storm, or during offshore easterlies persisting into the afternoon.

1 Introduction

1.1 Deployment information and study purpose

Two Rocks occupies a section of the northern coastline in the Perth metropolitan area. This coast is microtidal and wave-dominated, with strong seasonal winds driving both local ocean currents and the sea wave climate (Pattiaratchi *et al*. 1997). Offshore swell waves originating from distant high latitude storms propagate towards this coastline and comprise a consistent component of the area's wave climate throughout the year. The Two Rocks metocean climate is important to understand when investigating how wrack particles are transported and deposited on Two Rocks beaches. This is relevant for devising appropriate wrack management strategies.

To improve understanding of the Two Rocks metocean environment, DoT deployed an Acoustic Wave And Current profiler (AWAC) south of the main Two Rocks breakwater at a water depth of approximately -5m AHD (Figure 1), recording waves and currents in 1m bin intervals from 29/10/2018 to 21/11/2019. To assess problematic summer wrack accumulations at Two Rocks southern beaches, AWAC data were analysed alongside hourly beach wrack photos captured by a DoT fixed monitoring camera between 4/07/2017 to 18/10/2019 (Figure 1).

Figure 1: Two Rocks West AWAC location (31.4994º S, 115.5808º E) and Fixed Monitoring Camera location (31.4988º S, 115.5832º E); the deployed AWAC depth was approximately 5m.

In addition to AWAC data and the photo monitoring records, analyses of concurrent Ocean Reef wind data, Fremantle water level data, and Rottnest Island wave buoy data were undertaken over the same period (Figure 2). After collating and analysing these metocean data over the time periods specified in Figure 3, wrack accumulation and clearing events could be compared with metocean conditions to investigate consistent patterns.

The purpose of this investigation is therefore to gain a greater understanding of summer wrack accumulations at Two Rocks southern beaches and identify metocean conditions in summer months (more precisely, between November and March) that lead to occasional wrack clearing events. These findings can assist wrack management strategies for the crescent bay beach south of Two Rocks marina.

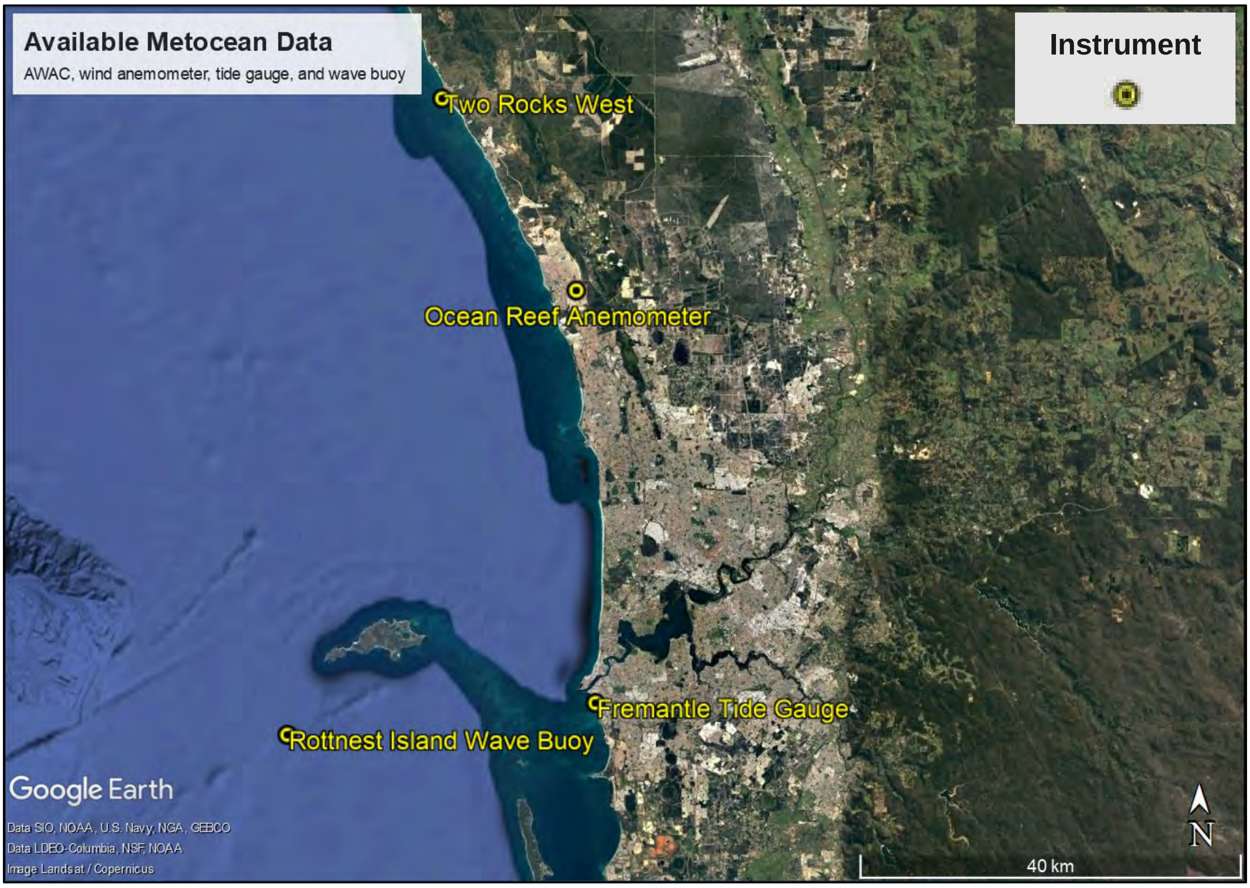


Figure 2: Location of metocean data measuring instruments relative to the Two Rocks West AWAC

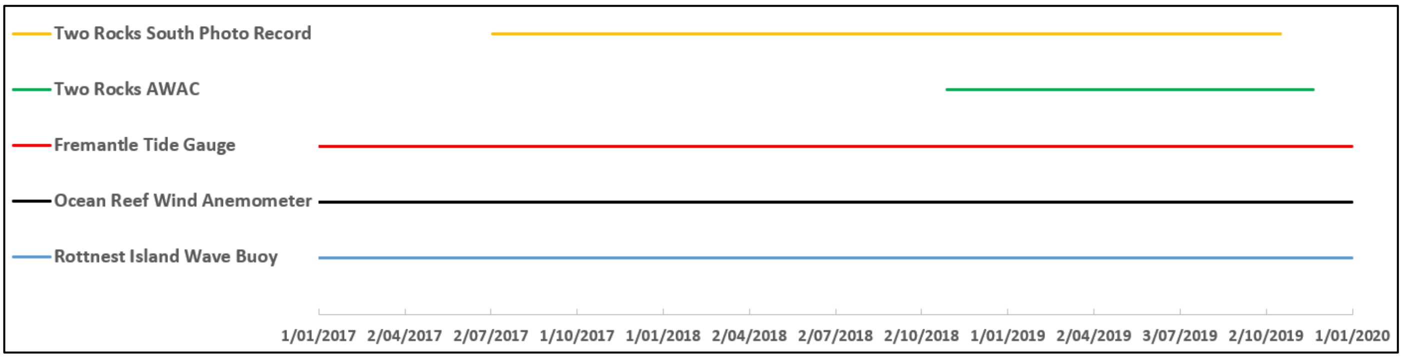


Figure 3: Summary of metocean data available for this study, including where the record starts/stops

1.2 Geological and biological context

Two Rocks comprises a mixture of rocky, sandy, and perched beach coastlines. Figure 4 displays local bathymetry in the area to provide geological context for wave transformation towards Two Rocks.

Fringing reefs and rocky outcrops afford some protection from offshore wave conditions propagating towards the Two Rocks coast. In conjunction with wave shoaling effects and depth limitations, wave breaking over reefs will generally result in smaller waves recorded at the nearshore AWAC compared to offshore.

In addition to wave transformation control, rocky reef systems like those at Two Rocks in Figure 4 can provide a habitat for kelp colonies (Wernberg *et al.* 2003), which may later detach and join seagrass leaves shed from local sandy seagrass meadows. These reefs and meadows therefore act as a wrack source, providing insight into wrack pathways that eventually lead to large wrack accumulations on Two Rocks southern beaches. However, the precise source locations and quantities of wrack from rocky reefs and sandy seagrass meadows in the Two Rocks nearshore zone remain poorly defined.

While generalisations can be made about likely wrack source locations, an important knowledge gap exists around precise, quantitative origins from accumulated wrack on Two Rocks southern beaches. Other key gaps also include: specific volumes from a contributing wrack source, the proportion and timing of each contributing wrack source, exact proportions of macroalgae to seagrass, and the time taken for wrack to transport to Two Rocks. These knowledge gaps cannot be fully accounted for in this report, thus subsequent studies would benefit from knowledge gained around those parameters. The priority is to first identify local wrack sources supplying Two Rocks southern beaches.

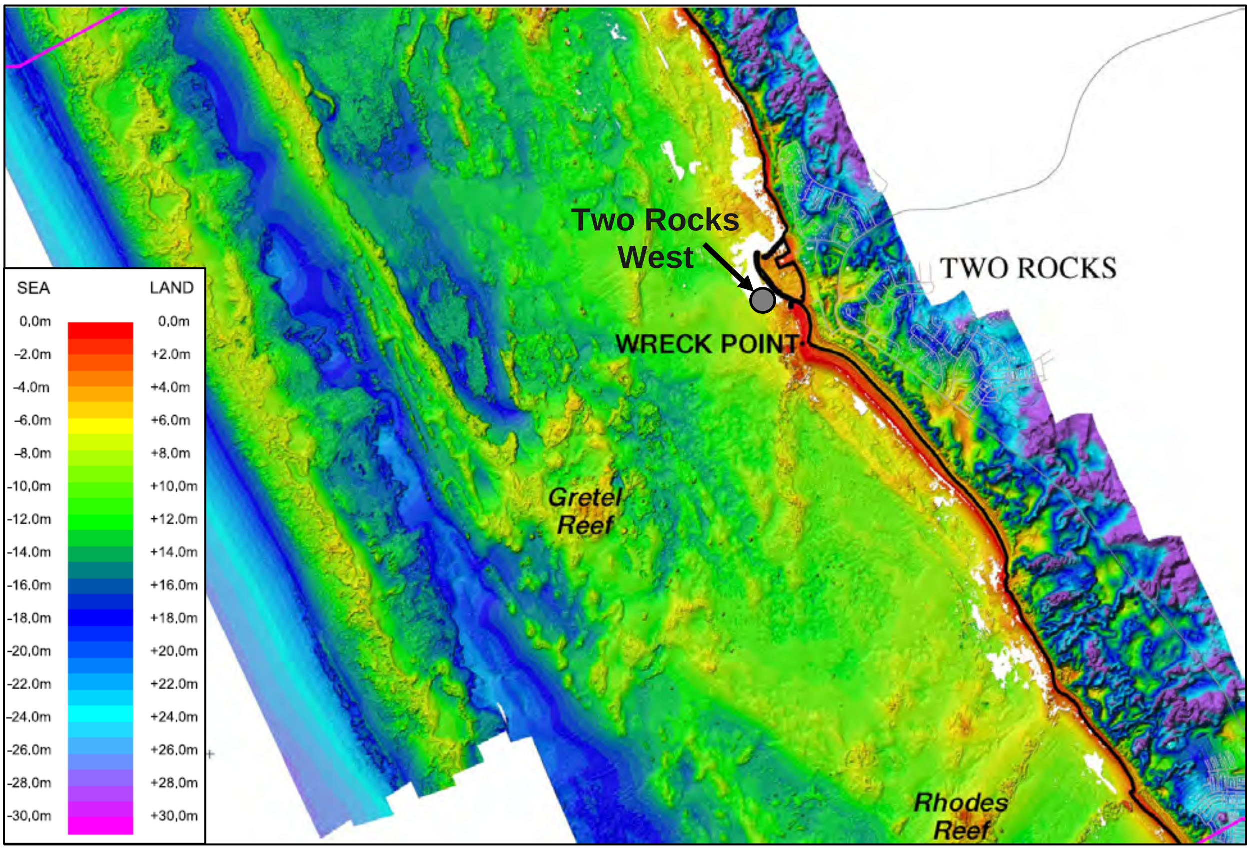


Figure 4: Bathymetry of the Two Rocks seabed and AWAC location, extracted from DoT Chart 1762-07-15, to AHD surveyed on 21/10/2016.

2 Metocean environment

2.1 Low water levels in summer

Useful water level data are available from both the Two Rocks West AWAC and the Fremantle tide gauge 65km SSE of Two Rocks. Another tide gauge resides within the Two Rocks marina, however frequent gaps and data quality issues omit this dataset as a reliable resource.

While the Two Rocks West AWAC provides relevant and proximal water level data, the available Fremantle tide gauge dataset is a long-term record already split into predicted tidal and Non-Tidal Residual (NTR) signals to highlight seasonal patterns. Therefore, both of these water level records were used in this investigation. The Two Rocks AWAC water level record is referred to primarily in Section 3.

Water levels from 2017 to 2019 are provided in Figure 5, with a specific record for the 2018/19 summer period expanded underneath. Figure 5 illustrates the seasonal trend in tidal dynamics along Perth metropolitan coasts. General observed water levels and ranges are lower in summer months. In December and January, the water level rarely rises above 1.2m Chart Datum (CD) with a mean water level around 0.77m (Figure 5)

For the 2018/19 summer, Figure 5 indicates observed water levels were even lower at Two Rocks than predicted when combined with NTR, likely due to high pressure systems creating negative residuals. Conversely in winter, storms and low-pressure systems frequently bring storm surges and the observed water level rises above 1.2m CD every couple of days. The lower tidal range experienced during summer is considered the critical component influencing wrack accumulation at Two Rocks southern beaches (discussed further in Section 3).

