6. BUSSELTON JETTY: ON-SITE CONSERVATION SURVEY REPORT

By Vicki Richards

Site location and survey

The ALA Fellowship programme concluded with an expedition to Western Australia's southwest coast (25–28 February 2009), which included a practical training session in on-site conservation survey techniques on the Busselton jetty for the visiting fellows.

The Busselton Jetty is located in Geographe Bay, a wide, open, north facing embayment situated between Cape Bouvard and Cape Naturaliste on the south-west coast of Western Australia. It is a relatively protected and shallow bay. Water movement in Geographe Bay is mainly wind driven. Geographe Bay has a relatively short flushing period of 3–15 days dependent on the wind direction and is, therefore, a well-mixed system.

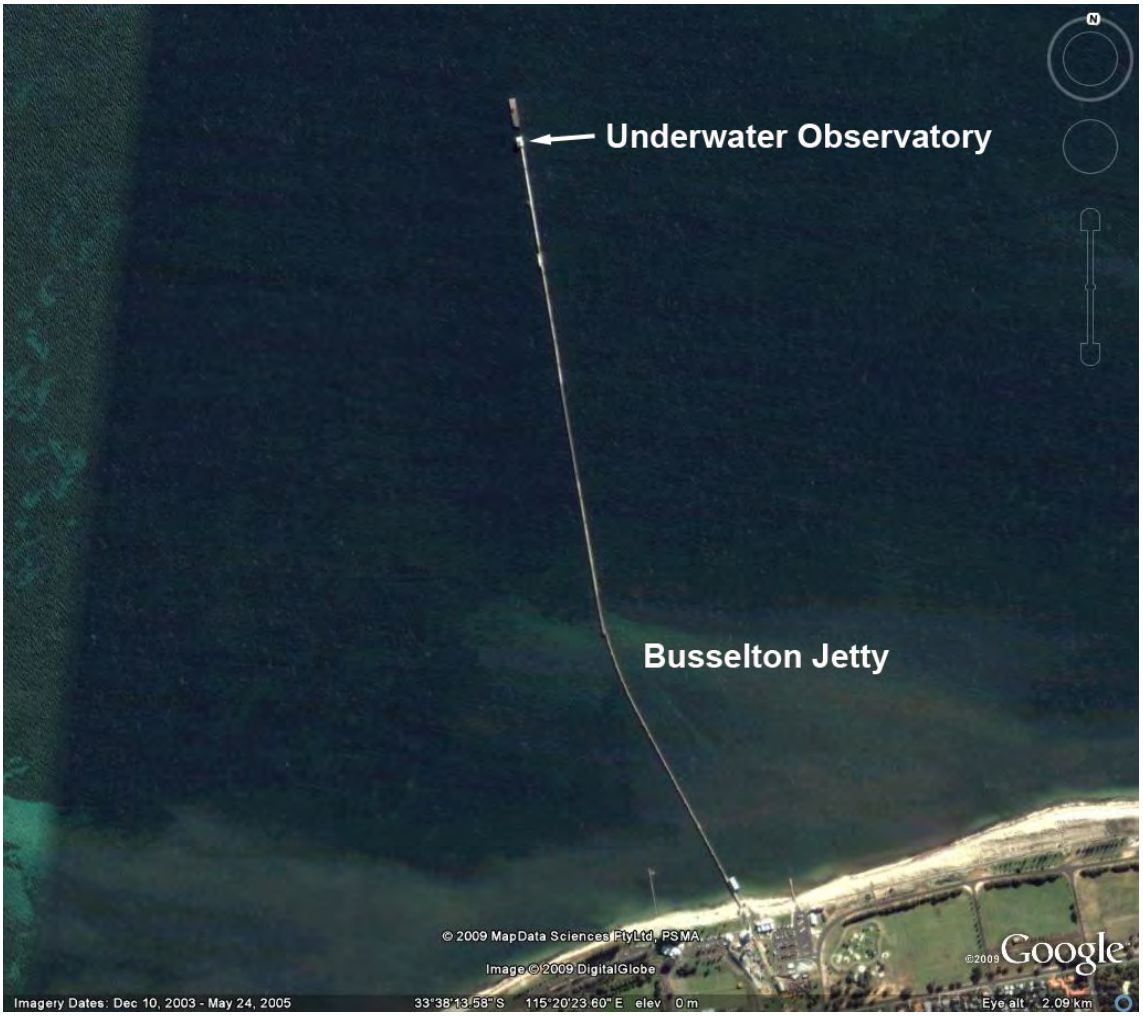

Figure 6-1 Busselton jetty, Busselton, WA. (Google Earth 2009)

Figure 6-2 Visitors inside the Underwater Observatory. (Photograph: R. Anderson, WA Museum)

Figure 6-3 The approximate position of the survey area adjacent to the Underwater Observatory, Busselton jetty. (Google Earth 2009)

Figure 6-4 Under water view of the seaward side of the Observatory and colonised wooden piles from the Busselton jetty. (Photograph: R. Anderson, WA Museum)

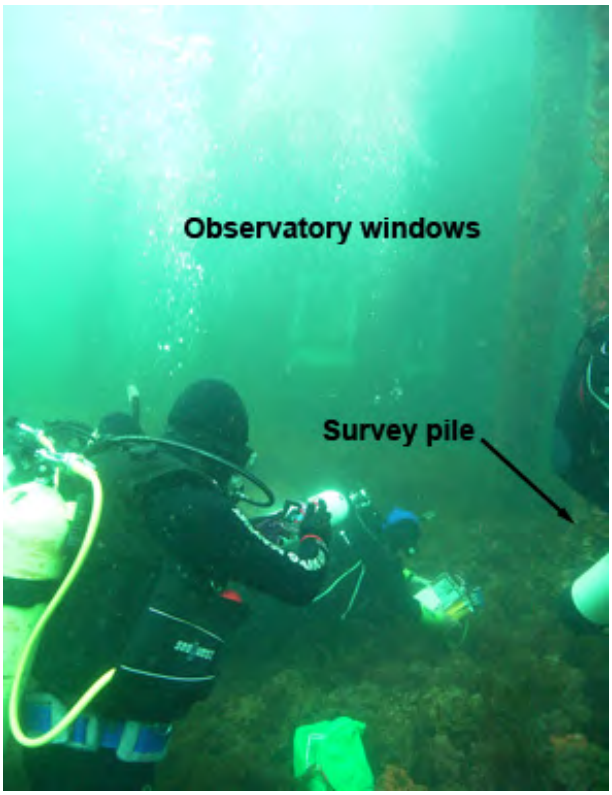

Figure 6-5 Survey pile approximately 10m north-east from the seaward side of the Observatory. (Photograph: R. Anderson, WA Museum)

Figure 6-6 Marine growth on historical wooden piles, Busselton jetty. (Photograph: R. Anderson, WA Museum)

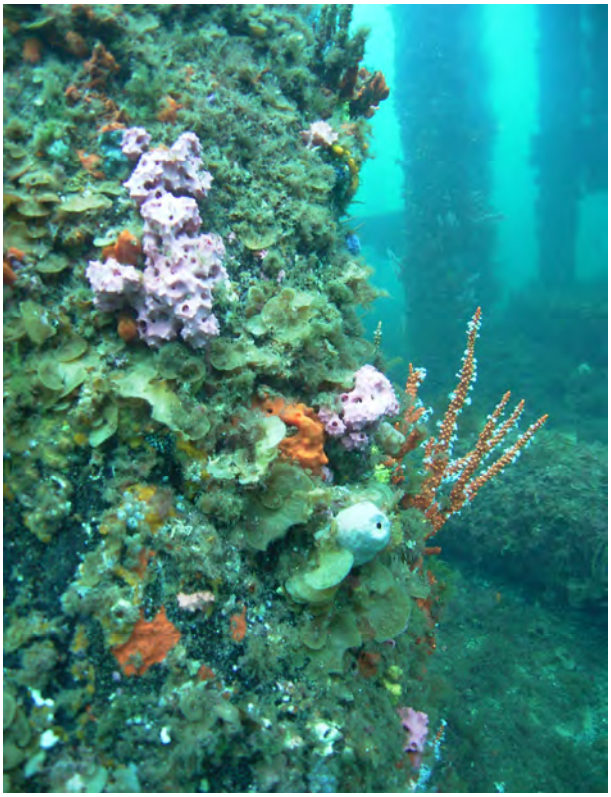

Figure 6-7 Marine growth on historical wooden piles, Busselton jetty. (Photograph: R. Anderson, WA Museum)

The Busselton jetty survey site was adjacent to the Underwater Observatory (33° 37.790´S; 115° 20.284´E), located approximately 1.8 kilometres from the shore-end of the jetty (Figs. 3-1 and 6-1). As discussed in chapter 3, construction of the Busselton jetty commenced in 1853, thus at the time of the survey, the jetty was 156 years old. However, due to continuous in-shore sediment accretion, causing the area to become too shallow for ship access, numerous extensions were added to the jetty from 1872, continuing until the final extension was completed in 1960.

The Underwater Observatory descends 8 metres from the seawater surface and can accommodate up to 40 visitors at one time. There are eleven viewing windows located at various levels within a 9.5-metre diameter observation chamber (Figs. 6-2 and 6-4). The approximate position of the survey area was about 10 metres north-east from the seaward side of the Underwater Observatory (Figs. 6-3 and 6-5).

The on-site conservation survey included physico-chemical measurements and visual observations of the seawater and sediment column, corrosion parameter measurements of an iron artefact and pH profiles, maximum water contents and wood identification of a wooden pile. The results of this survey are summarised below.

The seabed in the vicinity of the survey site was relatively level and comprised of loosely packed, very coarse-grained calcareous sand with little organic detritus on the sediment surface. The pH of the surface sediment was similar to that of the immediate water column, indicating mobile sediment and irregular packing of the coarse-grained sand, which allows the passage of seawater through the sediment. However, from the physico-chemical measurements and visual observations of the sediment core sample, the depth to stable sediment was approximately 7–9 centimetres and materials buried below this zero-E_h interface would be subjected to less deterioration than those artefacts present in the more oxidising, upper 7 centimetres of the sediment column.