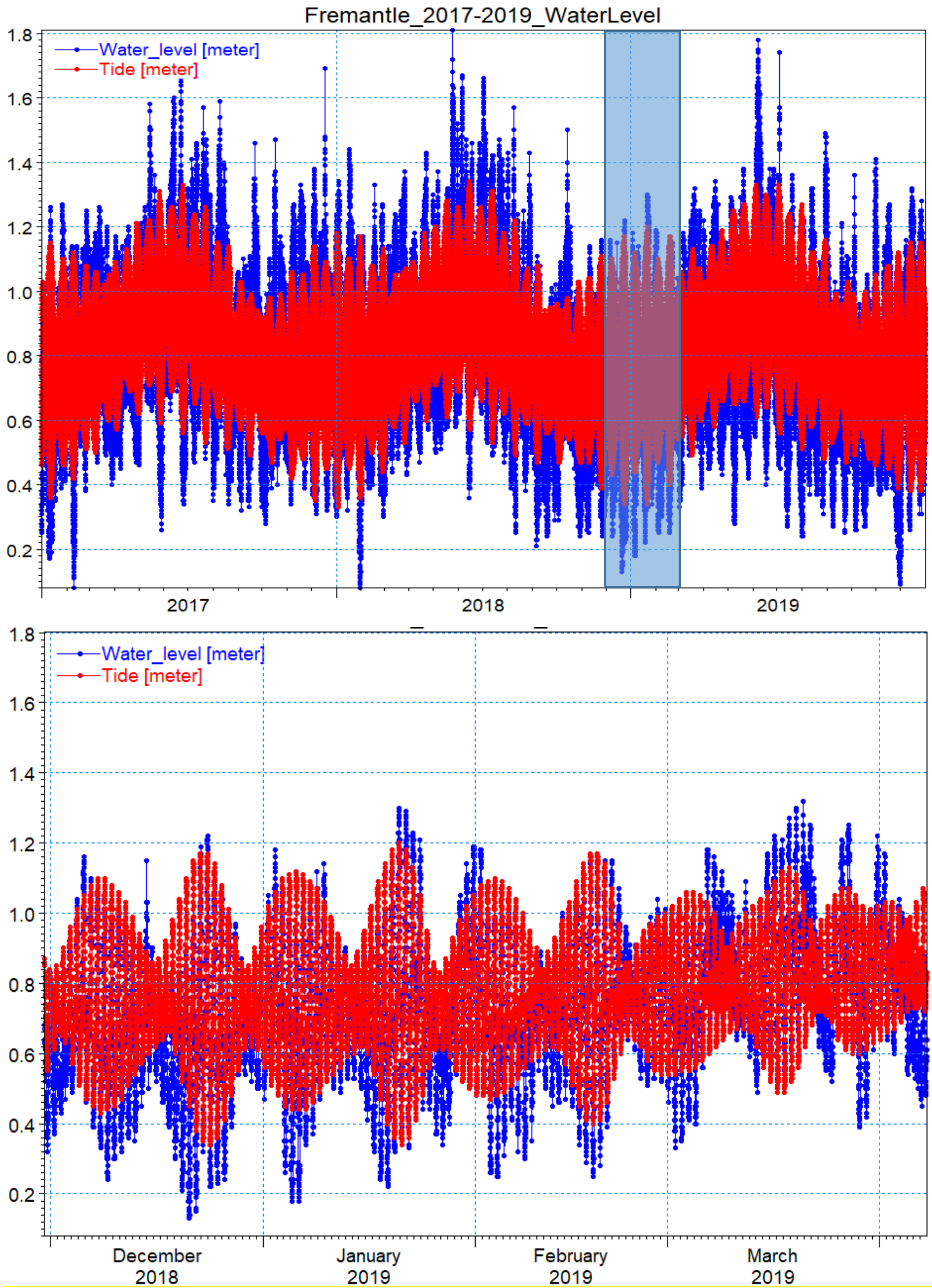


Figure 5: Observed water levels to LAT with the tidal component at Fremantle tide gauge; the seasonal trend is shown over 2017 – 2019 (top), with the 2018/19 summer highlighted and expanded (bottom)

2.2 Measured local wind

Hourly and half-hourly wind data collected by Bureau for Meteorology (BoM) at the Ocean Reef wind anemometer from 17/10/1996 to 11/07/2019 were analysed and presented below. Figure 6 displays a wind rose of the 23-year dataset, while Figure 7 provides roses by season. The anemometer location is 25km SE of Two Rocks, which is shown back in Figure 2.

While this wind record does not cover the full extent of the AWAC record, it does cover the critical 2018/19 summer season and earlier, which is the focus period of wrack analysis. Extended wind data records beyond 11/07/2019 were eventually received from BoM after the main wrack investigation was conducted, however the existing data coverage over the 2018/19 summer season made any further updates unnecessary to the plots below.

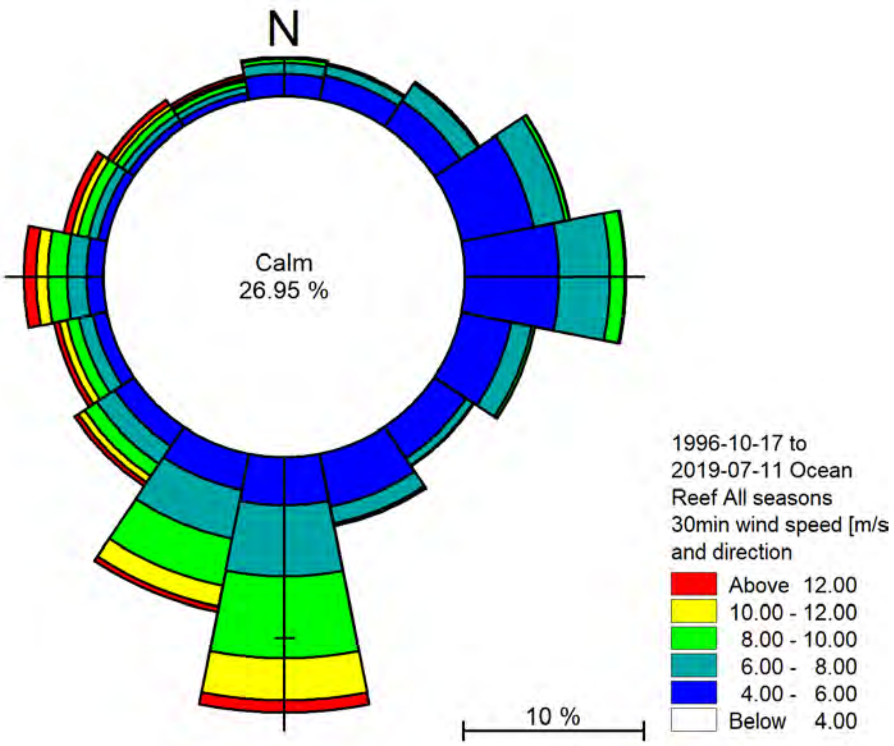
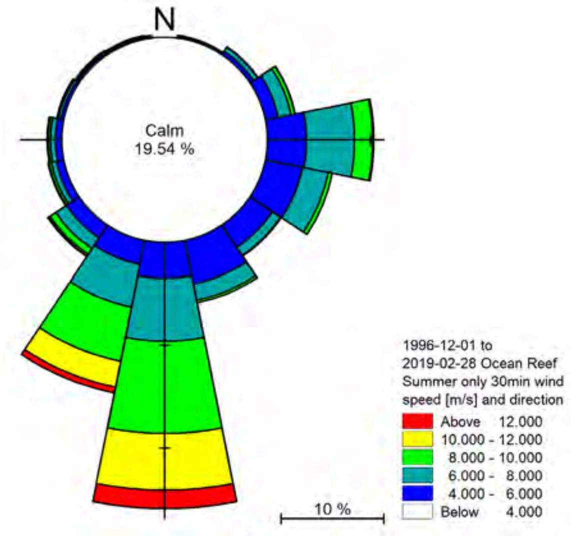
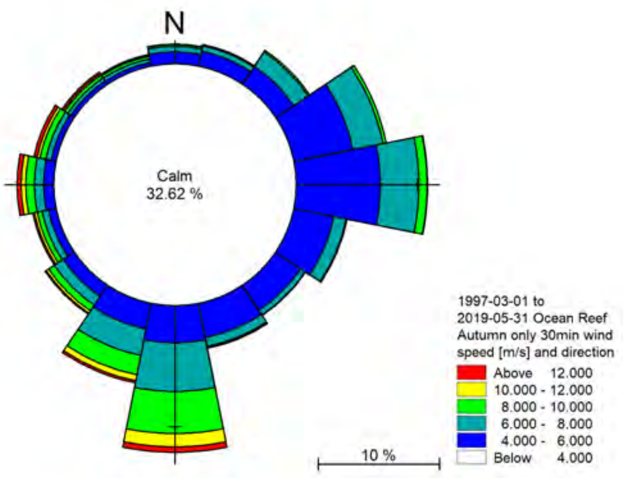


Figure 6. Ocean Reef long-term wind rose from 1996 to 2019 at the BoM anemometer

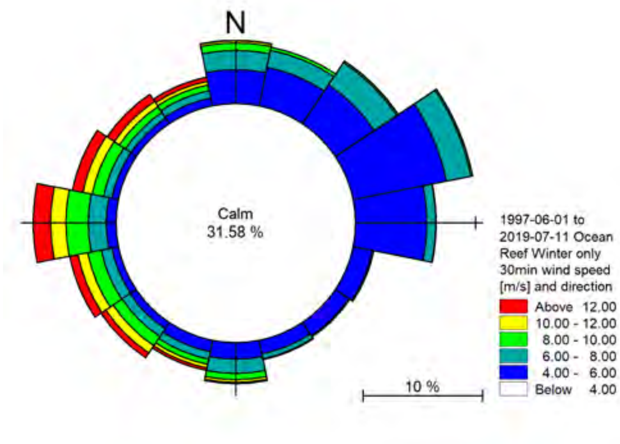
Figure 7 demonstrates that the Two Rocks wind climate is characterized by seasonal variability. There are significant SW, westerly, northerly, and NW wind components associated with storms in winter, then calm or north to east winds in-between. For summer, there is a regular daily component of south and SW winds during the sea breeze cycle, accompanying morning easterly and SE winds. Spring and autumn wind patterns appear transitionary, with a mixture of west to NW storms, calm winds, easterlies, and south to SW sea breeze cycles as summer transitions to winter and vice versa.



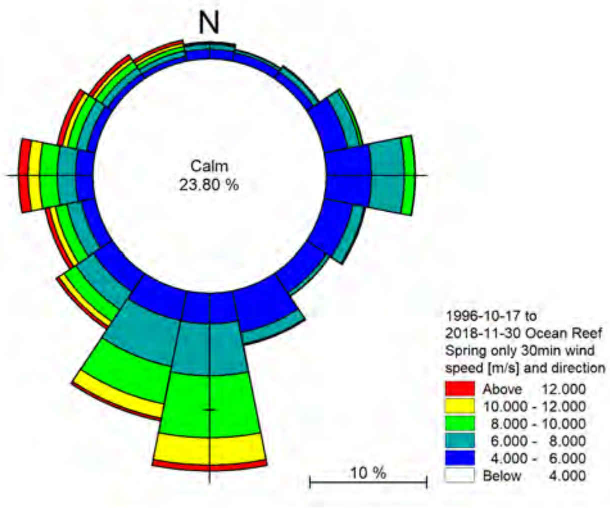
(a) Summer



(b) Autumn



(c) Winter



(d) Spring

Figure 7. Ocean Reef seasonal wind roses demonstrating variation of the long-term wind climate, 1996 to 2019

Although overall mean wind speeds were highest in summer, wind speed variability was highest in winter. Most of the strongest wind events (>15 m/s) occur during this period in association with storms. These winds are predominantly directed from the west and NW, then shift to SW as the storm passes over the coast.

2.3 Measured nearshore currents

Figure 8 plots a summary time series of current information near both the seabed and water surface, in addition to water depths, over thirteen months from 29/10/2018 to 21/11/2019. Time series of each parameter are colour-coordinated for ease of reference.

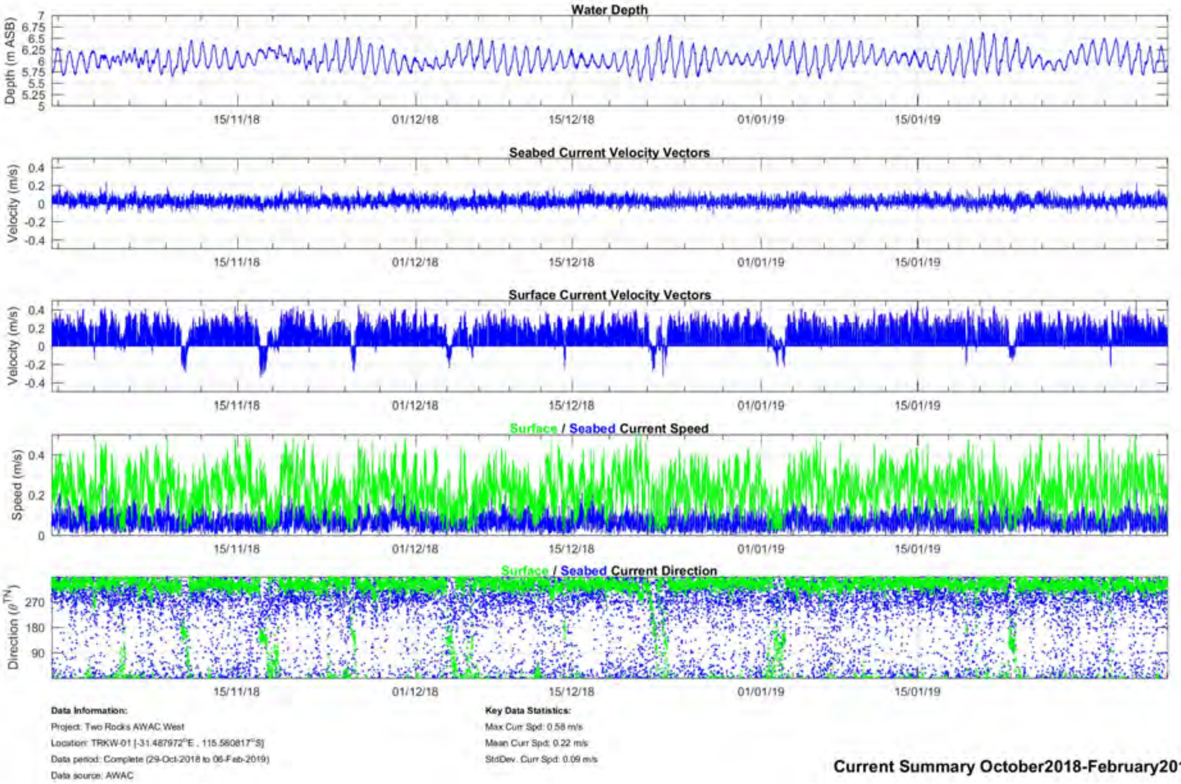
When broken down by season, currents were calmer on average in winter; this season had the largest proportion of currents flowing to the south, likely due to more frequent northerly winds experienced in winter, such as during storms. Reversals in current direction were therefore more frequent in winter months. Following the prevalence of stronger average winds during summer, this season demonstrated the highest current magnitudes as well. Summer currents mostly flowed to the north and NNW during sea breeze cycles, with infrequent reversals in current direction.

There were 12 major current reversal events recorded by the AWAC current data in the summer period between 01/11/2018 to 31/03/2019. The reversal events typically last less than a day, and the intervals between events range from one week to four weeks as shown in Figure 8.

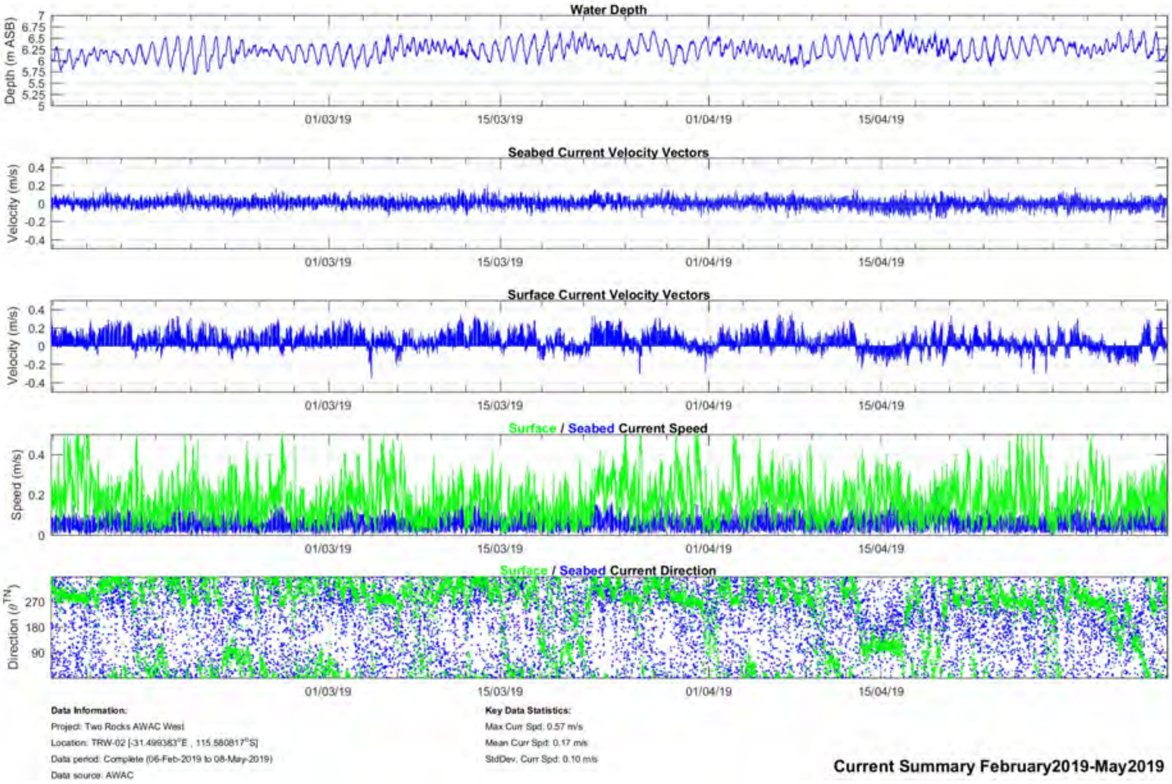
The strongest current speed recorded by the AWAC was a wind-driven surface current of 0.58m/s during a summer morning easterly wind event (~10m/s). This occurred on 31 January 2019, flowing towards the WNW with a direction of 289°. Strong wind-driven current events also occurred during the sea breeze cycle between mid-spring, summer, and mid-autumn – regularly reaching >0.3m/s during afternoons and usually flowing between the north and NW. The NW flow bias is likely linked to the Two Rocks breakwater exerting some degree of control on coastal processes at the AWAC location.

Figure 8 indicates autumn and spring current climates were broadly similar to each other, representing a transitional state between winter and summer; both recorded strong north to NW flowing currents with occasional south flowing currents during early/mid-spring storms. These storms resulted in the strongest surface current recorded outside of summer at 0.53m/s on 4/10/2019 towards a SSE direction of 167°. This event was also when the largest significant wave height was recorded during the deployment.

Surface currents and seabed current trends were broadly similar directionally for each season, though seabed currents were less directionally consistent owing to low magnitudes. The primary differences between current types were thus in current magnitude, whereby surface currents were consistently stronger than seabed currents across all seasons.



Current Summary October2018-February2019



Current Summary February2019-May2019

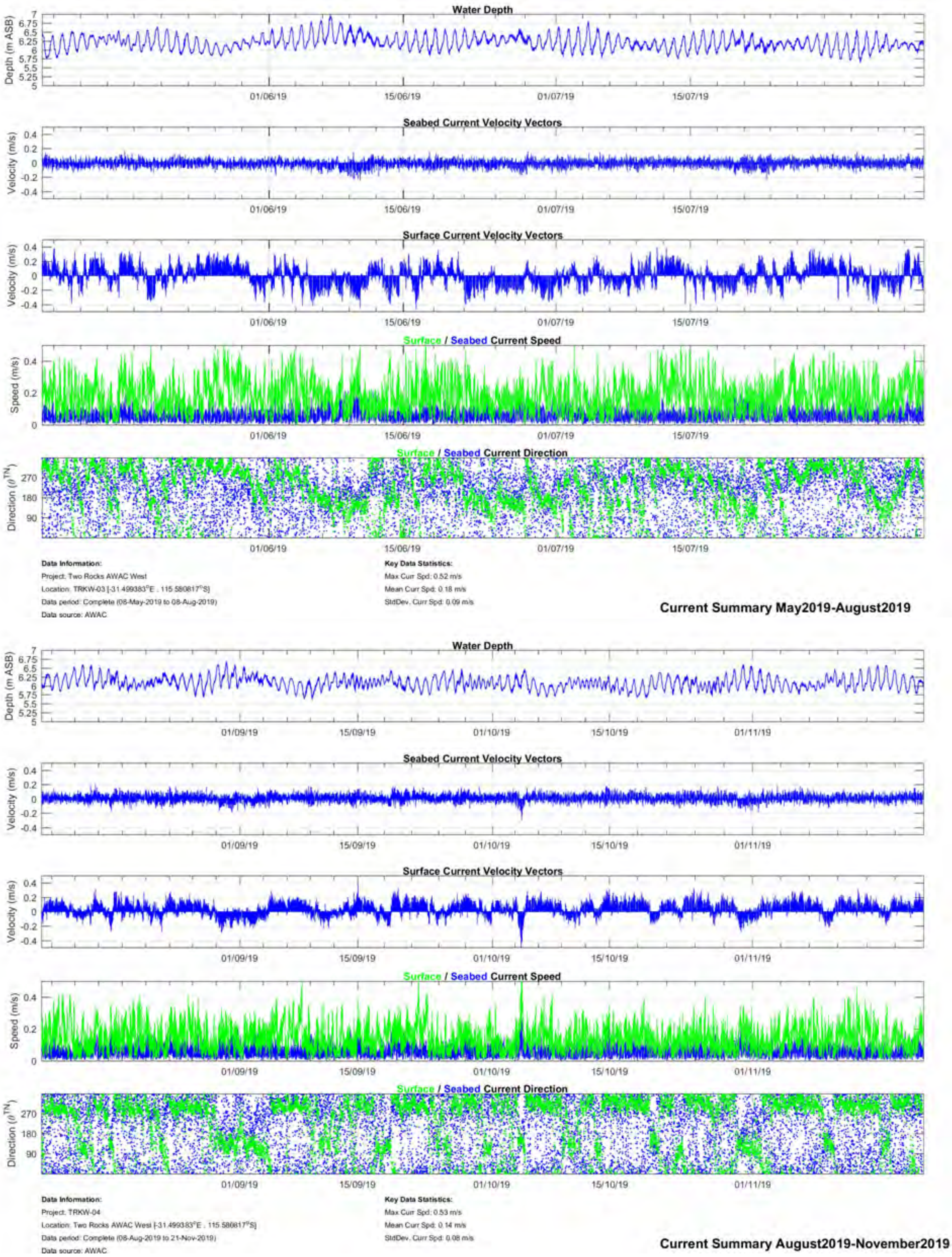


Figure 8: Time series of AWAC current parameters from 29/10/2018 to 21/11/2019 recorded at Two Rocks West, note different vertical scales per deployment

In addition to Figure 8, rose plots were created from the Two Rocks AWAC current climate. Figure 9 shows roses of current velocities for depth-averaged, surface, and seabed (~1m above the AWAC) layers respectively. As observed earlier, surface currents are stronger than the other cells, indicating a strong influence of winds on the nearshore current climate. It appears current direction shows similar trends across all depths, with a strong north to NW flowing current component, likely driven by a combination of sea breeze winds and shoreline/marina geometry.

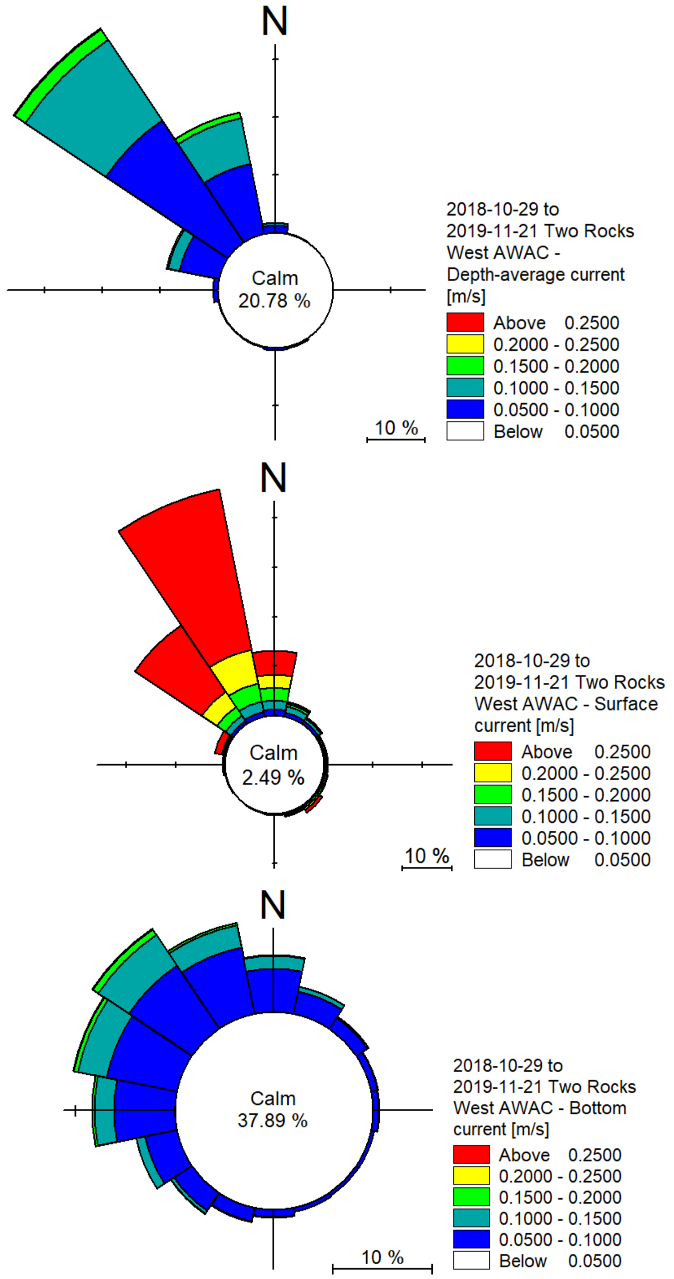


Figure 9: Two Rocks AWAC West current roses from 29/10/2018 to 21/11/2019 (direction flowing to): [top] depth-averaged current velocities; [middle] surface current velocities; [bottom] current velocities near the seabed

Given surface currents were the strongest currents in the record, it is anticipated that the surface layer would be the most capable at moving wrack once mobilised into the water column. Resultantly, a surface current rose between 1/11/2018 to 31/03/2019 has been provided in Figure 10. This figure illustrates how currents behaved during the worst months for wrack accumulation, and provides context for current behaviour during rare wrack clearing events over this period (discussed further in Section 3).

A key finding is that surface current directions in Figure 10 were not significantly divergent from surface current directions over the full deployment, with only a slightly greater proportion of west flowing currents during summer morning easterlies, and a slightly calmer current record in general. This appears to solidify the role of low summer tides even further: currents were often available to take wrack away in summer, though if they could not access the wrack, then wrack did not get removed (discussed in Section 3).

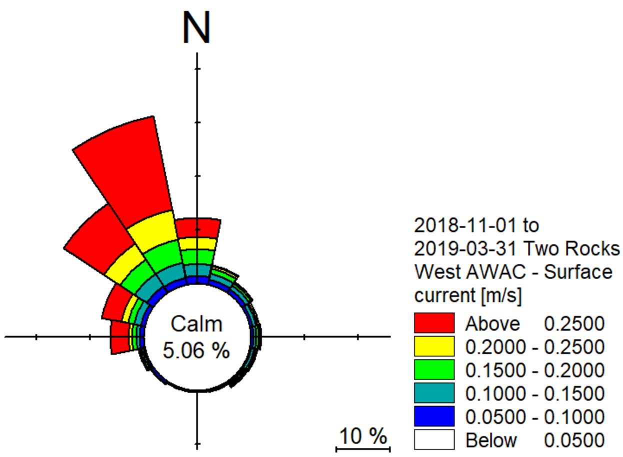


Figure 10: Two Rocks surface current velocities (direction flowing to), 01/11/2018 to 21/03/2019

2.4 Measured nearshore waves

Waves, particularly wave height, are considered important for beach wrack removal by physically loosening wrack accumulations on the beach ready for mobilisation by currents, provided that tides are high enough for wave action to reach the wrack. However, strong controls on wave direction by the crescent bay and marina are anticipated to result in a lower importance of wave direction for this investigation, given that waves generally interact with wrack accumulations directly on the beach face.

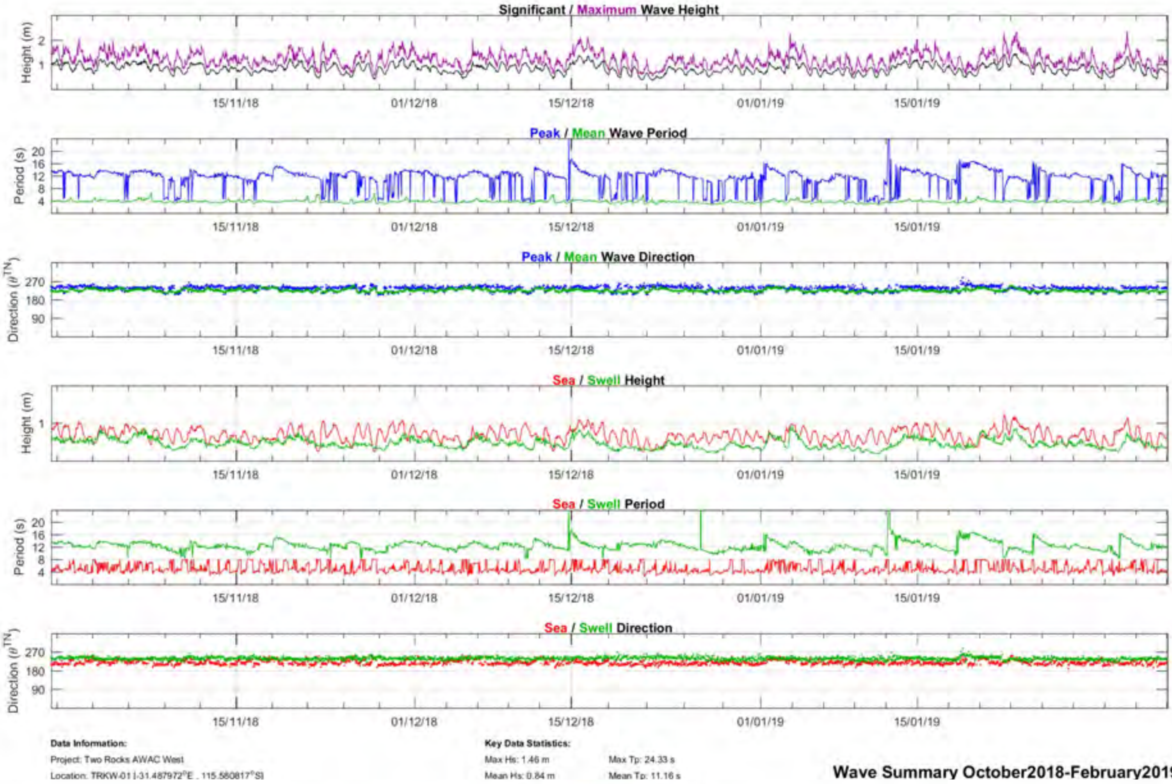
Figure 11 plots significant and maximum heights for total waves, plus significant heights and directions for total, swell, and sea waves, alongside peak spectral and mean wave periods, over thirteen months from 29 October 2018 to 21 November 2019. Time series of each parameter are colour-coordinated for ease of reference.

Figure 11 indicates that the large wave events at the Two Rocks West AWAC occur in winter and spring, during storms between April and October. Sixteen large wave events >1.5m Hs were recorded between these months, meanwhile no wave event >1.5m Hs occurred outside of these months. The largest significant wave height recorded was 2.41m during a spring storm on 4 October 2019. These storm waves entailed a peak spectral direction of 268º and peak spectral period of 11s. It is anticipated that the larger waves between April and November are an important component influencing wrack accumulation arrival and dissipation at Two Rocks southern beaches.