Other than the heavily colonised jarrah jetty piles, there were very few historical artefacts observed in the survey area, with the exception of a large anchor and some iron bollards. The corrosion parameters measured on an iron bollard indicated that it was actively corroding, but the relatively thin concretion and corrosion layer would suggest that the bollard had not been subjected to this oxidising marine environment for an extended period of time. The pH profiles and the maximum water contents indicate that the survey pile, despite having some superficial marine worm damage, is in excellent condition and possesses a relatively thin degraded outer layer (<20 mm) overlying an extensively non-degraded inner core. Hence, based on the fact that the iron bollard and survey pile were in relatively good condition, it can be assumed safely that this section of the jetty is part of the more contemporary extensions carried out in the mid 1900s.

Date of inspection: 26 February 2009

Personnel

Vicki Richards (conservation scientist)
Jon Carpenter (on-site conservator)
Worrawit Hassapak (ALA fellow)
Chandraratne Wijamunige (ALA fellow)
Ross Anderson (photography)

Dive times for conservation staff are reproduced in Appendix A.

Weather and sea conditions

The weather was overcast in the early morning, but the cloud cover dissipated by mid morning, resulting in fine weather for the remainder of the day. There was a slight to moderate (10–15 knots) south-westerly wind in the morning increasing steadily as the day progressed (http://www.buoyweather.com). Sea conditions adjacent to the jetty were calm with minimal swell. There was no discernible current. The tide was semi-diurnal (Table 6-1) with the first high tide stand being approached during the survey period.

26 February 2009	
Height (m)	**Time**
0.35	4:27
0.68	11:16
0.48	16:03
0.72	20:18

Table 6-1 Tidal predictions for Bunbury, WA (http://www.dpi.wa.gov.au/imarine/19102.asp)

The temperature of the sea directly under the Underwater Observatory has been monitored hourly since February 2001 as part of an on-going research programme to monitor environmental conditions in the Busselton town jetty area. The temperature logger is mounted on a jetty pile five metres above the seabed. The results have shown the typical seasonal patterns in southern Geographe Bay: the average summer water temperature is 21.6°C in February/March, decreasing to 15.0°C in July for an annual range of 6.6°C (http://www.busseltonjetty.com.au). The water temperature measured during the February conservation survey was 22°C. There was no significant temperature gradient throughout the water column (0–8.5 m).

The through-water visibility was about 5–10 metres. The average pH of the seawater at the seabed surface (8 m) was 7.97±0.01 and the average redox potential was 0.214±0.009V, indicative of a typical open circulation, oxygenated saline environment. The salinity and dissolved oxygen content of the water column were not measured at the time of the survey.

Description

General observations

The Busselton jetty was built from jarrah wood in 1853 and extended numerous times between 1872 and 1960. The jetty was closed to commercial shipping in 1972 and faced demolition. However, with local community and Busselton shire support, the jetty was saved and partly restored with ongoing maintenance a priority. With the opening of the Interpretation Centre in 2001 and the Underwater Observatory in 2003, the Busselton jetty became one of the Southwest's premier tourist attractions. Geographe Bay is a relatively pristine marine embayment fed by the warm Leeuwin current. The mixing of this current with cooler Indian Ocean currents is responsible for the success of Busselton jetty as an artificial reef; the rich and abundant sealife that it supports makes it one of the top ten dive sites in WA.

An incredibly diverse array of tropical and sub-tropical species have been introduced into Geographe Bay. Sessile invertebrates, such as sponges, tunicates bryozoans and ascidians, flowering soft corals, especially Telesto corals, hydroids and algal

forms have colonised the jetty piles (Figs. 6-6 and 6-7). There was a large variety of higher vertebrates present on the site as well, with the team observing boxfish, buffalo bream, bulleyes, herring, hulafish, leatherjackets, morwongs, blackheaded pullers, samson fish, yellow tailed scads, sweep, trevally, wrasse and other fish species.

Geographe Bay has a temperate, Mediterranean type climate characterised by warm, dry summers and cool, wet winters (Walters, 1979). The annual rainfall is 800 millimetres with 85% of the rain falling between May and October (Fahrner & Pattiaratchi, 1995). There are a number of brooks, rivers, river drains and estuaries that discharge into Geographe Bay. Without measuring the salinity on the survey site, it is difficult to ascertain if there is any fresh water influence, however, it is likely that any such effect would be minimal during the summer season.

The jetty is aligned in a roughly north-south direction (Fig. 6-1) and has a gentle sloping bathymetry towards the north, with the depth to the seabed at the survey site about 8 metres. The survey site was relatively level, comprised of coarse grain calcareous sand with little organic detritus and epiphytes on the seabed surface. There are extensive seagrass beds throughout the bay, but there are no sea grass beds or reefs in close proximity to the survey site.

Degree of site exposure

The jetty piles were driven about 4 metres into the seabed and extended approximately 2–3 metres above the seawater surface. Other historical and contemporary materials were exposed on the seabed surface.

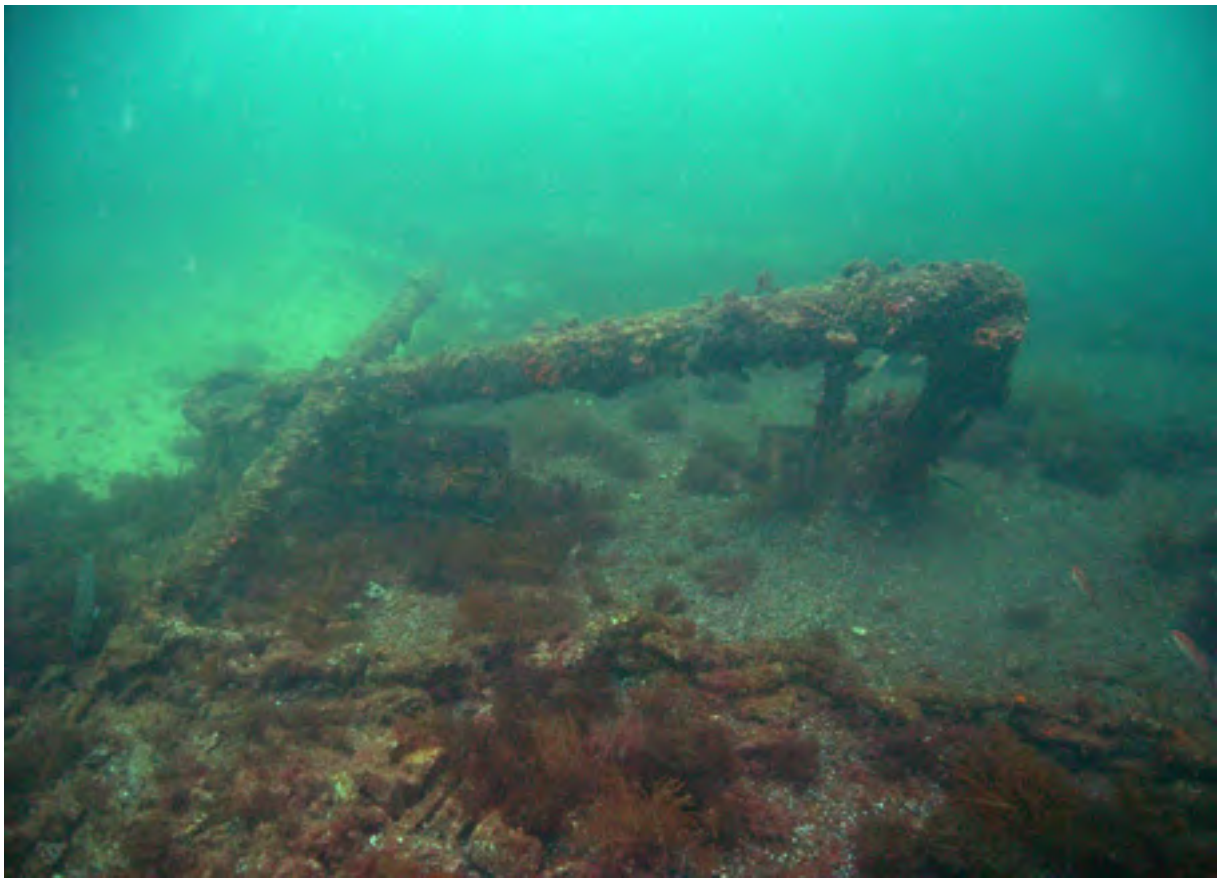

Figure 6-8 Anchor on the survey site, Busselton jetty. (Photograph: R. Anderson, WA Museum)

Seasonal exposure

The site appeared to be reasonably stable with no evidence of seasonal exposure at the time of the survey.

Human disturbance

The historical association of the jetty with the Busselton Township has resulted in an accumulation of cultural and modern material on the site. However, there were very few historical artefacts observed in the survey area, with the exception of a large anchor (Fig. 6-8) and some large iron bollards.

Conservation survey results: Metal survey

Ferrous Materials

Conservation staff measured the corrosion parameters of an iron bollard (Position 1: VR & JC), and then similar measurements were repeated by the ALA Fellows in an adjacent area (Position 2: WH & CW). The results are presented in Table 6-2.

Description	pH	Corrosion potential (rel. NHE) (V)	Depth of concretion + graphitisation (mm)	Water depth (m)
Bollard: Position 1 (VR & JC)	6.61	-0.357	7	7.9
Bollard: Position 2 (WH & CW)	7.20	-0.357	9	7.9

Table 6-2 Corrosion parameters of the iron bollard on the Busselton jetty site.

The concretion acts as a semi-permeable layer on the surface of the iron, effectively separating the anodic and cathodic sites and producing an acidic, iron and chloride rich microenvironment at the residual iron surface. Hence, the pH of the residual metal surface of actively corroding iron should decrease as corrosion proceeds. It is important to note that the surface pHs measured by both teams were different, although the corrosion potentials were the same. This is simply explained by the fact that the second team (ALA Fellows) was less experienced than the conservation staff and more seawater penetrated the drill hole, concomitantly increasing the final pH measurement recorded.

By plotting the measured voltages and the corresponding surface pH on the Pourbaix diagram for iron at 10^{-6}M in aerobic seawater at 25ºC, the thermodynamic stable state of the iron can be ascertained (Fig. 6-9). Both sets of measurements of the iron bollard on the Busselton jetty indicate that it was actively corroding. This would suggest that other ferrous materials, such as the anchor, would also be actively corroding. It is important to note that Pourbaix diagrams do not include kinetic information. They are only thermodynamic stability maps that indicate the corrosion mechanisms, but not the corrosion rate. However, they can be used as a general guide for interpretating corrosion data.