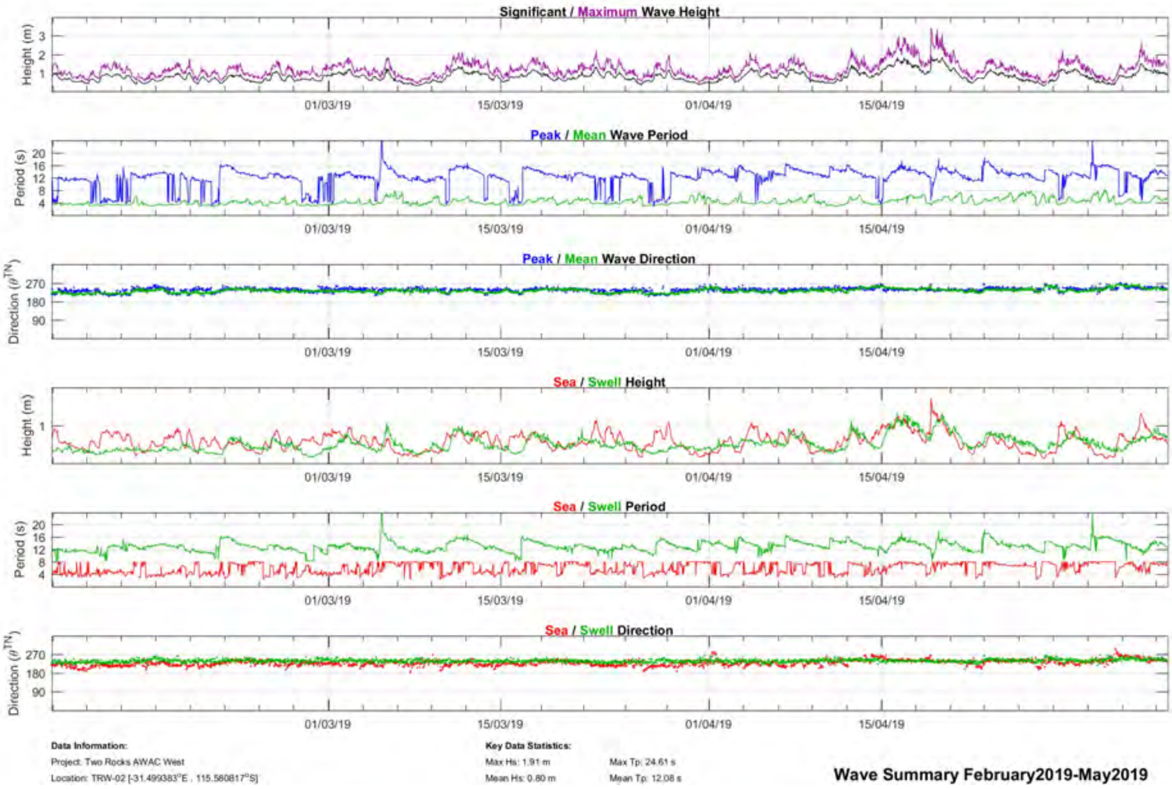
By contrast, waves were smaller in summer and autumn. The largest significant wave heights in summer appear to have occurred during a summer storm on 23 January 2019. These waves were 1.45m high, from a peak direction of 233º, and with an 11.41s peak period.

Both sea and swell waves were largest in winter and spring, associated with higher frequencies of storm activity during these seasons, as shown in Figure 11. Summer and autumn demonstrated lower average sea and swell wave heights, with the largest waves during these seasons occurring during summer sea breeze cycles.

Swell direction consistently propagated from the SSW to SW all year round. Meanwhile sea wave directions indicated higher seasonality. There was a greater tendency for sea waves to propagate from the SSW to SW in summer, coinciding with sea breeze cycles. Conversely, winter sea wave directions displayed a greater west, WNW, and WSW directional component following similar trends to wind patterns for this season.



Wave Summary October2018-February2019



Wave Summary February2019-May2019

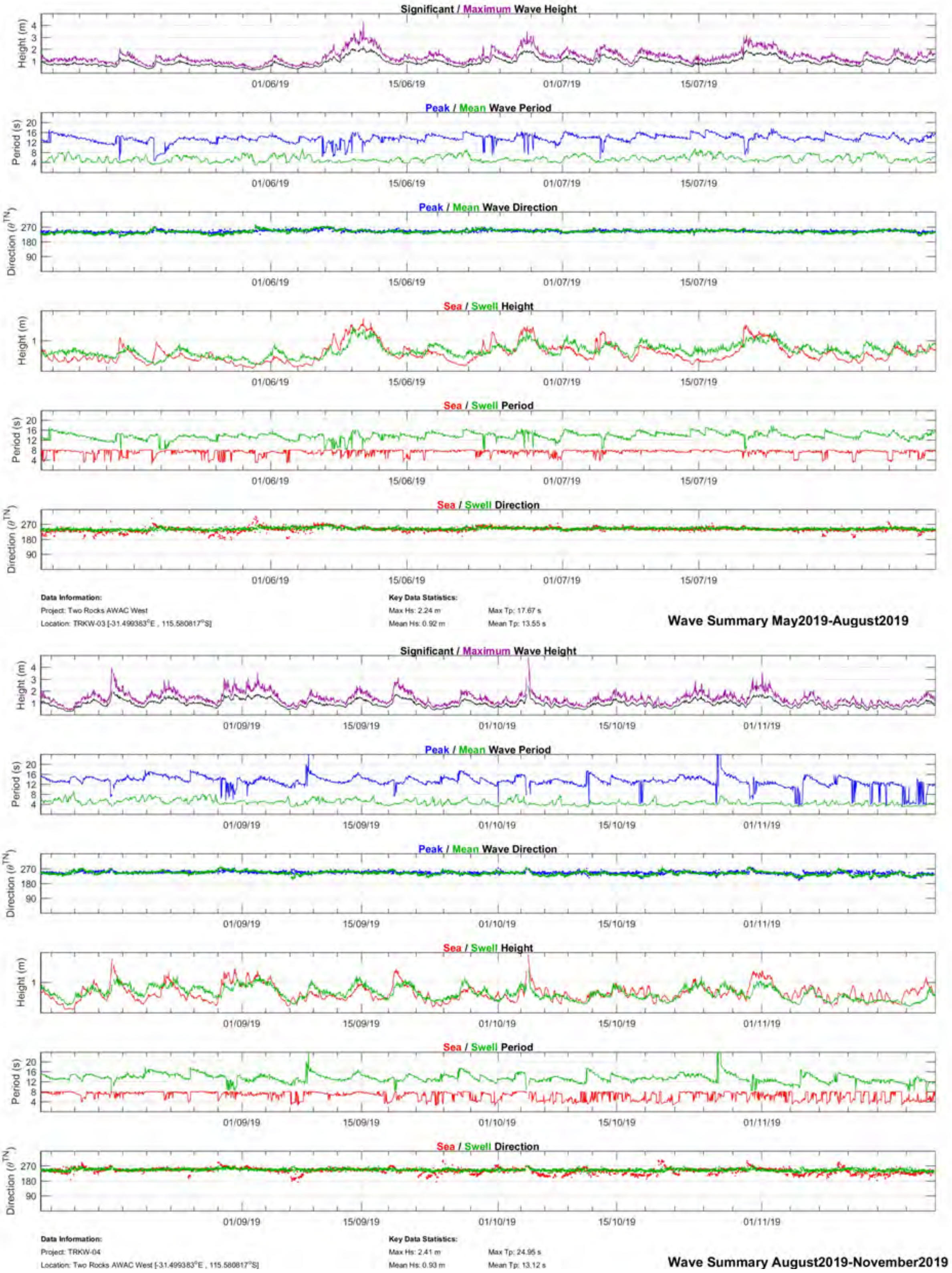


Figure 11: Time series of AWAC wave parameters from 29/10/2018 to 21/11/2019 recorded at Two Rocks West, note different vertical scales per deployment

In addition to Figure 11, rose plots were created from the Two Rocks AWAC wave climate (Figure 12). The total wave rose indicates that all significant wave heights >0.5m were within the south to west directional bands, and predominately from the SW. The swell wave rose in Figure 12 is similar to the total wave rose, being consistently from the southwest, albeit with smaller wave heights. Figure 12 indicates that sea waves were less consistent, with more waves propagating from the west and WNW. There are also more sea waves from the SSW following the sea breeze influence. Sea waves were larger on average than swell waves during the 13-month deployment.

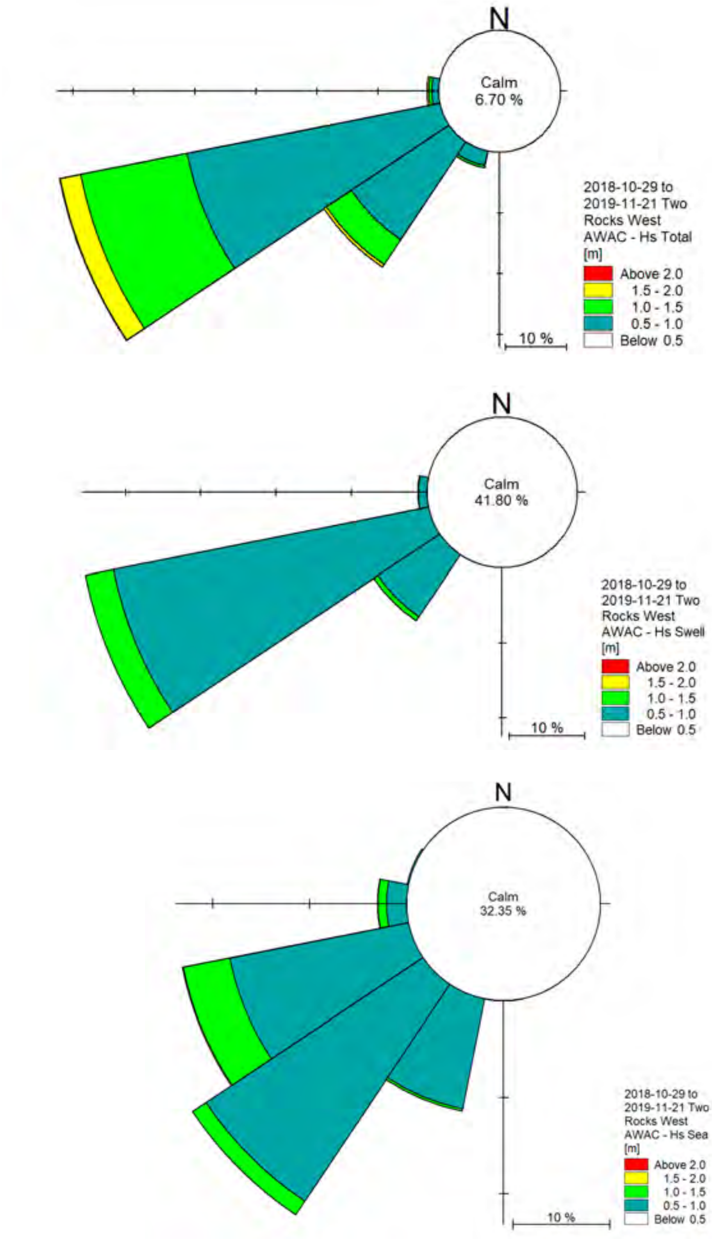


Figure 12: Two Rocks wave roses with significant wave height and peak direction, from 29/10/2018 to 21/11/2019: [top] total Hs and total Dp; [middle] swell Hs and swell Dp; [bottom] sea Hs and sea Dp

3 Wrack photo monitoring analysis

3.1 Historical wrack accumulations at Two Rocks southern beaches

Wrack accumulations occur during both winter and summer along Two Rocks southern beaches (DoT 2013, DoT 2014). Using independent methods, both DoT (2014) and MRA (2000) identified wrack accumulations exceeding 30,000m^3 between November and March at the crescent bay immediately south of Two Rocks marina. MRA (2000) identified that wrack accumulations gradually increased over summer after the marina was constructed in 1972/73. Refer to Table 1 and Figure 13 for wrack accumulation volumes at this location. Winter accumulations were usually below 1,000m^3, up to two orders of magnitude smaller compared to summer (DoT 2013).

Table 1: Wrack accumulations between November and March at the crescent bay south of Two Rocks marina; adapted from MRA (2000)

Photograph Date	Wrack Area (m3)	Wrack Volume (m3)
06/12/1973	7,500	11,250
13/03/1974	10,000	15,000
15/11/1976	22,000	33,000
08/12/1980	7,500	26,250
18/03/1983	13,000	19,500
15/12/1983	14,300	21,450
08/1/1985	17,800	26,700
20/02/1987	18,900	28,350
14/11/1988	10,800	16,200
05/12/1989	13,400	20,100
11/03/1990	21,400	32,100
14/11/1990	12,100	18,150
30/12/1991	5,700	8,550
07/01/1993	11,700	17,550
06/12/1993	5,000	7,500
07/12/1994	12,900	19,350
09/01/1996	10,700	16,050
17/12/1996	10,700	16,050
13/02/1998	9,700	14,550
02/01/2000	5,500	8,250
Averages	**12,500**	**18,750**

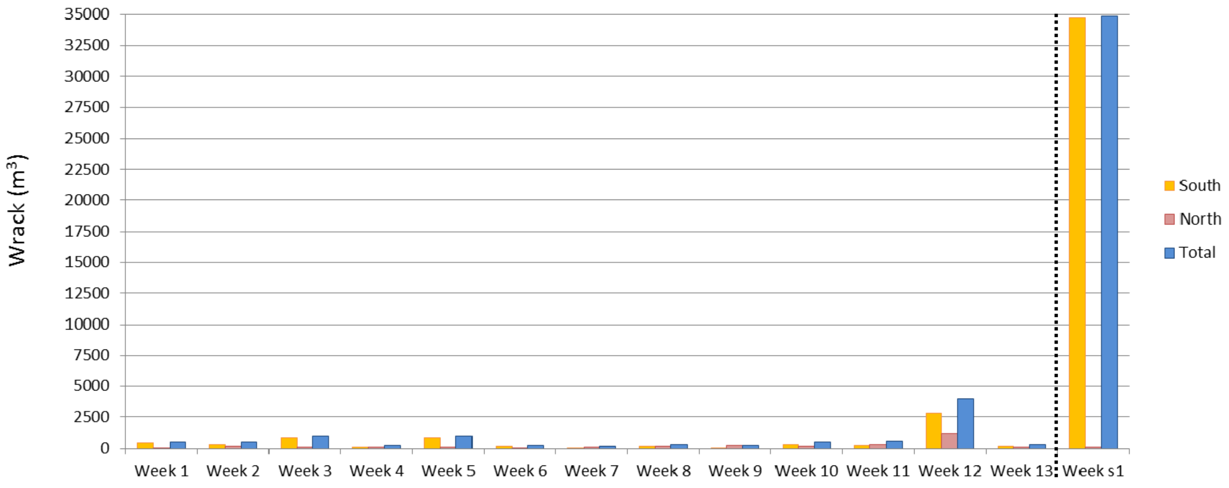


Figure 13: Wrack accumulations recorded over thirteen subsequent weeks in winter 2013 (Week 1 was 03/05/2013, Week 13 was 26/07/2013), alongside a recording of wrack in summer (Week s1 was 14/02/2014); adapted from DoT (2014)

Weekly field photo monitoring during the DoT (2013, 2014) campaigns is also pictured in Figure 14. It is noted that beaches on the northern side of Two Rocks marina experienced no wrack accumulation problems during summer, as shown in Figure 13.

Figure 14: Photos of winter (top) and summer (bottom) during the DoT monitoring campaign. Winter photos were taken on 26/07/2013 (Week 11) and summer photos were taken on 14/02/2014 (Week s1)

It is clear from previous studies that wrack accumulations are seasonal at Two Rocks, with wrack volumes peaking around summer between November and March. Figure 15 demonstrates that this was also evident in the subsequent Two Rocks fixed DoT monitoring camera record at the southern breakwater between 2017 and 2019.

Figure 15: Fixed monitoring photos of the crescent bay south of Two Rocks marina during winter (left) and summer (right)

It is anticipated that lower average water levels during summer, in conjunction with smaller tidal ranges (refer back to Figure 5), are an important component to the seasonality in wrack accumulation patterns (MRA 2000). In addition, past studies have indicated seagrass biomass is higher here in summer than in winter (WAoWA 1995), creating added supply for the beach. Finally, the Two Rocks marina acts as a northern barrier to sand and wrack transport, leading to increased wrack and sand deposits trapped at the crescent bay south of the marina (MRA 2000). It is considered the Two Rocks marina is the primary component leading to excessive wrack accumulation to the south.