The iron bollard used in the corrosion survey was covered with thin concretion, lightly encrusted with secondary marine growth (Fig. 6-10). Iron is not biologically toxic and increases the growth rate of encrusting organisms. The relatively thin concretion and corrosion layer (7–9mm) suggest that the bollard has not been subjected to aggressive environmental conditions, although the corrosion parameters indicate that it is actively corroding. The smaller depth of penetration could also suggest that the bollard has not been exposed to this oxidising marine environment for an extended

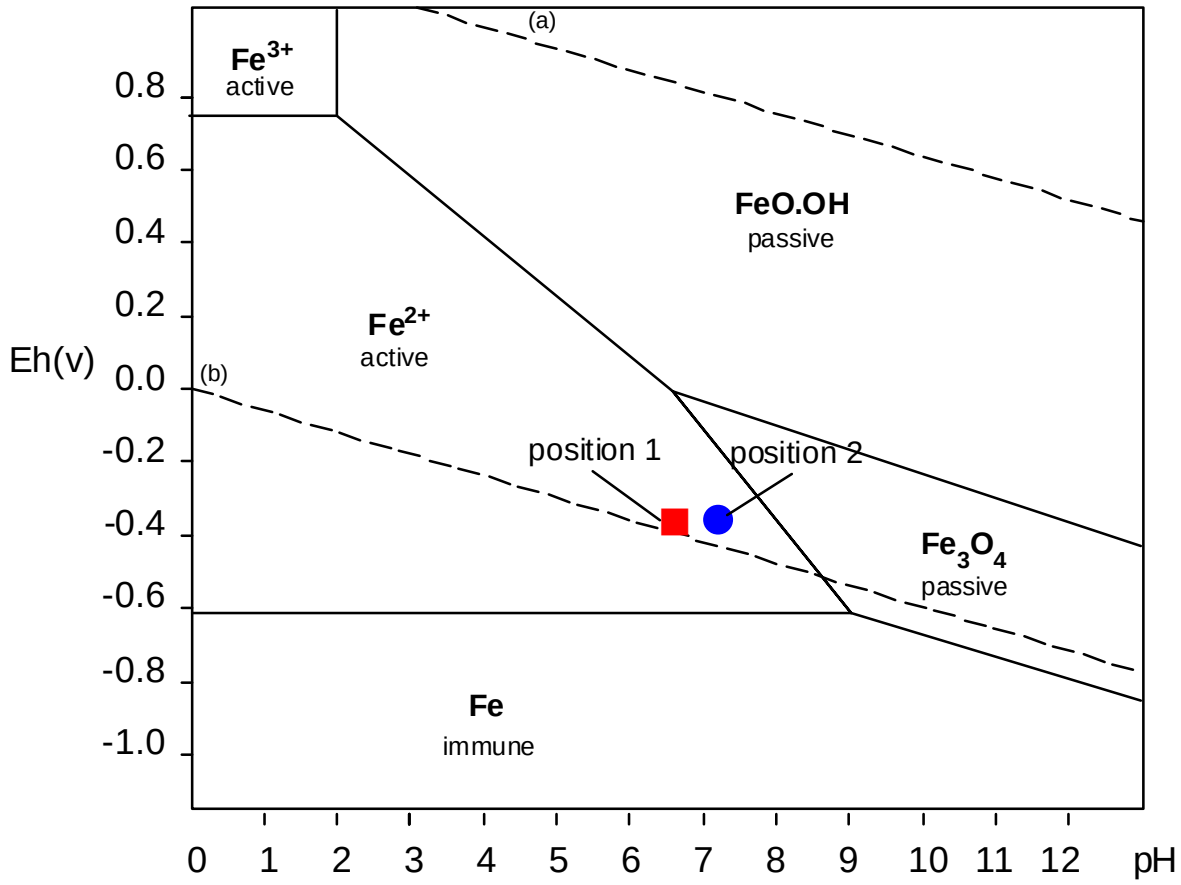

Figure 6-9 Pourbaix diagram for iron (10^{-6}M) in aerobic seawater at 25°C indicating the state of the iron bollard on the Busselton jetty site. (Diagram: V. Richards, WA Museum)

period of time and/or the metal is of a more contemporary composition, which may better inhibit corrosion.

The standard corrosion rate for isolated iron in aerobic seawater is 0.1 mmy^{-1} and the final extension to the jetty was completed in 1960. From this information, if the iron bollard is corroding at the standard rate, then the depth of corrosion should be about 5mm. Hence, based on the fact that the depth of penetration was about 7–9 millimetres, it could be safely assumed that this bollard is part of the more contemporary extensions.

Conservation survey results: Organic survey

Wood

The wooden jetty piles were heavily encrusted with sessile invertebrates, however, after removal of these marine organisms from the survey pile surface prior to the pH profile measurements, it was evident that the wood had been attacked, albeit only slightly, by teredo worms. The survey team obtained in-situ pH profiles of the survey pile at a height of 40cm above the seabed, and collected wood samples from the measured pile directly adjacent to the drill holes for species identification and

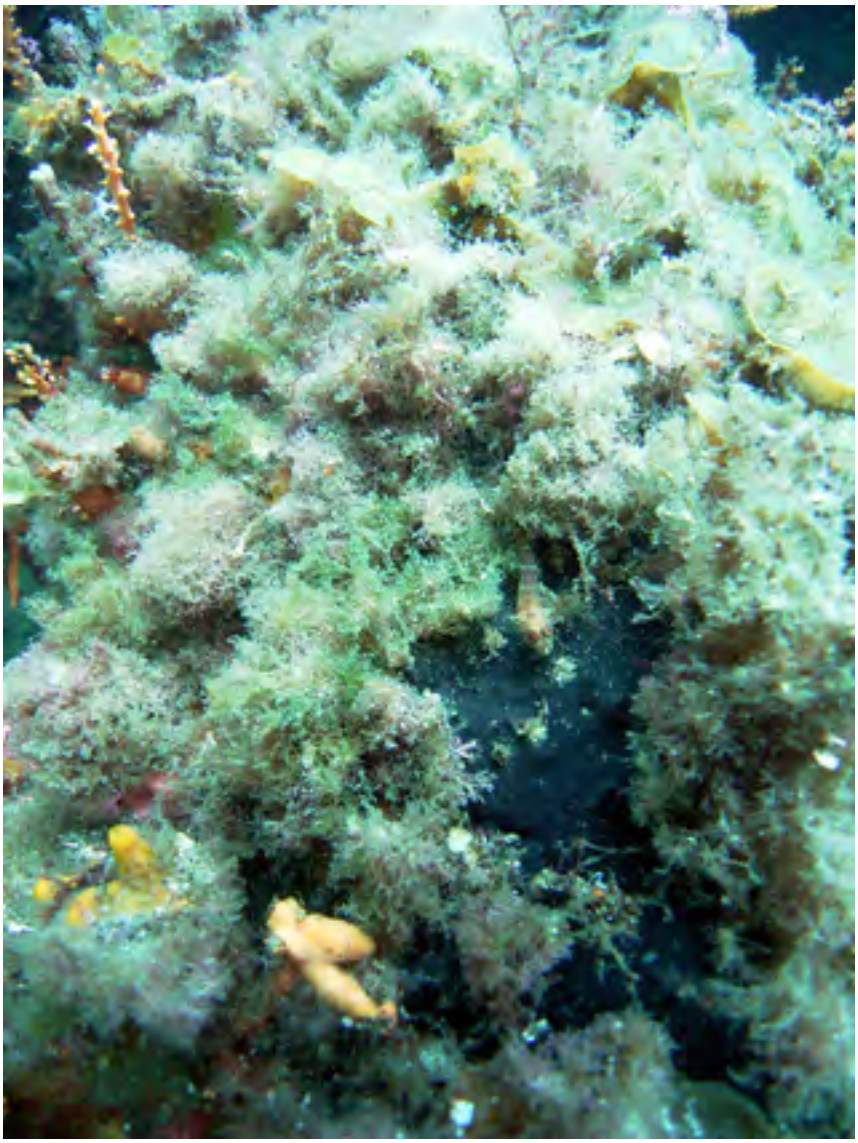

Figure 6-10 Iron bollard used for the corrosion survey, Busselton jetty. (Photograph: R. Anderson, WA Museum)

maximum water content (U_{max}) determination (Fig. 6-11). Again, the first pH profile was measured by conservation staff (Position 1: VR & JC) and an adjacent area subsequently measured by the ALA Fellows (Position 2: WH & CW). The results of the pH profiles are presented in Table 6-3 and shown diagrammatically in Figure 6-12.

Description	Depth of penetration (mm)	pH measurement
Survey pile: position 1 (VR & JC)	0	7.41
	8	7.35
	17	7.66
	29	6.11
Survey pile: position 2 (WH & CW)	3	7.97
	3	7.98
	13	7.25

Table 6-3 Results of the pH profiles on the survey pile from the Busselton jetty.