During summer, there appear to be occasions where substantial amounts of wrack are periodically cleared away by metocean forces at the crescent bay south of Two Rocks. Rare combinations of wind, tide, current, and wave behaviour can lead to wrack clearing for short periods. These events will thus be the subsequent focus of this study, as they may inform wrack management planning for the area. The Two Rocks fixed monitoring camera was used to capture wrack clearing events throughout the year (refer back to Figure 1).

3.2 2017 to 2019 hourly fixed camera photo analysis

The photo record captured by the Two Rocks fixed monitoring camera spans more than 26 months, between 4/07/2017 to 18/10/2019, for a total of 10,868 photos. Photos were captured during daylight hours only, usually hourly between 6:00AM and 6:00PM. The photo record was analysed to identify the date, accumulation start time, and accumulation end time when wrack appears on the beach south of the Two Rocks marina.

The restriction of photography to daylight hours has introduced some limitations to this investigation, as it appears many wrack clearing events started or ended at night. This limitation also affects assessment of wrack clearing conditions, as only a maximum twelve-hour window or less was available to directly link wrack clearing on the beach with metocean conditions at the AWAC and other instruments.

Figure 16 provides a summary of wrack accumulation durations captured by the fixed DoT monitoring camera at the crescent bay south of Two Rocks marina. The end of each accumulation might be caused by one or more wrack clearing events, as many wrack clearing events were not strong enough to remove the full accumulation alone. Otherwise, the accumulation may eventually diminish slowly over time when wrack supply ceased.

41 accumulations were identified in total of varying duration from Figure 16. Longer times between clearing events indicate when wrack persisted on the beach to putrefy, which was most severe during summer and early autumn. February was a notable month in both 2018 and 2019, whereby wrack was trapped on the beach without any clearing event the entire time. In late December, January, and March of each year, the beach was also persistently ailed by wrack accumulations for most of the time.

Approximately 50% of wrack accumulations that began between November and March persisted for ten days or longer in Figure 16. No accumulations persisting longer than ten days were recorded that began outside of November to March. Wrack piles starts to disappear in early April in both 2018 and 2019 with the arrival of the first storms and higher water levels.

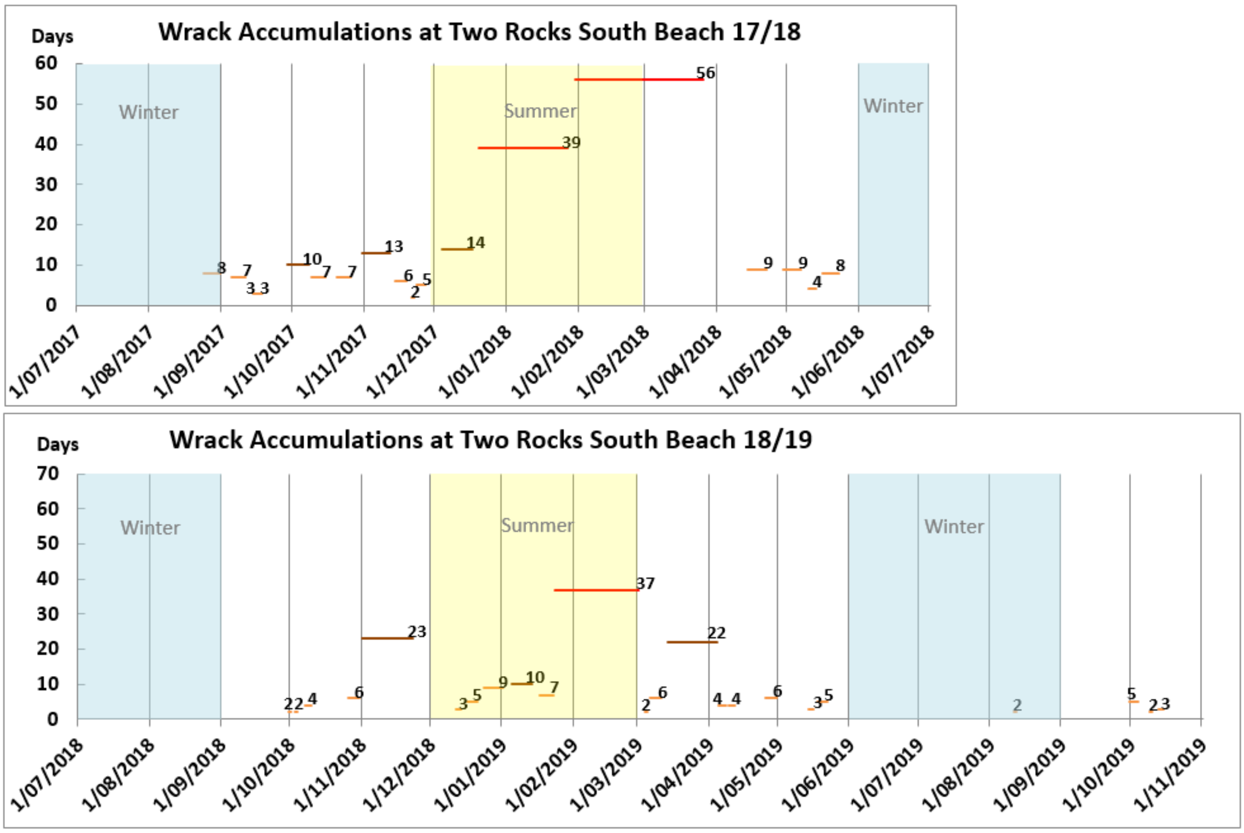


Figure 16: Wrack accumulation durations at the crescent bay beach south of Two Rocks marina between July 2017 and November 2019; the end of each accumulation is due to a wrack clearing event

The top five longest wrack accumulation events are all occurred between November and March, as shown in Table 2. It is again evident that the worst month for wrack accumulation duration is February, with two of the three longest persisting accumulation events occurring over this month.

Table 2: The top five longest persisting wrack accumulation events between 4/07/2017 to 18/10/2019

Rank	Duration	Accumulation Start	Accumulation End
1	56	30/01/2018	26/03/2018
2	39	20/12/2017	27/01/2018
3	37	24/01/2019	1/03/2019
4	23	1/11/2018	23/11/2018
5	22	14/03/2019	4/04/2019

In addition to the figures and tables above, detailed information about the metocean conditions that lead to wrack clearing from the beach have been compiled in Table 3. The table indicates tide, wind direction, current direction, and wave height coincide with wrack clearing events. Although wind and current magnitudes are important to note, it was considered that wind and current directions were more important parameters to report for wrack clearing events.

In addition to Table 3, graphical representations of important metocean parameters are provided in Figure 17 and Figure 18, noting Figure 18 only covers the eight wrack clearing events identified while the AWAC was recording. Here the behaviour of tides, winds, currents, and waves can be observed in the context of each wrack clearing event. It should be noted that NTR was also investigated alongside tides for each wrack clearing event, however no clear pattern in NTR was found in relation to wrack clearing, so this component has neither been graphed nor investigated further.

From Table 3, Figure 17, and Figure 18, eight key characteristics were applicable to wrack clearing event occurrence at Two Rocks southern beaches:

1. Almost all events were during a rising tide (14/15 events), which was usually a spring tide (6/9 events when the AWAC was recording)
2. Most events (10/15 events: 2, 3, 4, 7, 8, 9, 10, 11, 13, and 15) experienced winds from the WSW to south, noting this is the dominant wind direction between November and March (refer back to Figure 7)
3. Some events (3/15 events: 1, 6, and 12) experienced winds from the NE, WNW, and SW, noting this is the wind direction observed during a rare frontal storm in summer
4. The remaining events (2/15 events: 5 and 14) experienced winds from the ENE to ESE, noting this is a wind direction observed during morning easterlies that occasionally persist into the afternoon
5. For all nine events recorded by the AWAC, current directions were wind-driven, flowing according to wind direction in general
6. No clear pattern was associated with reversal in current directions for a wrack clearing event, a wind-driven current from any direction was all that was needed
7. Wave heights were higher than average during all nine events recorded at the AWAC, noting the average AWAC significant wave height was 0.8m between November to March
8. (Not shown on the figures and tables) Events 7, 8, and 10 only demonstrated mild wrack clearing and concurrently all had lower water levels than most other clearing events, being 0.9m CD or lower

Table 3: Metocean conditions during observed wrack clearing events in the photo monitoring record; currents are direction to and winds are direction from

Wrack clearing Event				Frem. tide gauge		Rott. Wave	Two Rocks West AWAC				Ocean Reef wind anemometer		
Event no.	Clearing start	Clearing end	Duration (day)	Max WL (m, CD)	Tide after Max	Peak Hs (m)	Peak Hs (m)	Morning current Dir.	Mid-day current Dir.	Afternoon current Dir.	Morning wind Dir.	Mid-day wind Dir.	Afternoon wind Dir.
1	16/11/2017 7:30	16/11/2017 16:30	0.38	0.73	Rising	0.96	-	-	-	-	NE to N	N	N to NW
2	16/12/2017 9:30	16/12/2017 17:00	0.31	1.05	Rising	1.65	-	-	-	-	SW to WSW	WSW to SW	SW
3	26/01/2018 8:30	26/01/2018 16:30	0.33	1.14	Rising	1.94	-	-	-	-	S to SSW	SSW	SSW to S
4	27/01/2018 8:30	27/01/2018 17:00	0.35	1.09	Rising	1.62	-	-	-	-	S to SSW	SSW	SSW to S
5	25/03/2018 9:00	25/03/2018 16:30	0.31	1.31	Rising	2.39	-	-	-	-	E to ENE	ENE to E	E to ESE
6	26/03/2018 7:00	26/03/2018 17:00	0.42	1.37	Rising	2.18	-	-	-	-	N to NNW	NNW	NNW to SW
7	23/11/2018 8:30	23/11/2018 17:00	0.35	0.85	Rising	2.11	1.12	WNW	WNW to NNW	NNW to NW	SSW	SSW to SW	SW to SSW
8	7/12/2018 9:00	7/12/2018 17:30	0.35	0.86	Rising	2.42	1.13	NW to WNW	WNW to NNW	NNW to WNW	SSW	SSW	SSW to S
9	14/12/2018 11:00	14/12/2018 18:00	0.29	0.79	Rising	1.54	0.85	-	WNW	WNW to NW	-	S	S
10	15/12/2018 10:00	15/12/2018 18:00	0.33	0.90	Rising	3.18	1.37	WNW to W	W to WNW	WNW to NNW	SSW	SSW to SW	SW to SSW
11	1/01/2019 9:00	1/01/2019 18:00	0.38	1.02	Rising	1.82	1.13	NW to NNW	NNW to WNW	WNW to NW	SSW	SSW to SW	SW
12	23/01/2019 11:00	23/01/2019 18:00	0.29	0.99	Rising	4.50	1.45	-	SE	SE to SSW	-	WNW	WNW to WSW
13	1/03/2019 11:00	1/03/2019 18:00	0.29	0.94	Rising	2.49	0.98	-	NNW to NW	NW to W	-	SSW	SSW
14	5/03/2019 11:00	5/03/2019 18:00	0.29	0.94	Rising	2.30	1.25	-	WNW to W	W	-	E	E to ESE
15	11/03/2019 6:00	11/03/2019 18:00	0.50	0.99	Falling	2.29	1.35	NW	NW to NNW	NNW to NW	SSE to S	S	S

*Clearing begins when wrack first begins dissipating on that day, noting the record can be cutoff overnight

**Clearing ends when it appears wrack is no longer being removed from the beach, or photography gets cutoff overnight (usually the latter)

***Wind and depth-averaged current directions for morning (~8am to 11am), mid-day (11am to 1pm), and afternoon (1pm to ~6pm) are only for the duration where wrack clearing was observed

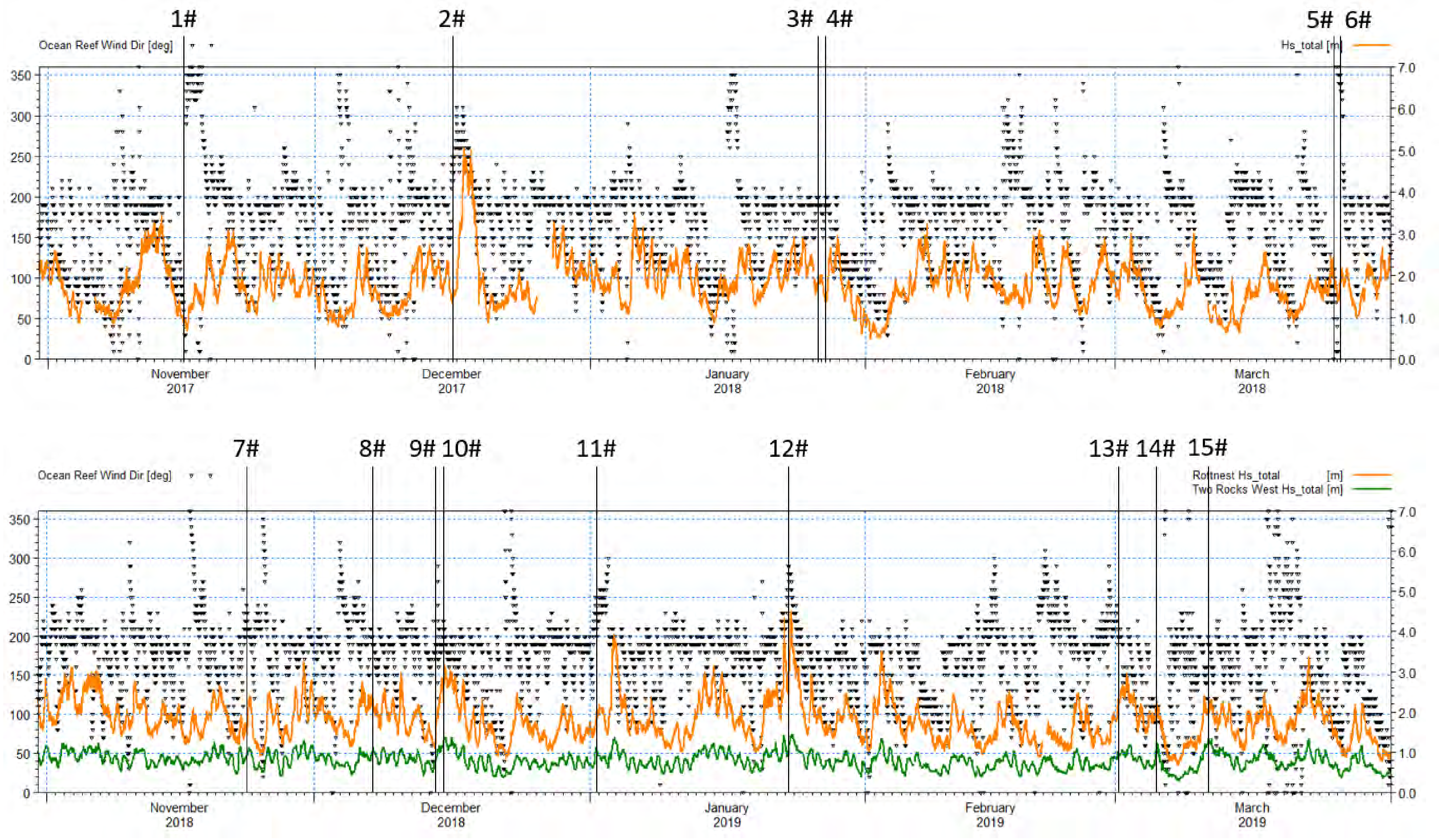


Figure 17: Wind direction, Rottnest Island Wave Buoy Hs, and Two Rocks West AWAC Hs over the photo monitoring period with 13 wrack clearing events identified

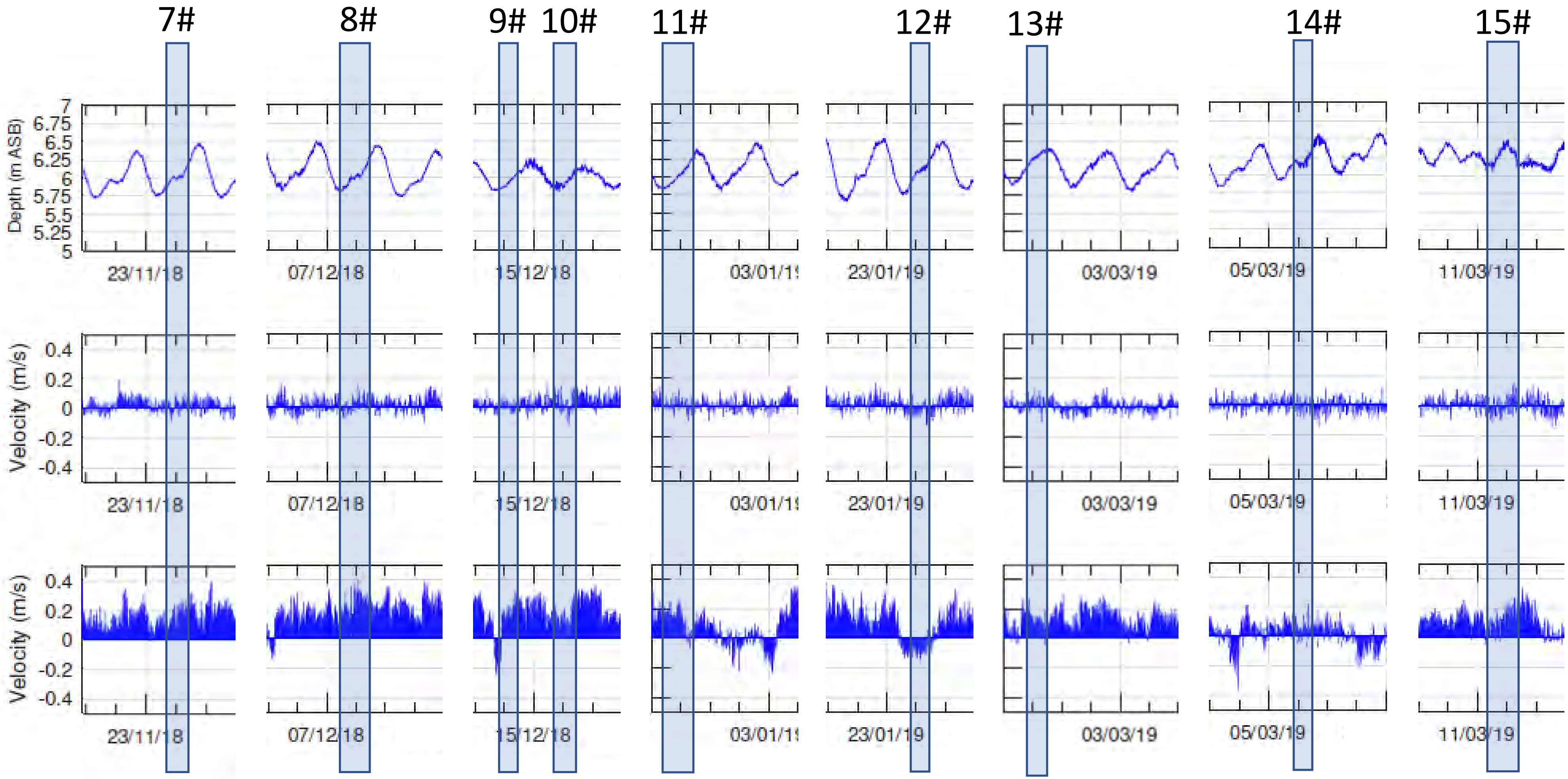


Figure 18: Two Rocks AWAC record of water depth (top) showing tidal movement, seabed current speed (middle), and surface current speed (bottom); the duration of each wrack clearing event is highlighted in blue, noting that only event 7 – 15 occurred during the AWAC deployment period.

The most consistent component in Table 3 to occur during wrack clearing events was a rising tide. The tide was rising in 14 out of 15 wrack clearing events. The only event with a falling tide had already seen a rising tide occur earlier during that event. In addition, the rising tides were usually a spring tide, with 6 out of 9 rising tide events in the AWAC record suggesting a spring tide (Figure 18). This meant the maximum water level was usually during the final photo of the day in the photo monitoring record, indicating that wrack clearing events likely persisted into the night as the tide continued to rise.

Another key finding in Table 3 and Figure 17 was that wind appeared to be the main driver of current direction during each event. Currents generally recorded an opposing direction to winds for each event in broad terms, although geometric constraints of the location appear to prevent exact opposite wind/current directions from occurring. Regardless, comparison of wind directions in Table 3 with the net north/south current plots in Figure 18 indicate currents were clearly driven by wind direction for each event.

Waves also demonstrate a consistent pattern with wrack clearing events. Wave heights appear higher than average during wrack clearing events. Larger waves may result in greater erosion of wrack from the beach, particularly during a rising tide allowing greater access to wrack for wave action. The average AWAC Hs during November to March was 0.8m, meanwhile the peak AWAC Hs was always above 0.85m during wrack clearing events, and was >1.1m during 6 our of nine events when the AWAC was recording in Table 3 and Figure 17. Note that wave direction was not considered overly relevant to analyse for this location, given refracted waves generally interact with wrack directly on the beach face.

The main type of wrack clearing event to occur in summer was a ‘Seabreeze event’ (10/15 events), characterised by strong sea breeze winds from the south to SW and coincident with a rising tide. Although the sea breeze cycle is common in summer and has been linked with increased beach wrack accumulation, occasionally these winds generate waves and currents that combine with a rising tide, potentially allowing NW flowing wind-driven currents to transport freshly eroded wrack away from the beach for brief periods. Section 3.3 documents specific metocean conditions and wrack accumulation patterns for these events.

Another important type of summer wrack clearing event was a ‘Storm event’ (3/15 events), characterised by infrequent frontal sytems that occasion summer months. These events, while weaker than winter storms by comparison, still provide temporary wrack clearing conditions through rising tides and strong winds from the west to NW, generating local sea waves as well as driving south to SE flowing currents. At the crescent bay, the marina does not block transport to the south, so wrack can be readily removed during these events. Section 3.4 documents specific metocean conditions and wrack accumulation patterns for these events.

The third event type, an ‘Offshore event’, can also clear wrack during summer (Table 3). Strong easterly winds can create offshore-bound currents to transport wrack away from the beach during a rising tide. This event appears to be rarest, requiring strong morning easterlies that persist into the late afternoon to align with tidal phasing. Only two of this event type was found in the two-year photo monitoring record. Section 3.5 documents specific metocean conditions and wrack accumulation patterns for these events.

3.3 Seabreeze event example in the AWAC record

As discussed in Section 3.2, most wrack clearing events during summer were Seabreeze events. The Seabreeze event is characterised by cross-shore/onshore south to SW winds, along with rising tides and west to NNW flowing currents at the AWAC location. A conceptual model of wind and current dynamics during these events is presented in Figure 19.

Figure 19: Conceptual model of current circulation patterns expected during a Seabreeze event, smaller arrows present anticipated weakening currents as they encounter friction with the shore

An example of a Seabreeze event is assessed from the wrack clearing event on 01/01/2019 (event 11 on Table 3), where wrack coverage change during the event has been estimated in Figure 20 from the photo monitoring record. A SSW to SW wind occurred during a rising summer spring tide for this event, and a WNW to NNW flowing current was observed at the AWAC (Figure 21). During the event, significant wave heights up to 1.13m at the AWAC and 1.82m at the Rottnest Island wave buoy were recorded.

Figure 20: Wrack accumulation change estimated from a Seabreeze event on 01/01/2019

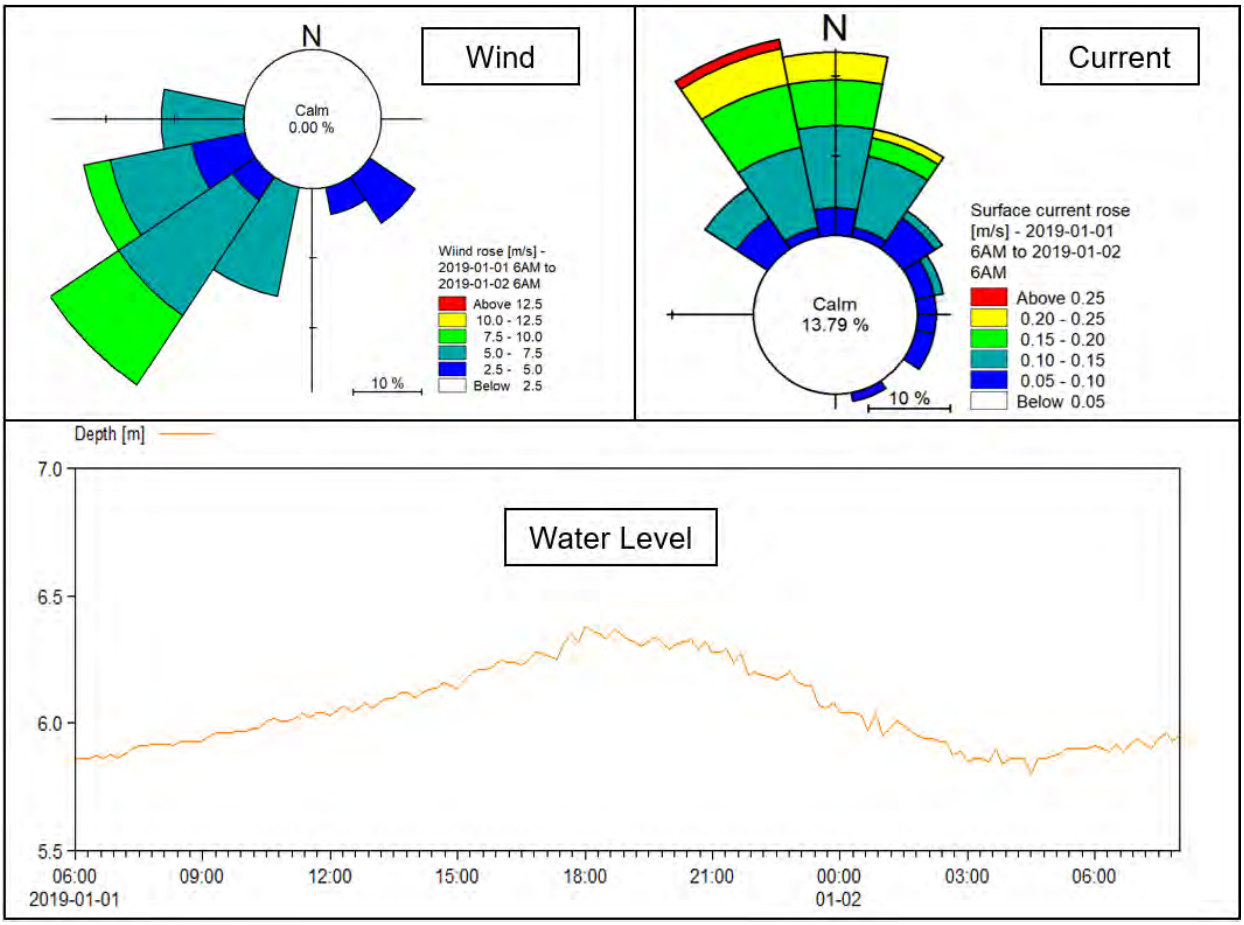


Figure 21: Metocean conditions recorded at the AWAC and wind anemometer on 01/01/2019, containing a Seabreeze event

3.4 Storm event example in the AWAC record

A Storm event as described in Section 3.2 is characterised by strong onshore winds tending west to NNW, along with rising tides and south to SE flowing currents at the AWAC location. Developed wind waves may erode accumulated wrack, where a rising tide may provide reach for waves further up the beach, acting to lift wrack from the beach face. It is then possible that wind-driven currents form a SW flow to transport wrack away from the area as per the conceptual model presented in Figure 22.

Figure 22: Conceptual model of current circulation patterns expected during a Storm event, smaller arrows present anticipated weakening currents as they encounter friction with the shore

An example of a short-lived Storm event is assessed from the wrack clearing event on 23/01/2019 (event 12 in Table 3), where wrack coverage change during the event has been estimated in Figure 23 from the photo monitoring record. A WNW wind occurred during a rising summer spring tide for this event, and a SE current was observed at the AWAC (Figure 24). During the event, significant wave heights up to 1.45m at the AWAC and 4.5m at the Rottnest Island wave buoy were recorded; these were the highest waves recorded in Table 3.