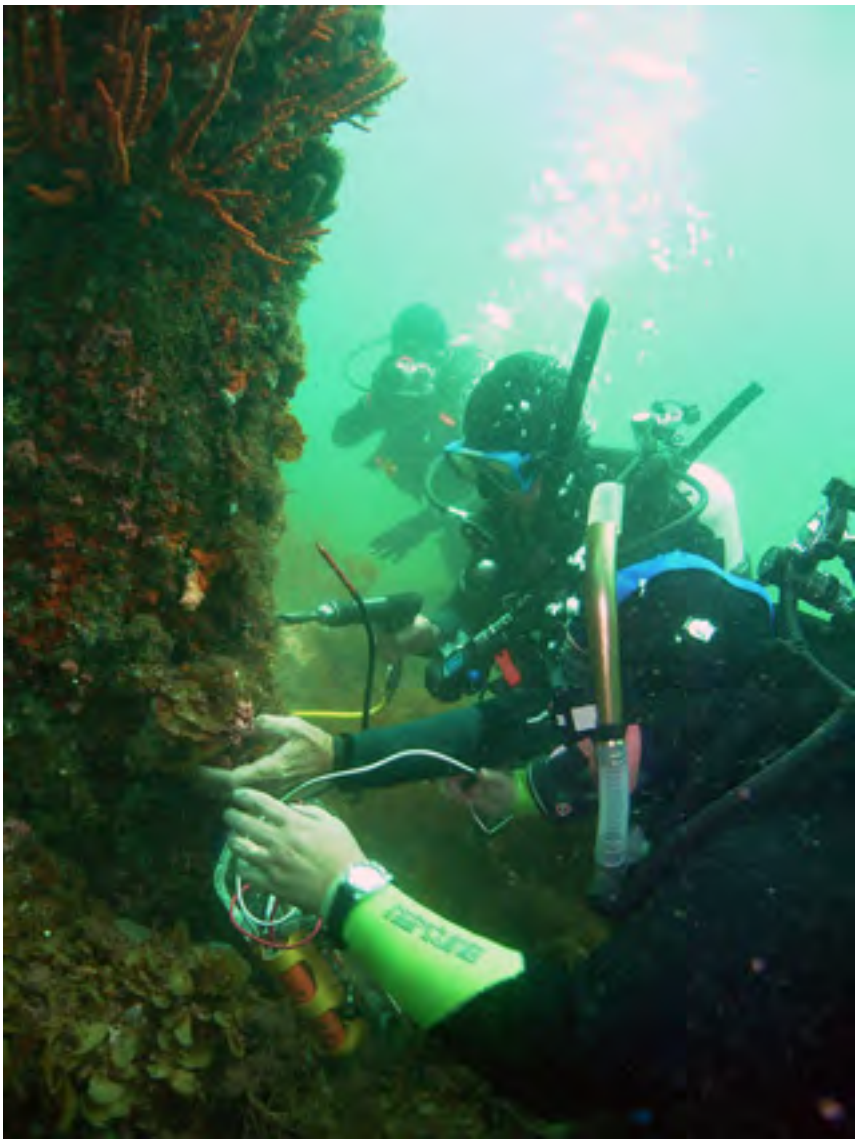

Figure 6-11 ALA fellows taking core samples from wooden pylons of the Busselton jetty. (Photograph: R. Anderson, WA Museum)

Wood is degraded in the marine environment by physical (water movement, sand impingement), chemical (chemical reactions in the wood and hydrolysis reactions with sea water) and biological (marine borers, fungi and bacteria) processes. Degradation commences on the exposed surface, but, under the right environmental conditions, will continue into the wood until it is totally destroyed. As the wood deteriorates, there is an increase in the accessibility and size of the pore spaces through which alkaline seawater can penetrate into the wood structure. Therefore, in general, the plots of pH versus depth of penetration follow a typical sigmoidal relationship. That is, the pH of the wood near the surface is high then as the depth into the timber increases there is a sharp and rapid decrease in pH that tends to plateau with increasing core depth. The higher pH measured on the wood surface, slightly more acidic than seawater, is indicative of the pH being controlled by the buffering capacity of the sea water. More importantly, this maximum pH denotes the area of greatest deterioration. Degradation occurs from the outer, more exposed areas in the initial instance. Hence, the normally acidic nature of the wood becomes progressively more alkaline with increasing degradation due to the inward diffusion of seawater.

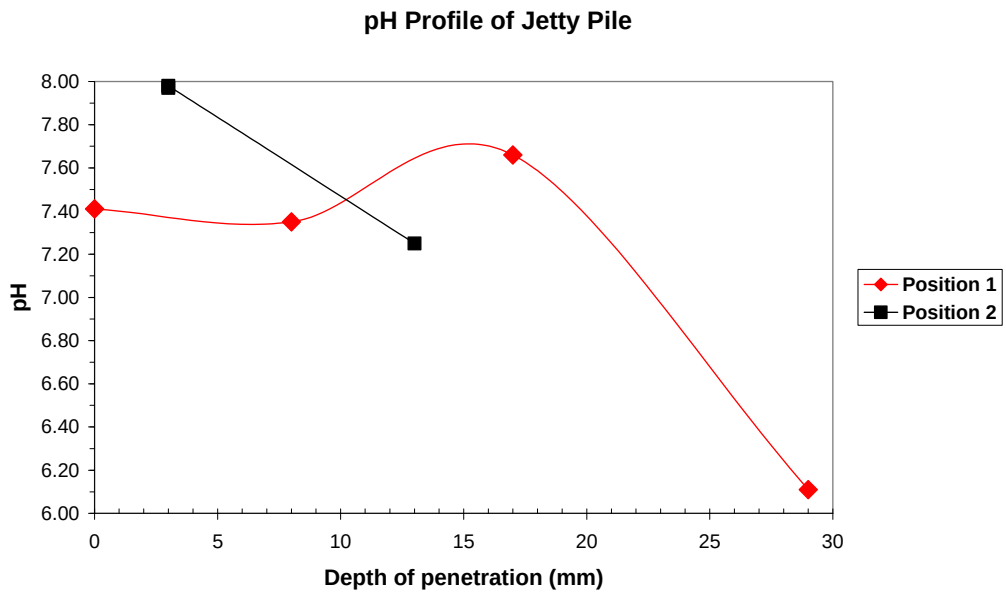

Figure 6-12 pH profiles of the wooden pile measured on the Busselton jetty. (Graph: V. Richards, WA Museum)

Typically, pH decreases rapidly as the core depth increases, indicating a decrease in the extent of degradation. The pH will eventually reach a minimum that denotes the area of least deterioration where the wood is least waterlogged. The overall decrease in pH of the wood core is an indication of the inherent acidity of wood. The innermost wood is still waterlogged, albeit to a lesser extent than the outer surfaces, therefore the pH will be more alkaline than the standard pH of seasoned, modern, non-degraded wood of the same species.

The pH profiles for the wooden pile on the Busselton jetty are typical of wood with a relatively thin outer layer (<20 mm) of degraded wood overlying an extensive non-degraded inner core in excellent condition. Hence, if the estimated diameter of the survey pile is about 300 millimetres, then this pile has less than 10% total deterioration. This may suggest that the pile has not been exposed to the marine environment for an extended period of time and that it is likely to be part of the more recent extensions to the jetty in the mid 1900s.

One important point to note is the second pH profile (position 2) measured by the ALA fellows was outside the typically acceptable reproducibility range of 5% of the mean pH value for each depth interval. This highlights the fact that, in order to obtain reasonably consistent results, the operators must have extensive experience in this measurement procedure.

Maximum moisture content is an easily measured quantity which may be related to specific gravity and thus to the extent of degradation of the wood. It is universally used as an indicator of wood deterioration and is the basis of a classification scheme. Waterlogged timbers may be classified as follows: Class I (>400%)—an extremely degraded, extensive outer surface with very little solid core; Class II (185–400%)—a degraded outer surface with a thin, partially degraded area and a considerably larger solid core; Class III (<185%)—a very thin degraded outer surface layer overlying an extensive, non-degraded core (Pearson 1987).

Core sample 8, collected adjacent to pH profile measurement position 1, was 21 millimetres thick and possessed a very soft degraded surface (3 mm), beyond which

the wood was in relatively good condition, although there was evidence of teredo damage throughout the core's entire length. Core sample 9, collected near measurement position 2, was 12 millimetres thick and exhibited a less degraded surface (2 mm) than the first sample, with no evidence of biological attack. The maximum water contents of these wood core samples were 86% and 80%, respectively, indicating that the wooden pile is Class III, which is in good agreement with the results obtained from the pH profiles.

The pile was tentatively identified as a Eucalyptus species, most probably jarrah (pers. comm. Godfrey 4 May 2009). Eucalypt species are often used as jetty piles because of their durability in the marine environment, especially in the cooler waters of the southwest coast of WA.

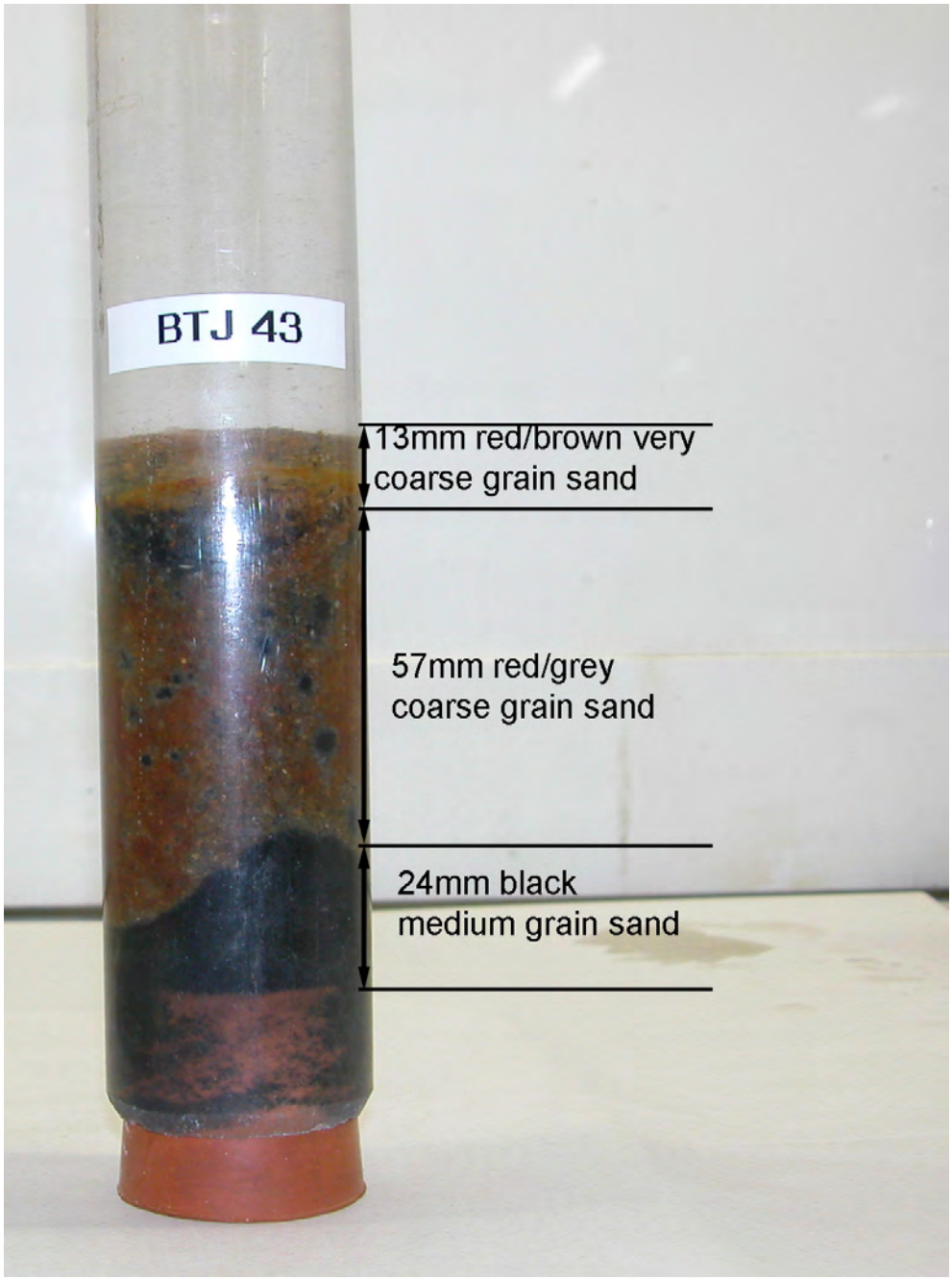

Figure 6-13 Sediment core sample (BTJ 43) from the Busselton jetty survey site. (Photograph: V. Richards, WA Museum)

Sediment

The pH of the sediment at a depth of 30 millimetres was 7.79. This pH, indicative of the surface sediment, is slightly more acidic than the surrounding aerobic seawater (7.97_{av}), which is to be expected due to the oxidation of organic detritus by aerobic and facultative bacteria producing acidic metabolites and by-products. However, this pH difference is not particularly significant and there was very little organic detritus observed on the seabed, which could explain the relatively higher pH of the surface sediment due to less aerobic oxidation of organic material. In addition, due to the more open packing of the coarser grained surface sand, seawater could have more easily penetrated the surface layers, effectively increasing the pH of the interstitial water to a greater depth than would normally be expected for sediments of finer particle sizes.

The redox potential of the sediment at 90 millimetres was -0.058V, indicating that the sediment is neither oxidising nor reducing in nature at this depth. These redox potential and the pH measurements indicate that the zero-E_h interface lies at a depth of about 8–9 centimetres under the seawater/sediment interface. This implies that the overlying sediment above this depth is more alkaline and oxidising in nature.

One sediment core sample was collected approximately 10 metres east of the survey pile at a water depth of 8.2 metres. The total length of the core sample (BTJ 43) was only 94 millimetres because the coarser grain sand made it difficult to penetrate the sediment column to the full extent of the polycarbonate corer (300 mm). The core sample revealed a thin layer (13 mm) of red/brown very coarse-grained sand overlying 57 millimetres of red/grey coarse-grained sand. Below this depth (>70 mm) the particle size of the sediment decreased and possessed the typical grey to black discolouration, indicating an anaerobic environment that extended to the base of the core sample (70–94 mm) (Fig. 6-13). This implies that the depth to stable sediment is approximately 7–8 centimetres, which supports the electrochemical measurements that indicated that the zero-E_h interface also occurred at about this depth. It is important to note that when the sediment was first recovered, the upper sediment layers were white to grey in colour, but slowly turned red/brown over a period of a few weeks with the oxidation of the reduced iron species in the sediment. Hence, in order to avoid possible misinterpretation of the sediment data, the core samples should be photographed as soon as possible after recovery.

The results of the sediment survey indicate that the sand in the upper 8 centimetres of the sediment column is relatively coarse, well oxygenated and thus, more oxidising in nature. After this depth, however, the particle size decreases and the sediment becomes more stable, anoxic and therefore, more reducing in nature. The conservation implications of these observations is that artefacts in the upper sediment layers would be subject to more deterioration than those materials buried at depths greater than about 10 centimetres in this survey area.

Discussion

The Busselton jetty site is an open circulation, oxidising marine environment, typical of the Geographe Bay area. The jetty has a gentle sloping bathymetry towards the north with the depth to the seabed at the survey site about 8m. The seabed in the vicinity of the survey site was relatively level and comprised of loosely packed, very coarse-grained calcareous sand with little organic detritus on the sediment surface. The pH of the surface sediment was similar to that of the immediate water column, further indicative of mobile sediment and irregular packing of the coarse grained sand, allowing the passage of seawater through the sediment. However, physico-chemical

measurements and visual observations of the sediment core sample indicate that the depth to stable sediment was approximately 7–9 centimetres and materials buried below this zero-E_h interface would be subjected to less deterioration than those artefacts present in the more oxidising, upper 7 centimetres of the sediment column.

Other than the heavily colonised jarrah jetty piles, a large anchor and some iron bollards were the only historical artefacts observed in the survey area. The corrosion parameters measured on an iron bollard indicate that it is actively corroding, but the relatively thin concretion and corrosion layer suggest that the bollard has not been subjected to this oxidising marine environment for an extended period of time. The pH profiles and the maximum water contents indicated that the survey pile, despite having some superficial marine worm damage, is in excellent condition. It possesses a relatively thin degraded outer layer (<20 mm) overlying an extensively non-degraded inner core. Based on the conditions of the iron bollard and survey pile, it can be safely assumed that this section of the jetty is part of the more contemporary extensions carried out in the mid 1900s.

7. QUINDALUP JETTY: ON-SITE CONSERVATION SURVEY REPORT

BY Vicki Richards

Site location and survey

Following the archaeological and conservation survey of the Busselton jetty, the ALA Fellows assisted in a similar-type assessment of the Quindalup jetty remains.

The Quindalup jetty remains are located in Geographe Bay, a wide, open, north facing embayment situated between Cape Bouvard and Cape Naturaliste on the south-west coast of Western Australia. It is a relatively protected and shallow bay. Water movement in Geographe Bay is mainly wind driven. Geographe Bay has a relatively short flushing period of 3–15 days dependent on the wind direction and is, therefore, a well-mixed system.

The contemporary Quindalup jetty is about 30 metres in length (Figs. 7-1 and 7-2). The original Quindalup jetty remains lie approximately 100 metres offshore and about 100 metres north-west from the seaward end of the contemporary jetty (Figs. 7-1 and 7-2) in about 2.5 metres of water.

Figure 7-1 Quindalup jetty remains, Quindalup, WA (Google Earth 2009).

Figure 7-2 The Quindalup jetty site, Quindalup, WA. (Photograph: P. Baker, WA Museum)

As discussed in Chapter 3, the Quindalup jetty was constructed in 1855 (Garratt, 1993b), and thus it is possible that some of the jetty remains, especially the jetty piles, were 154 years old at the time of the 2009 survey.

The exposed jetty remains are aligned on a roughly north-south transit, covering an area approximately 10 metres^2 and consisting of a few iron wheels and jetty pile remains and an iron railway track. The on-site conservation survey included physico-chemical measurements and visual observations of the seawater and sediment column, corrosion parameter measurements of the iron artefacts on-site and pH profiles, maximum water contents and species identification of some wooden jetty pile remains.

The surrounding shoreline near the Quindalup jetty has a gentle sloping bathymetry towards the north. The seabed in the survey area is relatively level and comprised of fine-grained calcareous sand with little organic detritus and epiphytes evident on the seabed surface, with the exception of dead seagrass fronds. There are extensive seagrass beds surrounding the survey area, however there was some scouring of the seagrass in close proximity to the exposed iron wheels, probably caused by the contemporary mooring located on-site.

The sediment survey indicates that the sand in the upper 10 centimetres of the sediment column is fine-grained, relatively oxygenated and, thus, more oxidising in nature, containing appreciable quantities of organic material to support bacterial activity. However, beyond this depth the sediment became more stable, less oxygenated and, therefore, more reducing in nature with considerably less organic content. The conservation implication of these observations is that artefacts in the

upper sediment layers would be subjected to more deterioration than those materials buried at depths greater than about 10 centimetres on this site.

The corrosion survey indicates that all ferrous artefacts on the Quindalup jetty site are actively corroding; however the buried iron artefacts are in better condition than those materials constantly exposed to the aerobic marine environment. The corrosion survey of the exposed iron bogey suggests that it was part of the original Quindalup jetty and has been exposed for a considerable period of time (Fig. 7-3). There is also some evidence of recent exposure of the iron track, indicating that some sediment movement does occur on the site, however, the overall amount of sediment movement is minimal.

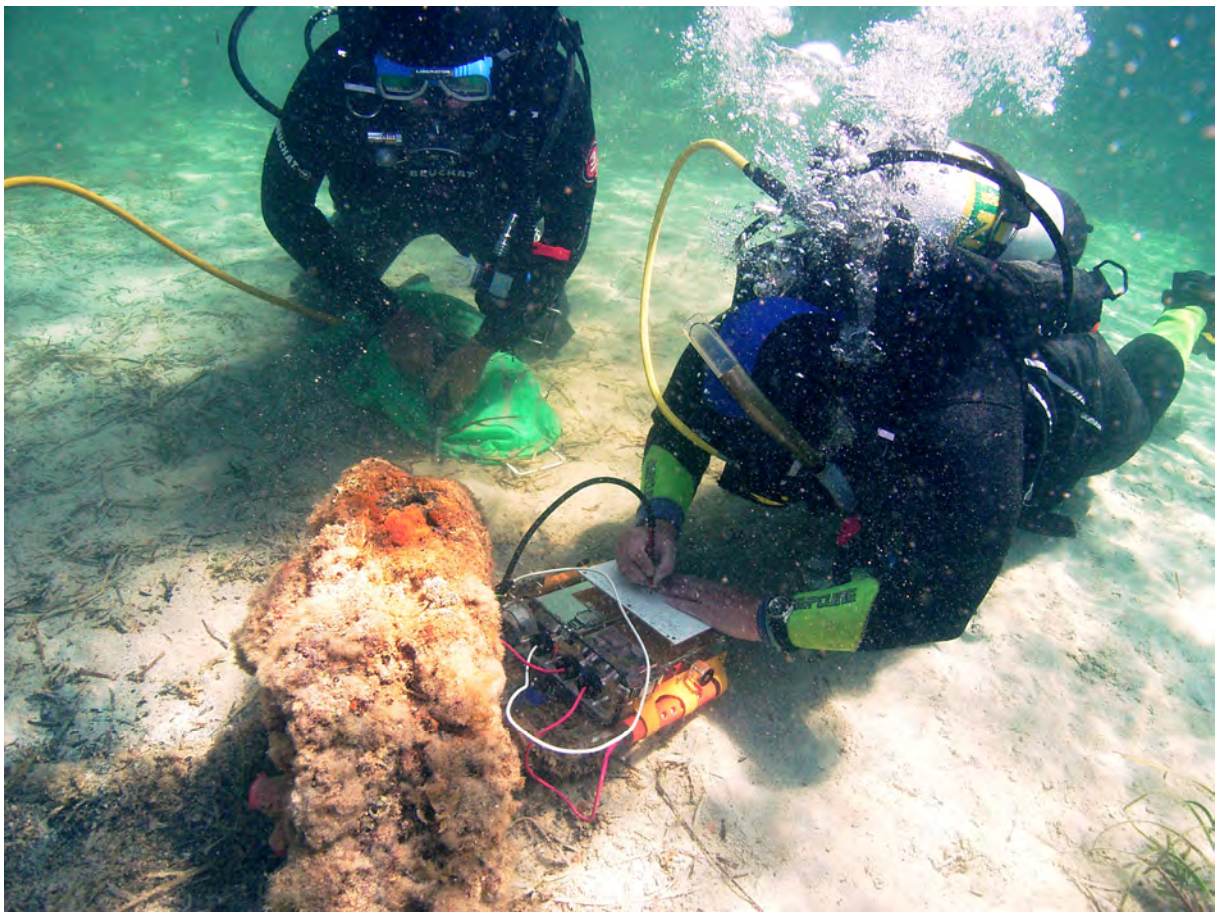

Figure 7-3 Conservation staff measuring corrosion parameters on an iron wheel on the Quindalup jetty, WA. (photograph: P. Baker, WA Museum)