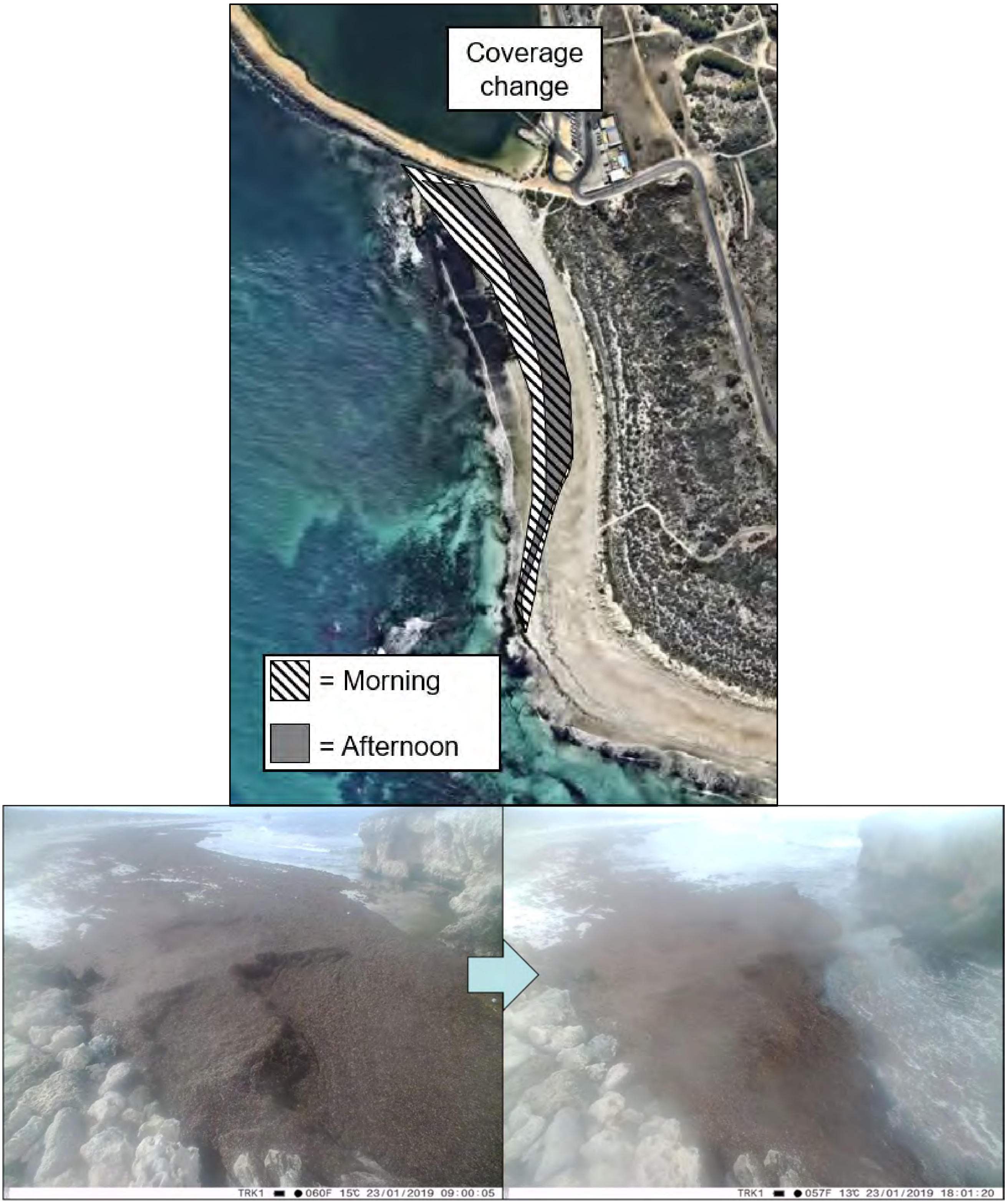


Figure 23: Wrack accumulation change estimated from a Storm event on 23/01/2019

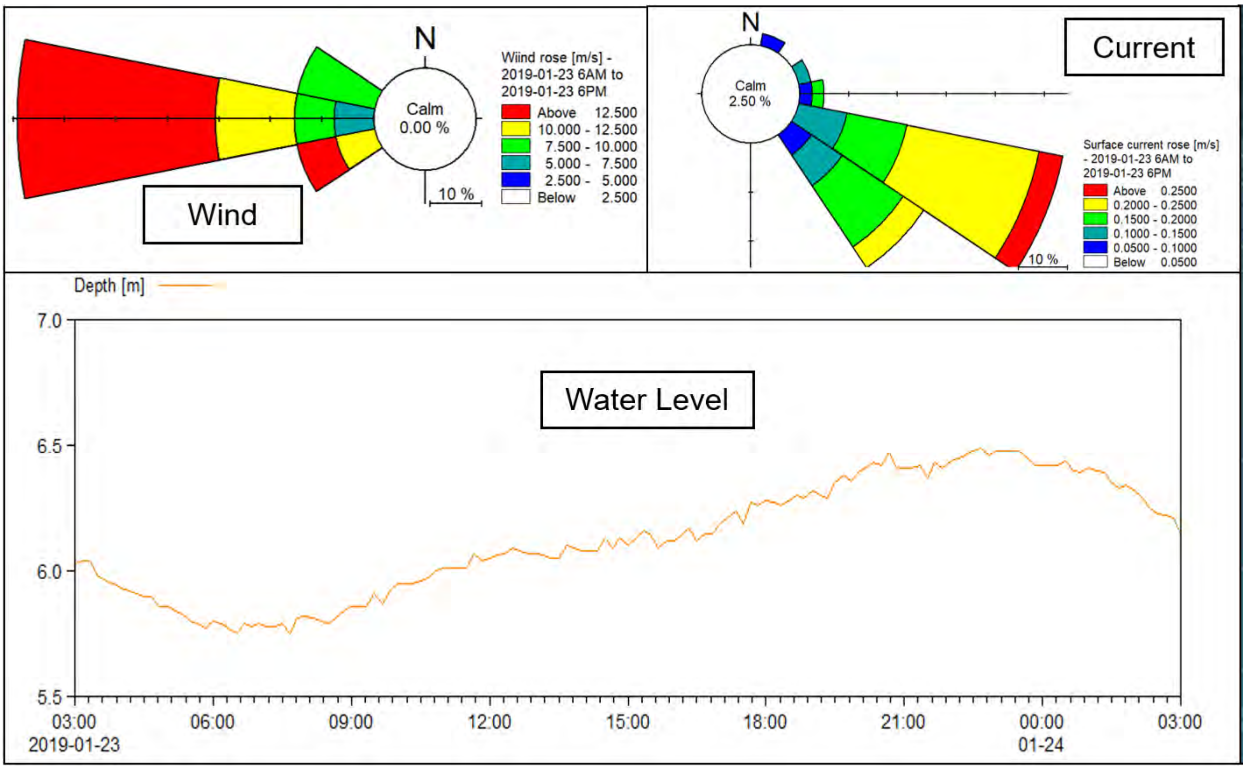


Figure 24: Metocean conditions recorded at the AWAC and wind anemometer on 23/01/2019, containing a Storm event

While this event is not considered a mild wrack clearing event, it did not clear as much wrack compared to some of the more powerful wrack clearing events in the record, so it is anticipated that Storm events play a relatively smaller role in wrack clearing during summer. Another significant finding is that a substantial wrack accumulation was observed on the beach the day after this Storm event, demonstrating the brief duration that a wrack clearing event may entail.

It must be emphasised that a Storm event between November and March may not be the best event to plan around for wrack management purposes. Wrack transported by a Storm event is likely pushed to the south. It is then anticipated that any wrack removed this way may return the next day when prevailing south to SW winds return. This may explain the short-lived duration of wrack cleared off the beach after some Storm events.

3.5 Offshore event example in the AWAC record

An Offshore event as described in Section 3.2 is characterised by strong offshore winds tending ENE to ESE, along with rising tides and west to NNW flowing currents at the AWAC location. Although fetch is very low, a developed offshore current can develop during a sustained offshore wind. Once waves erode the beach wrack, it is then possible for these wind-driven currents to transport wrack away from the area as per the conceptual model presented in Figure 25.

Figure 25: Conceptual model of current circulation patterns expected during an Offshore event

An example of an Offshore event is assessed from the wrack clearing event on 05/03/2019 (event 14 from Table 3), where wrack coverage change during the event has been estimated in Figure 26 from the photo monitoring record. An east to ESE wind occurred during a rising summer spring tide for this event, and a WNW to west flowing current was observed at the AWAC (Figure 27). During the event, significant wave heights up to 1.25m at the AWAC and 2.3m at the Rottnest Island wave buoy were recorded.

Figure 26: Wrack accumulation change estimated from an Offshore event on 5/03/2019

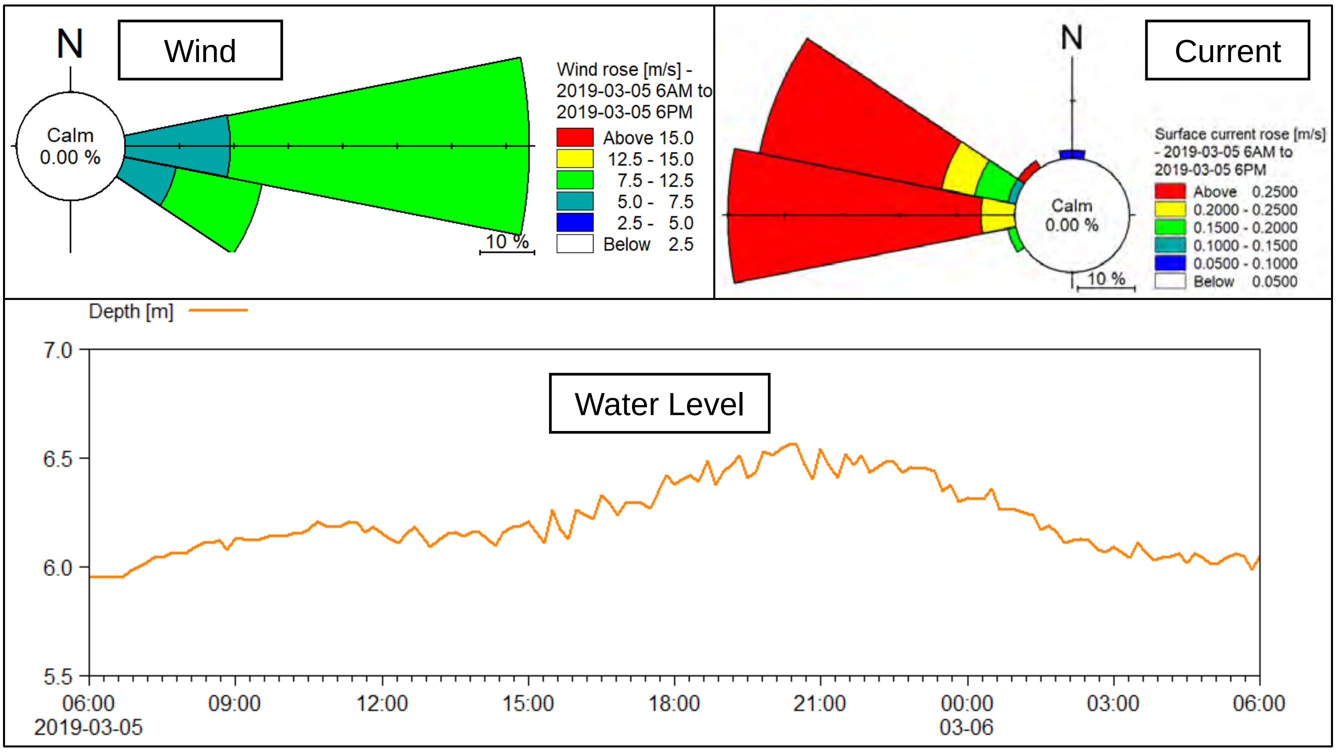


Figure 27: Metocean conditions recorded at the AWAC and wind anemometer on 5/03/2019, containing an Offshore event

4 Recommendations for managing wrack at Two Rocks

Wrack accumulations and wrack clearing events assessed in this study provide important information for wrack management at Two Rocks. Common to all wrack clearing events was the important role of tide, with a rising tide one of the key conditions to allow wrack removal.

Another critical finding was how wrack often returns rapidly after clearing events in summer, as soon as the next day in some cases. An example of this can be seen below during a mild Seabreeze event on 23/12/2018, noting this event could not be included back in Table 3 because most of the event happened at night (Figure 28). Wrack had also accumulated back on the beach the next morning for the Storm event described previously in Section 3.4. Furthermore, there were many instances of rising spring tides with strong SW winds apparent in the metocean record, yet significant wrack clearing was not always observed during such conditions from the photo record at Two Rocks. This inconsistency in wrack clearing events introduces added challenges into wrack management planning.

Figure 28: Wrack accumulation before and after an undocumented wrack clearing event on 23/12/2018

It is understood that high water levels during clearing events allow better access to wrack on the beach for waves and currents, enabling wrack to be eroded and potentially transported away. The mechanisms by which wrack returns, almost immediately afterwards in some cases, remains unclear and presents a significant knowledge gap for understanding the behaviour of wrack accumulation patterns at Two Rocks. The limitation of wrack photos to daytime-only also makes it difficult to learn more about the metocean conditions that lead to wrack returning so quickly.

Three mechanisms are hypothesised to explain how wrack rapidly returns to the beaches at the crescent bay south of Two Rocks marina after a summer clearing event:

1. Wrack is transported away from the beach by a clearing event, then that same wrack is returned directly after ambient summer metocean conditions recommence.
2. Wrack is transported away from the beach by a clearing event, then new wrack is deposited in its place directly after ambient summer metocean conditions recommence.

3. Wrack is lifted into the water column while the tide is rising during a clearing event, though very little is transported away by coastal processes, so that same wrack is redeposited onto the beach when the tide recedes.

It is also plausible that some combination of those three hypotheses are occurring at the same time. These possibilities also introduce significant uncertainty for devising effective wrack management strategies at Two Rocks.

One method of wrack management entails a trial of manually pushing wrack into the ocean prior to/during a wrack clearing event. Coastal processes could then transport wrack away, allowing nature to contribute most of the wrack management effort. However, if either Hypothesis 1 or 2 from the above list is true, then this management action would be ineffective.

A second wrack management method involves pushing beach wrack into the dunes behind the beach, letting it dry, and avoiding interaction with coastal processes altogether. This method would require more management effort, requiring a return of the dried wrack back to the ocean in winter. However, if Hypothesis 2 from the above list is true, then this method would not entirely prevent subsequent wrack accumulation on the beach either.

While this study considers water levels as the most important *metocean* component controlling wrack accumulations seasonally, the presence of the Two Rocks marina is the primary factor overall to cause wrack accumulation issues to the south (MRA 2000). The most effective solution devised to date therefore requires a complete rebuild and realignment of the Two Rocks southern breakwater (DoT 2019). The crescent bay to the south would be bisected and reshaped, improving wrack bypassing around the marina structures and reducing both sand accretion and wrack trapping to the south. A plan view of the relevant section in the proposal is presented in Figure 29.

Regardless of the available management methods, it is considered that small scale trials of the simplest methods be attempted first around the start of summer in 2020. This provides a least-regrets approach and iterative wrack management lessons to learn from. If desired, continued investigations to better determine wrack sources and transport pathways may deliver improved insight into predicting wrack accumulation behaviour at Two Rocks southern beaches.

If it is decided that wrack pushing into the ocean is to be trailed, to test its effectiveness at managing wrack accumulation at Two Rocks, then Table 4 can be used to assist timing of such trials. This table provides a window of spring tides ≥1.1m between March and November 2020/21 (see the Appendix for full BoM tide tables). Table 4 can be used to narrow down when wrack pushing should be undertaken. Promising date windows that time well with the holiday season appear to be mid-December 2020 and mid-January 2021. Wrack pushing should then be timed when wave heights are considerably high (e.g. Rottnest Hs >2m), and forecast winds are either during a strong seabreeze lasting beyond sunset, a storm, or during offshore easterlies persisting well into the afternoon.

Finally, it must be noted that wrack accumulation is a natural process common along WA beaches, experienced along large parts of the coastline in many local government areas. While minimizing public health hazards from excess wrack accumulations is important to manage, an entirely wrack-free beach anywhere along the Perth metropolitan coast via interventional wrack clearing cannot be recommended as a feasible management measure.