Exposed jetty pile remains are covered with algal mats, with very few higher marine organisms evident on the surfaces, but exhibit extensive marine borer damage. The pH profiles for the exposed Jetty Pile 1 and the buried jetty pile are typical of wood with a relatively thin outer layer (<20 mm) of extensively degraded wood overlying a less degraded inner core. However, the more acidic pH measurements noted for the buried jetty pile after a depth of about 50 mm indicate that the inner region of this pile is in better condition than the exposed pile. This is not unexpected, as it is well known that wood recovered from deoxygenated environments is usually better preserved than wood exposed to an aerobic environment, because the wood is largely protected from ongoing extensive physical and biological deterioration.

Date of inspection: 26 February 2009

Personnel

Vicki Richards (conservation scientist)
Jon Carpenter (on-site conservator)
Worrawit Hassapak (ALA fellow)
Chandraratne Wijamunige (ALA fellow)
Ross Anderson (archaeologist)
Wendy van Duivenvoorde (archaeologist)
Patrick Baker (photographer)

Dive times for conservation staff are reproduced in Appendix B.

Weather and sea conditions

The survey weather was fine, with a slight to moderate (10–15 knots) south-westerly wind in the morning increasing steadily as the day progressed (http://www.buoyweather.com). Sea conditions adjacent to the jetty were calm with minimal swell. There was no discernible current. The tide was semi-diurnal (Table 7-1) with the first high tide stand (0.95 m @ 11:37) being approached during the survey period.

27 February 2009	
Height (m)	**Time**
0.60	4:45
0.95	11:37
0.69	16:56
0.86	23:03

Table 7-1 Tidal predictions for Bunbury, WA. (http://www.dpi.wa.gov.au/imarine/19102.asp)

The through-water visibility was about 5–10 metres. The average pH of the seawater at the seabed surface (2.4 m) was 8.34 ± 0.01 and the redox potential was 0.164V. The water temperature measured at the seabed surface (2.4 m) was 22°C. The temperature, salinity and dissolved oxygen content (compensated for salinity) of the water column was measured at 0.5 metres intervals directly adjacent to the seaward end of the contemporary jetty, approximately 100 metres southeast of the historic jetty site. The results are shown in Table 7-2.

Water depth (m)	Dissolved oxygen (ppm(S))	Salinity (ppK)	Temperature (°C)
0.0	5.76	37.4	21.9
0.5	5.71	37.4	21.9
1.0	5.59	37.4	21.9
1.5	5.52	37.4	21.9
average	5.65 ± 0.11	37.4 ± 0.0	21.9 ± 0.0

Table 7-2 Temperature, salinity and dissolved oxygen content of the water column on the Quindalup jetty site.

The temperature of the sea under the seaward end of the Busselton jetty has been monitored hourly since February 2001 as part of an on-going research programme to monitor environmental conditions in the Busselton town jetty area. The results have shown the typical seasonal patterns in southern Geographe Bay. The average

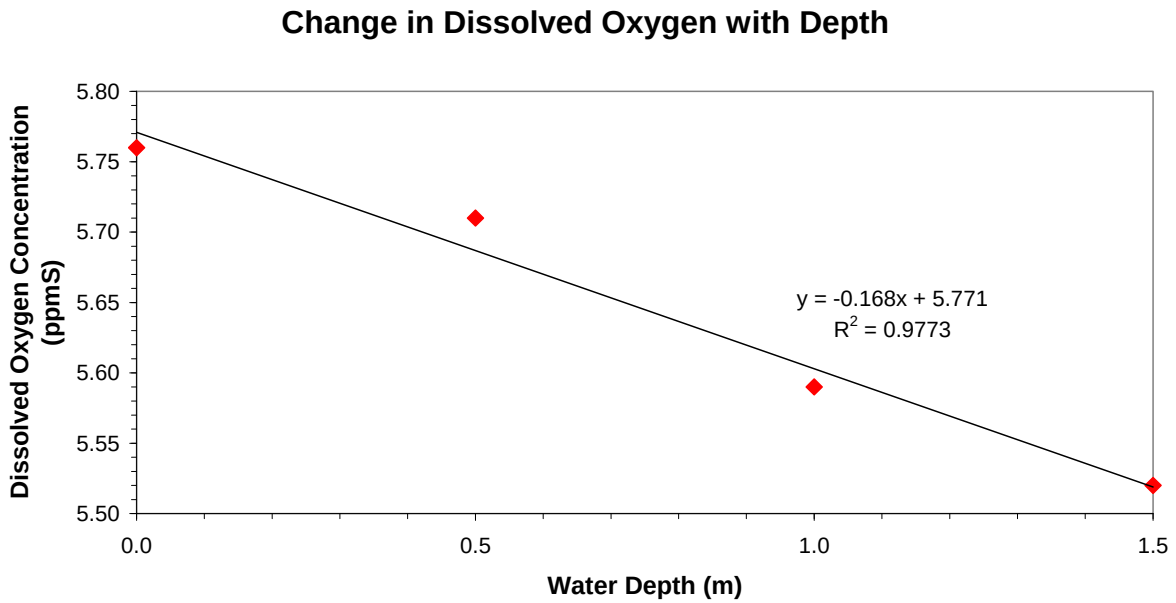

Figure 7-4 Change in dissolved oxygen concentration with increasing water depth on the Quindalup jetty site. (Graph: V. Richards, WA Museum)

summer water temperature is 21.6°C in February/March, decreasing to 15.0°C in July, for an annual range of 6.6°C (http://www.busseltonjetty.com.au). The average water temperature measured during the February conservation survey on the Quindalup jetty remains was 21.9 ± 0.0°C, which is in good agreement with the average summer water temperature (21.6°C) measured at the Busselton jetty, 18km south of Quindalup township. There was no significant temperature gradient through the water column (0–1.5 m).

The average salinity of the water column on-site was 37.4 ± 0.0ppK. There was no significant change in salinity with depth. The usual salinity range for the open ocean is 32–37ppK. The average dissolved oxygen concentration was 5.65 ± 0.11ppm. The change in dissolved oxygen concentration with increasing water depth is shown graphically in Figure 7-4. The dissolved oxygen concentration of the water column on the Quindalup jetty site decreased, albeit only slightly, with increasing water depth. Factors contributing to this trend are decreasing water movement, which leads to less oxygen exchange with the atmosphere and decreasing photosynthetic activity due to less light penetration, with increasing water depth. However the overall decrease in dissolved oxygen content is relatively insignificant over this small depth range, so the usual beneficial effects on material degradation would be minimal. This general decreasing trend and the other physico-chemical measurements outlined above are typical for an open circulation, well-oxygenated marine environment.

Description

General observations

Constructed in 1855 (Garratt 1993b), it is possible that some of the jetty remains, especially the jetty piles, were 154 years old at the time of the survey.

The exposed jetty remains, comprised of a few iron wheels and jetty pile remains (Fig. 7-5) and an iron railway track (Fig. 7-6), are aligned on a roughly north-south transect spread over an area approximately 10 metres^2 and about 2.5 metres deep.

Figure 7-5 Two iron wheels and the remains of one jetty pile. (Photograph: P. Baker, WA Museum)

Figure 7-6 The remains of an iron track. (Photograph: P. Baker, WA Museum)

The exposed concreted surfaces of the iron structures were sparsely covered with sessile marine organisms including bryozoans, sponges, ascidians and tunicates. In less concentrated areas of growth, algal forms were present (Fig. 7-7). Exposed jetty pile remains were covered with algal mats, with very few higher marine organisms evident on the surfaces, but exhibited extensive marine borer damage (Fig. 7-8).

The surrounding shoreline has a gentle sloping bathymetry towards the north. The survey area was relatively level, comprising of medium to fine grain calcareous sand with little organic detritus and epiphytes evident on the seabed surface, with the exception of dead seagrass fronds (Fig. 7-9). There are extensive seagrass beds surrounding the survey area (Figs. 7-5 and 7-6), however, it appears that there has been some scouring of the seagrass in close proximity to the remains, especially in the area where the iron wheels were situated (Fig. 7-10).

Geographe Bay has a temperate, Mediterranean-type climate characterised by warm, dry summers and cool, wet winters (Walters, 1979). The annual rainfall is 800mm, with 85% of the rain falling between May and October (Fahrner & Pattiaratchi, 1995: 3–12). There are a number of brooks, rivers, river drains and estuaries that discharge into Geographe Bay. However, based on the salinity measurements taken near the survey site (Table 7-2), any fresh water influence is negligible, as would be expected during the summer months.

Degree of site exposure

The most exposed artefacts were the partially buried iron wheels rising about 0.3 metre above the sediment on the north end of the site (Fig. 7-5). One jetty pile only just protruded through the sediment surface, whilst another jetty pile lay horizontally

on the seabed. Active marine borer damage was observed on all piles (Fig. 7-5). The iron track was also exposed in parts, in some places lying directly on the sediment surface (Fig. 7-6) while elsewhere lying buried just beneath the sediment surface. One iron wheel was almost totally buried with only a very small portion exposed, as evident from the seaweed and algal growth on the very top surface (Fig. 7-11).

Figure 7-7 Concreted surfaces of an iron railway wheel. (Photograph: P. Baker, WA Museum)

Figure 7-8 Degradation of a jetty pile by marine borers. (Photograph: P. Baker, WA Museum)

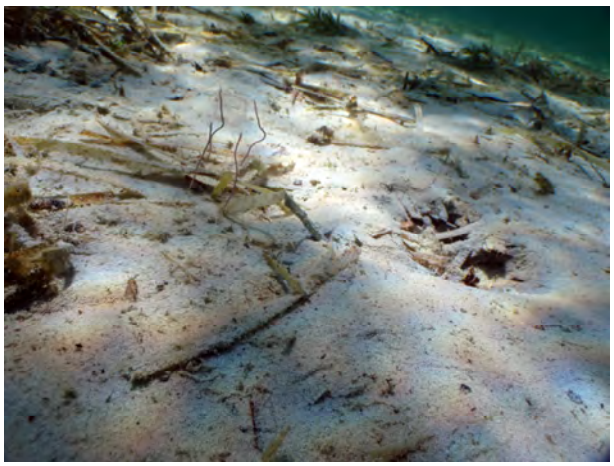

Figure 7-9 Survey area seabed with dead seagrass. (Photograph: P. Baker, WA Museum)

Figure 7-10 Scouring of the seagrass around the iron wheels. (Photograph: P. Baker, WA Museum)

Seasonal exposure

A jetty pile buried to a depth of about 20 centimetres was excavated just north-east of the pair of railway wheels. There was evidence of previous biological deterioration by marine borers, but it is impossible to determine when this degradation occurred (Fig. 7-12). More importantly, the concretion and the extent of biological growth on the exposed parts of the iron wheels suggest that these artefacts have been exposed to an aerobic marine environment for a considerable period of time, and there was no evidence of seasonal reburial/exposure cycles at the sediment/seawater interface. In addition, the rod connecting the two wheels was buried just under the sediment surface and there was no evidence of previous exposure to an aerobic marine environment. Furthermore excavation of the almost totally buried iron wheel revealed the typical black, dense concretion common to anaerobically corroded ferrous

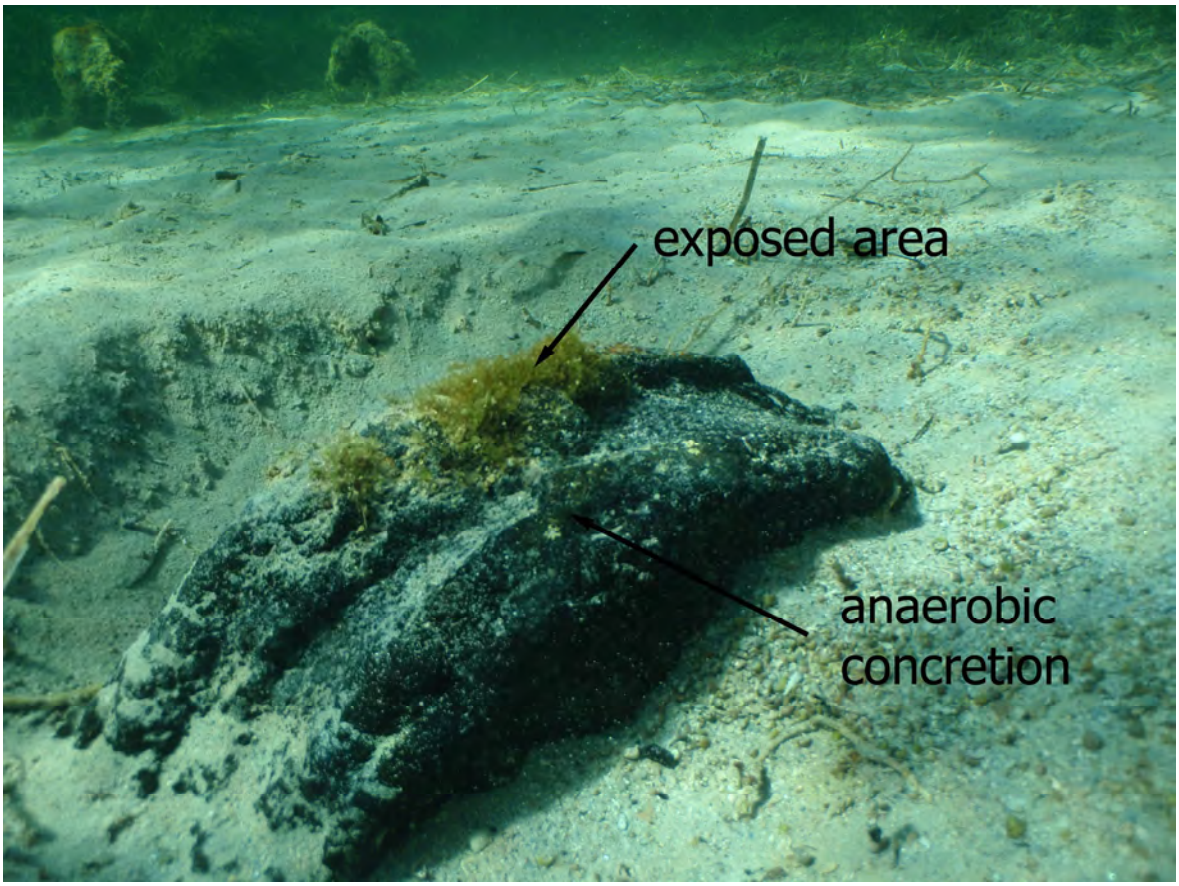

Figure 7-11 Buried iron wheel. (Photograph: P. Baker, WA Museum)

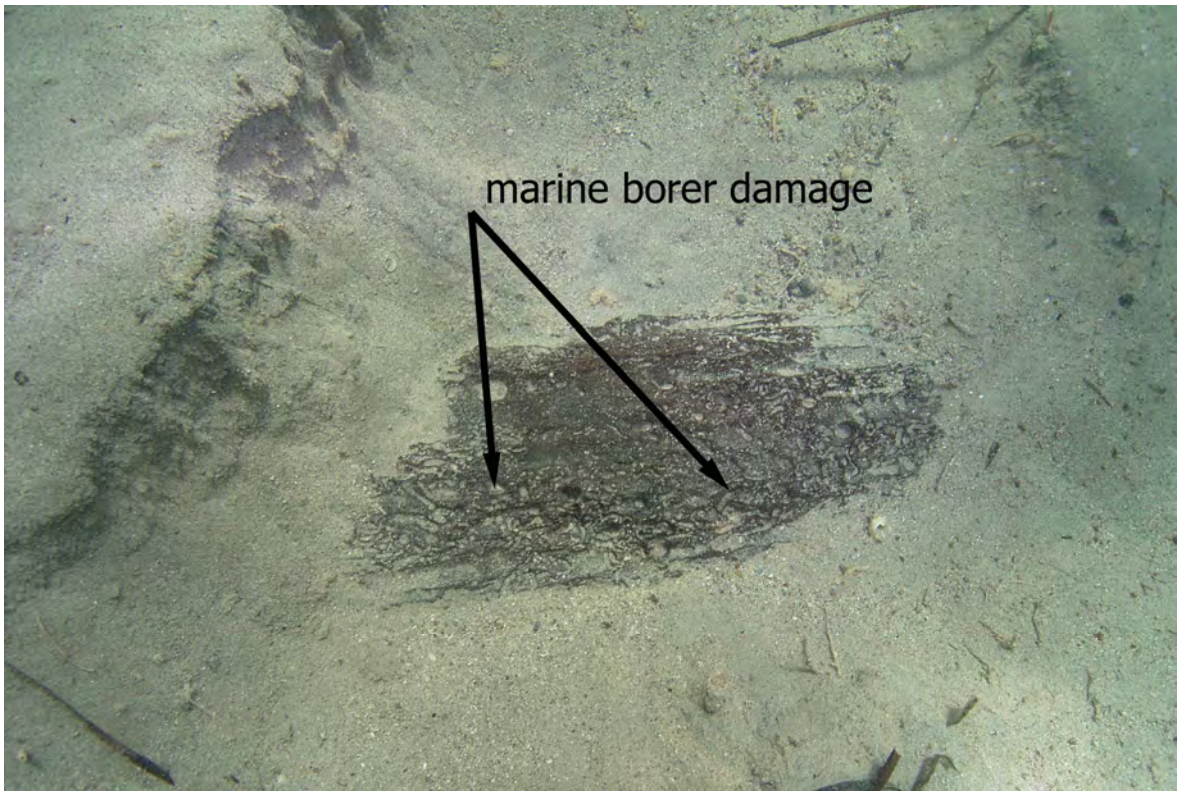

Figure 7-12 Buried jetty pile remains with evidence of previous marine borer damage. (Photograph: P. Baker, WA Museum)

Figure 7-13 Mooring post with chain located on the Quindalup jetty site. (Photograph: P. Baker, WA Museum)

materials, with no evidence of any past exposure to a more oxygenated environment (Fig. 7-11). Alternatively, on closer inspection of the exposed sections of railway track, the concretion was thin and quite dense with very little secondary marine growth, suggesting that the track had been only recently exposed. However, the extent of exposure was only slight as the seaward end of the track remained buried immediately below the sediment surface. Hence, at the time of the survey, the site appeared to be reasonably stable with little evidence of seasonal exposure.

Human disturbance

There is a mooring post and chain located on-site (Fig. 7-13) that may be connected to some buried historic structure, but without excavation this was impossible to ascertain. More importantly, it is likely that the chain is responsible for the extensive scouring and demise of the seagrass surrounding the exposed iron wheels. The loss of protection afforded by the seagrass beds could have caused increased corrosion of these artefacts by increasing the physical damage caused by water and sand impingement and by increasing the availability of dissolved oxygen at the concreted iron surfaces.