Figure 29: Southern section of DoT Masterplan for redeveloping Two Rocks marina; adapted from DoT (2019)

Table 4: Windows of high water levels in November to March 2020/21, with alternating shading for clarity

Windows in 2020	Max WL (m)	Max WL time (24h)	Windows in 2021	Max WL (m)	Max WL time (24h)
15/11/2020	1.11	21:05	1/01/2021	1.12	22:15
16/11/2020	1.14	21:27	9/01/2021	1.10	18:51
17/11/2020	1.13	21:47	10/01/2021	1.16	19:25
18/11/2020	1.10	22:10	11/01/2021	1.19	20:02
30/11/2020	1.12	20:55	12/01/2021	1.19	20:40
1/12/2020	1.12	21:21	13/01/2021	1.17	21:15
2/12/2020	1.12	21:49	14/01/2021	1.13	21:43
3/12/2020	1.10	22:18	25/01/2021	1.12	19:23
12/12/2020	1.11	19:48	26/01/2021	1.15	19:58
13/12/2020	1.17	20:15	27/01/2021	1.17	20:35
14/12/2020	1.19	20:45	28/01/2021	1.15	21:12
15/12/2020	1.18	21:12	29/01/2021	1.15	21:47
16/12/2020	1.15	21:36	30/01/2021	1.10	22:21
17/12/2020	1.10	21:57	7/02/2021	1.11	18:23
27/12/2020	1.11	19:44	8/02/2021	1.14	19:17
28/12/2020	1.14	20:10	9/02/2021	1.15	20:03
29/12/2020	1.16	20:40	10/02/2021	1.14	20:44
30/12/2020	1.16	21:12	11/02/2021	1.12	21:19
31/12/2020	1.15	21:44	23/02/2021	1.10	19:01
			24/02/2021	1.14	19:47
			25/02/2021	1.15	20:30
			26/02/2021	1.15	21:11
			27/02/2021	1.11	21:51
			24/03/2021	1.10	18:27
			25/03/2021	1.12	19:30
			26/03/2021	1.12	20:20

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Appendix

FREMANTLE – WESTERN AUSTRALIA 2020

LAT 32° 3' S LONG 115° 44' E

Times and Heights of High and Low Waters

Local Time

SEPTEMBER

	Time	m
1 TU	0045 0855 1700 2320	0.73 1.05 0.58 0.75
2 WE ○	0151 0924 1710 2325	0.71 1.03 0.61 0.77
3 TH	0240 0947 1713 2332	0.69 0.99 0.64 0.80
4 FR	0327 1007 1703 2341	0.68 0.95 0.66 0.83
5 SA	0414 1026 1701 2315	0.68 0.90 0.67 0.87
6 SU	0502 1048 1710 2330	0.69 0.84 0.67 0.91
7 MO	0556 1110 1714 2356	0.70 0.79 0.68 0.94
8 TU	0652 0851 1622	0.72 0.74 0.67
9 WE	0024 1612	0.95 0.65
10 TH ◐	0058 1435	0.96 0.61
11 FR	0148 0229 0311 1455	0.96 0.96 0.96 0.57
12 SA	0429 1515	0.98 0.53
13 SU	0550 1534	1.01 0.50
14 MO	0702 1552	1.05 0.49
15 TU	0757 1610 2304	1.07 0.50 0.74
16 WE	0122 0846 1630 2252	0.72 1.07 0.52 0.76
17 TH ●	0221 0940 1649 2311	0.68 1.04 0.57 0.79
18 FR	0329 1045 1704 2336	0.65 0.97 0.63 0.84
19 SA	0450 1155 1641	0.62 0.88 0.68
20 SU	0000 0557 1255 1607	0.89 0.62 0.77 0.69
21 MO	0019 0855 2315	0.94 0.60 0.98
22 TU	1226 2337	0.54 1.00
23 WE	1314	0.48
24 TH ◑	0008 0145 0220 1356	1.00 0.98 0.98 0.46
25 FR	0045 0208 0315 1435	0.97 0.95 0.96 0.46
26 SA	0132 0223 0418 1509	0.92 0.92 0.94 0.49
27 SU	0658 1533	0.93 0.52
28 MO	0744 1535 2210	0.93 0.56 0.75
29 TU	0037 0821 1535 2158	0.73 0.93 0.58 0.77
30 WE	0140 0854 1546 2159	0.70 0.91 0.61 0.80

OCTOBER

	Time	m
1 TH	0231 0927 1547 2157	0.66 0.89 0.63 0.84
2 FR ○	0318 0958 1528 2153	0.63 0.85 0.65 0.88
3 SA	0402 1024 1534 2202	0.61 0.81 0.66 0.92
4 SU	0445 1038 1546 2222	0.60 0.76 0.66 0.95
5 MO	0527 1054 1545 2246	0.59 0.71 0.66 0.98
6 TU	0609 1112 1501 2312	0.59 0.66 0.65 0.99
7 WE	0657 0816 0941 2339	0.60 0.61 0.60 0.99
8 TH	1037 1138 1315	0.58 0.59 0.57
9 FR	0009 1342	0.98 0.54
10 SA ◐	0045 1406	0.96 0.51
11 SU	0137 0239 0326 1428	0.93 0.93 0.93 0.50
12 MO	0458 1444	0.93 0.49
13 TU	0636 1455 2152	0.95 0.51 0.77
14 WE	0111 0747 1507 2129	0.73 0.95 0.54 0.80
15 TH	0226 0853 1523 2141	0.66 0.93 0.59 0.85
16 FR	0334 1007 1531 2154	0.60 0.88 0.64 0.91
17 SA ●	0432 1114 1455 2154	0.54 0.81 0.68 0.97
18 SU	0535 1214 1442 2200	0.50 0.73 0.68 1.02
19 MO	0733 1325 1412 2216	0.47 0.65 0.65 1.05
20 TU	0849 2237	0.45 1.06
21 WE	1147 2302	0.44 1.04
22 TH	1240 2332	0.43 1.00
23 FR ◑	1323	0.45
24 SA	0006 1400	0.94 0.49
25 SU	0041 1427 2253 2339	0.88 0.53 0.81 0.81
26 MO	0431 1431 2121	0.82 0.58 0.79
27 TU	0150 0725 1420 2043	0.76 0.81 0.61 0.82
28 WE	0229 0817 1424 2040	0.71 0.80 0.63 0.86
29 TH	0303 0912 1409 2041	0.66 0.79 0.65 0.91
30 FR	0337 1004 1400 2047	0.62 0.77 0.66 0.95
31 SA ○	0410 1052 1415 2102	0.58 0.75 0.67 1.00

NOVEMBER

	Time	m
1 SU	0444 1137 1429 2122	0.54 0.72 0.67 1.03
2 MO	0519 1222 1427 2145	0.52 0.68 0.67 1.05
3 TU	0559 2212	0.51 1.06
4 WE	0649 2238	0.51 1.05
5 TH	0901 2306	0.50 1.04
6 FR	0952 2337	0.51 1.01
7 SA	1045	0.51
8 SU ◐	0013 1313	0.97 0.51
9 MO	0054 1330 2221 2320	0.93 0.52 0.84 0.84
10 TU	0408 1324 2100	0.88 0.55 0.82
11 WE	0037 0556 1332 2017	0.77 0.84 0.58 0.86
12 TH	0202 0749 1347 2020	0.69 0.81 0.63 0.92
13 FR	0308 0929 1354 2030	0.59 0.78 0.67 0.99
14 SA	0406 1039 1325 2045	0.50 0.74 0.70 1.06
15 SU ●	0513 1143 1308 2105	0.43 0.70 0.69 1.11
16 MO	0639 2127	0.38 1.14
17 TU	0740 2147	0.36 1.13
18 WE	0831 2210	0.37 1.10
19 TH	0923 2235	0.41 1.06
20 FR	1200 2303	0.45 1.00
21 SA	1245 2332	0.50 0.93
22 SU ◑	1319 2356	0.56 0.87
23 MO	1329 2149	0.61 0.84
24 TU	1227 1948	0.64 0.86
25 WE	1230 1944	0.67 0.91
26 TH	0458 0901 1205 1947	0.67 0.70 0.68 0.96
27 FR	0346 1005 1222 1956	0.63 0.70 0.68 1.01
28 SA	0411 1052 1245 2010	0.57 0.70 0.69 1.06
29 SU	0446 1143 1300 2030	0.52 0.69 0.69 1.09
30 MO ○	0527 2055	0.48 1.12

DECEMBER

	Time	m
1 TU	0612 2121	0.45 1.12
2 WE	0658 2149	0.44 1.12
3 TH	0742 2218	0.44 1.10
4 FR	0826 2248	0.45 1.07
5 SA	0909 2320	0.47 1.03
6 SU	0953 2353	0.50 0.98
7 MO	1034	0.53
8 TU ◐	0025 1110 2055 2358	0.91 0.57 0.85 0.82
9 WE	0045 1138 1922	0.82 0.62 0.89
10 TH	0307 0507 1157 1920	0.72 0.73 0.67 0.96
11 FR	0341 1929	0.61 1.04
12 SA	0428 1948	0.51 1.11
13 SU	0516 2015	0.42 1.17
14 MO	0603 2045	0.35 1.19
15 TU ●	0647 2112	0.32 1.18
16 WE	0729 2136	0.33 1.15
17 TH	0808 2157	0.37 1.10
18 FR	0842 2218	0.43 1.04
19 SA	0912 2243	0.49 0.98
20 SU	0935 2305	0.56 0.93
21 MO	0752 2136	0.60 0.88
22 TU ◑	0756 1947	0.62 0.86
23 WE	0801 1852	0.63 0.91
24 TH	0728 1857	0.63 0.97
25 FR	0545 1907	0.61 1.02
26 SA	0519 1922	0.56 1.07
27 SU	0522 1944	0.52 1.11
28 MO	0534 2010	0.47 1.14
29 TU	0554 2040	0.43 1.16
30 WE ○	0620 2112	0.41 1.16
31 TH	0649 2144	0.40 1.15

Datum of Predictions is Chart Datum

Times are in local standard time (Time Zone UTC +08:00)

Moon Phase Symbols ● New Moon ◑ First Quarter ○ Full Moon ◐ Last Quarter

FREMANTLE – WESTERN AUSTRALIA

2021

LAT 32° 3' S   LONG 115° 44' E

Times and Heights of High and Low Waters

Local Time

JANUARY

Date	Time	m	Date	Time	m
1 FR	0719 2215	0.41 1.12	16 SA	0752 2213	0.49 1.01
2 SA	0749 2246	0.44 1.08	17 SU	0750 2232	0.55 0.96
3 SU	0815 2316	0.48 1.02	18 MO	0656 2249	0.58 0.91
4 MO	0828 2342	0.53 0.94	19 TU	0654 2115	0.59 0.87
5 TU	0813 2114	0.58 0.86	20 WE	0701 1729	0.60 0.88
6 WE ◐	0759 1821	0.61 0.88	21 TH ◑	0656 1737	0.60 0.93
7 TH	0753 1820	0.63 0.95	22 FR	0601 1755	0.60 0.98
8 FR	0336 0434 0601 1827	0.61 0.62 0.61 1.03	23 SA	0530 1820	0.57 1.03
9 SA	0407 1851	0.51 1.10	24 SU	0502 1849	0.53 1.08
10 SU	0445 1925	0.42 1.16	25 MO	0507 1923	0.49 1.12
11 MO	0524 2002	0.36 1.19	26 TU	0522 1958	0.45 1.15
12 TU	0601 2040	0.34 1.19	27 WE	0541 2035	0.43 1.17
13 WE ●	0637 2115	0.34 1.17	28 TH	0600 2112	0.41 1.17
14 TH	0708 2143	0.37 1.13	29 FR ○	0619 2147	0.42 1.15
15 FR	0733 2159	0.42 1.07	30 SA	0639 2221	0.44 1.10
			31 SU	0657 1341 1518 2250	0.48 0.72 0.72 1.03

FEBRUARY

Date	Time	m	Date	Time	m
1 MO	0706 1404 1615 2314	0.53 0.76 0.74 0.95	16 TU	0551 1326 1730 2246	0.61 0.86 0.77 0.86
2 TU	0658 1432 1724 2326	0.59 0.81 0.78 0.85	17 WE	0558 1351 1843 2053	0.62 0.90 0.80 0.83
3 WE	0641 1503	0.61 0.87	18 TH	0559 1422	0.62 0.94
4 TH	0634 1540	0.62 0.94	19 FR	0515 1504	0.62 0.97
5 FR ◐	0517 1625	0.59 1.00	20 SA ◑	0457 1558	0.60 1.00
6 SA	0319 1720	0.52 1.06	21 SU	0425 1700	0.57 1.03
7 SU	0354 1823	0.45 1.11	22 MO	0410 1806	0.53 1.07
8 MO	0431 1917	0.40 1.14	23 TU	0425 1901	0.50 1.10
9 TU	0508 2003	0.39 1.15	24 WE	0442 1947	0.48 1.14
10 WE	0541 2044	0.40 1.14	25 TH	0456 2030	0.47 1.15
11 TH	0606 2119	0.43 1.12	26 FR	0508 1227 1325 2111	0.47 0.76 0.76 1.15
12 FR ●	0620 1245 1402 2146	0.47 0.72 0.71 1.07	27 SA ○	0524 1200 1428 2151	0.50 0.77 0.74 1.11
13 SA	0622 1249 1457 2201	0.53 0.74 0.71 1.02	28 SU	0542 1214 1519 2229	0.54 0.80 0.73 1.04
14 SU	0617 1251 1545 2212	0.57 0.77 0.72 0.96			
15 MO	0558 1304 1633 2228	0.61 0.81 0.75 0.91			

MARCH

Date	Time	m	Date	Time	m
1 MO	0554 1236 1616 2258	0.59 0.85 0.73 0.94	16 TU	0433 1148 1709 2226	0.68 0.96 0.74 0.85
2 TU	0546 1302 1732 2306	0.65 0.90 0.74 0.83	17 WE	0442 1129 1800 2246	0.69 1.01 0.75 0.80
3 WE	0520 1329 2153 2304	0.67 0.96 0.73 0.73	18 TH	0442 1145 1852 2022	0.69 1.04 0.76 0.77
4 TH	0049 0152 0512 1359	0.72 0.72 0.66 1.00	19 FR	0400 1211	0.68 1.06
5 FR	0128 0248 0400 1437	0.61 0.62 0.62 1.04	20 SA	0354 1240	0.66 1.07
6 SA ◐	0207 1526	0.54 1.06	21 SU ◑	0230 1315	0.63 1.07
7 SU	0246 1624	0.49 1.08	22 MO	0249 1539	0.60 1.06
8 MO	0325 1750	0.46 1.08	23 TU	0310 1700	0.58 1.07
9 TU	0400 1923	0.47 1.09	24 WE	0329 1827	0.56 1.10
10 WE	0431 2006	0.49 1.09	25 TH	0341 1930	0.55 1.12
11 TH	0449 2043	0.53 1.08	26 FR	0351 1125 1314 2020	0.56 0.86 0.85 1.12
12 FR	0445 1122 1342 2114	0.57 0.81 0.77 1.05	27 SA	0405 1048 1422 2110	0.59 0.87 0.80 1.09
13 SA ●	0452 1128 1436 2139	0.61 0.84 0.76 1.01	28 SU	0422 1057 1541 2209	0.63 0.92 0.76 1.03
14 SU	0457 1135 1528 2156	0.65 0.88 0.75 0.96	29 MO ○	0433 1117 1648 2325	0.69 0.98 0.72 0.95
15 MO	0441 1144 1618 2208	0.68 0.92 0.74 0.90	30 TU	0411 1140 1754	0.74 1.04 0.70
			31 WE	0030 0350 1159 2031	0.85 0.75 1.09 0.67

APRIL

Date	Time	m	Date	Time	m
1 TH	0130 0335 1118	0.76 0.73 1.13	16 FR	0116 0241 1105 2134	0.77 0.76 1.18 0.71
2 FR	0000 1133	0.62 1.16	17 SA	1132 2226 2323	1.18 0.70 0.71
3 SA	0048 1158	0.56 1.16	18 SU	0100 1201	0.69 1.18
4 SU ◐	0132 1229 1356 1440	0.53 1.13 1.12 1.12	19 MO	0129 1233	0.67 1.16
5 MO	0213 1306 1417 1538	0.53 1.09 1.08 1.09	20 TU ◑	0156 1315	0.65 1.13
6 TU	0249 1648	0.55 1.06	21 WE	0217 1600	0.65 1.11
7 WE	0318 1913	0.60 1.04	22 TH	0230 1730	0.65 1.10
8 TH	0332 1957	0.65 1.03	23 FR	0235 1037 1243 1901	0.67 0.96 0.95 1.09
9 FR	0324 1009 1436 2033	0.69 0.92 0.86 1.01	24 SA	0243 0931 1410 2010	0.69 0.98 0.88 1.06
10 SA	0330 1011 1521 2109	0.72 0.96 0.82 0.98	25 SU	0255 0932 1524 2129	0.74 1.04 0.80 1.01
11 SU	0332 1014 1558 2145	0.75 1.00 0.79 0.94	26 MO	0259 0946 1625 2248	0.79 1.10 0.73 0.95
12 MO ●	0300 1012 1630 2229	0.76 1.05 0.77 0.90	27 TU ○	0235 1000 1732 2352	0.83 1.17 0.67 0.88
13 TU	0308 1010 1703 2334	0.77 1.10 0.75 0.85	28 WE	0221 1006 1925	0.83 1.23 0.62
14 WE	0322 1020 1740	0.77 1.14 0.73	29 TH	0101 0200 1018 2033	0.80 0.80 1.27 0.59
15 TH	0027 0318 1041 1821	0.80 0.77 1.17 0.73	30 FR	1038 2144 2221 2310	1.29 0.58 0.58 0.58

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Moon Phase Symbols ● New Moon ◑ First Quarter ○ Full Moon ◐ Last Quarter