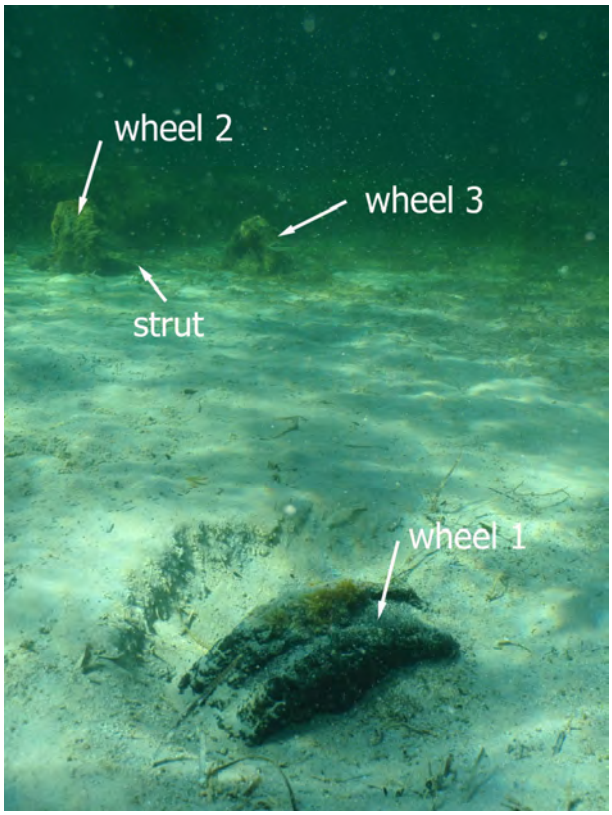

Figure 7-14 Positions of the iron wheels measured on the Quindalup jetty site. (Photograph: P. Baker, WA Museum)

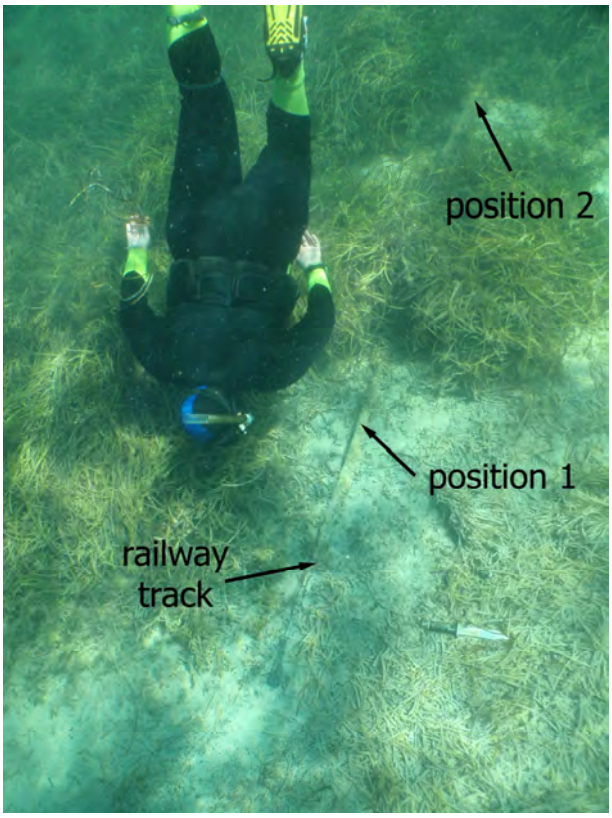

Figure 7-15 Measurement positions on the exposed sections of the railway track. (Photograph: P. Baker, WA Museum)

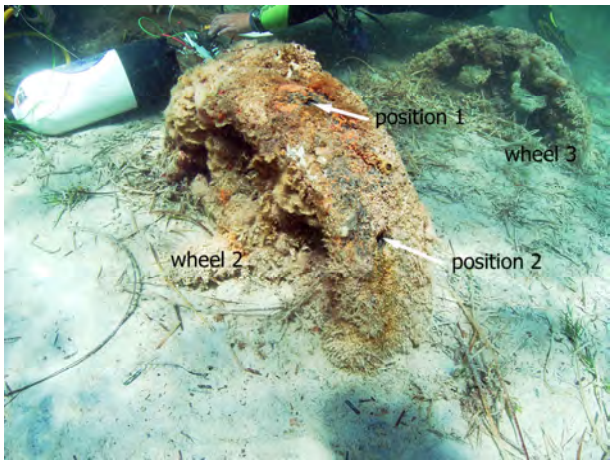

Figure 7-16 Positions of the corrosion measurements on wheel 2. (Photograph: P. Baker, WA Museum)

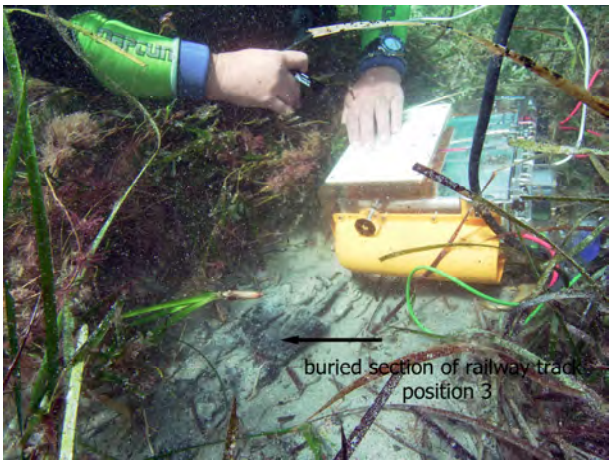

Figure 7-17 Measurement position on the buried section of the railway track. (Photograph: P. Baker, WA Museum)

Conservation survey results: Metal survey

Ferrous materials

The corrosion parameters of the three iron wheels and the iron railway track were measured and the measurement positions are shown in Figures 7-14, 7-15, 7-16, and 7-17. The results of the corrosion survey are presented in Table 7-3.

Description	pH	Corrosion potential (rel. NHE) (V)	Depth of penetration (depth of concretion + graphitisation) (mm)	Water depth (m)
Wheel 1 (buried)	7.12	-0.351	8	2.4
Wheel 2: position 1	6.83	-0.324	25	2.3
Wheel 2: position 2	6.01	-0.324	15	2.3
Wheel 3	6.65	-0.324	16	2.4
Strut connecting wheels 2 and 3 (buried)	7.71	-0.324	4	2.5
Railway track: position 1	7.09	-0.306	4	2.5
Railway track: position 2	7.37	-0.347	1	2.5
Railway track: position 3 (buried)	6.99	-0.344	10	2.5

Table 7-3 Corrosion parameters of the ferrous artefacts measured on the Quindalup jetty site.

Concretion on the surface of these objects acts as a semi-permeable layer, effectively separating the anodic and cathodic sites and producing an acidic, iron and chloride rich micro-environment at the residual iron surface. Hence, the pH of the residual metal surface of actively corroding iron should decrease as corrosion proceeds.

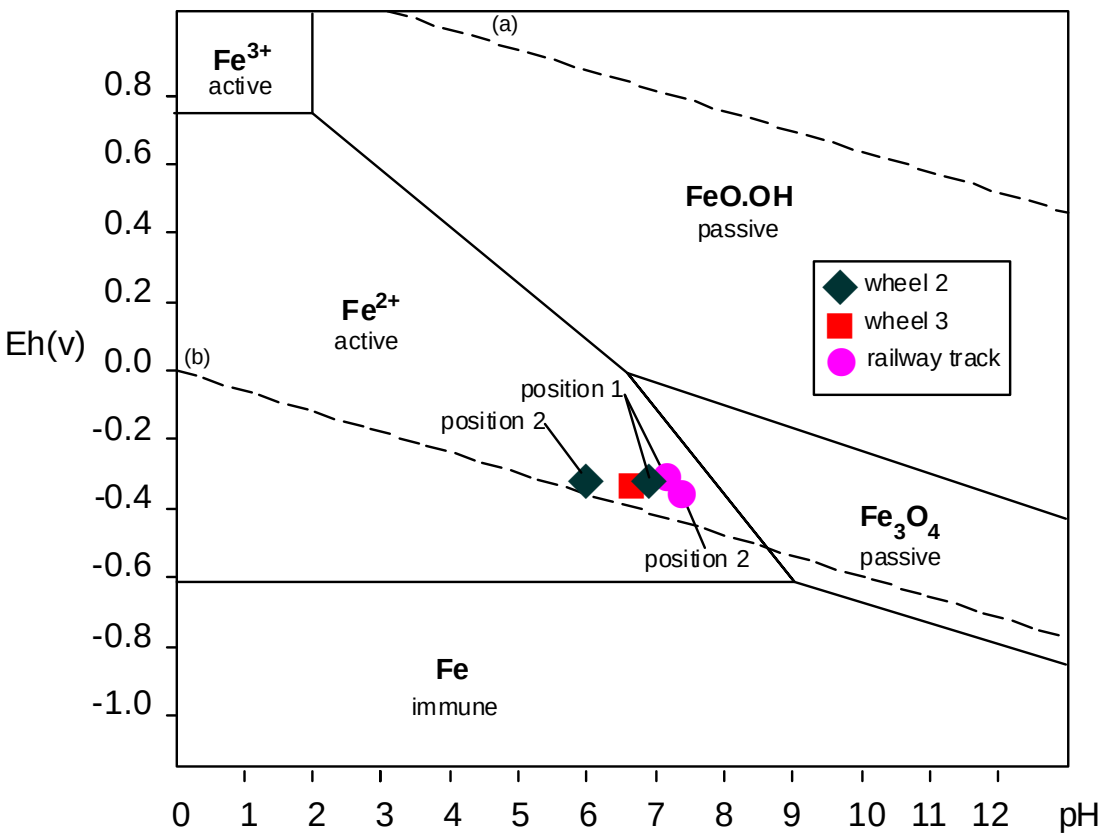

Figure 7-18 Pourbaix diagram for iron (10^{-6}M) in aerobic seawater at 25°C indicating the state of the exposed iron artefacts on the Quindalup jetty site. (Graph: V. Richards, WA Museum)

By plotting the measured voltages and the corresponding surface pH on the appropriate Pourbaix diagram for iron in a particular environment, the thermodynamic stable state of the iron can be ascertained (Figs. 7-18 and 7-19). It is important to note that Pourbaix diagrams do not include kinetic information. They are only thermodynamic stability maps that give an indication of the corrosion mechanisms

and not the corrosion rate. However, they can be used as a general guide for interpreting corrosion data.

The corrosion survey indicates that all ferrous artefacts on the Quindalup jetty site are actively corroding (Figs. 7-18 and 7-19). On closer inspection of the corrosion data, it is obvious that there are some subtle differences in the corrosion behaviour of the iron artefacts. The average corrosion potential of wheels 2 and 3 and the buried strut between them was -0.324 ± 0.001V, indicating that the entire structure is electrically connected. However, the differences in pHs of the residual metal surfaces and the depths of penetration indicates that different areas on the artefact are corroding at different rates.

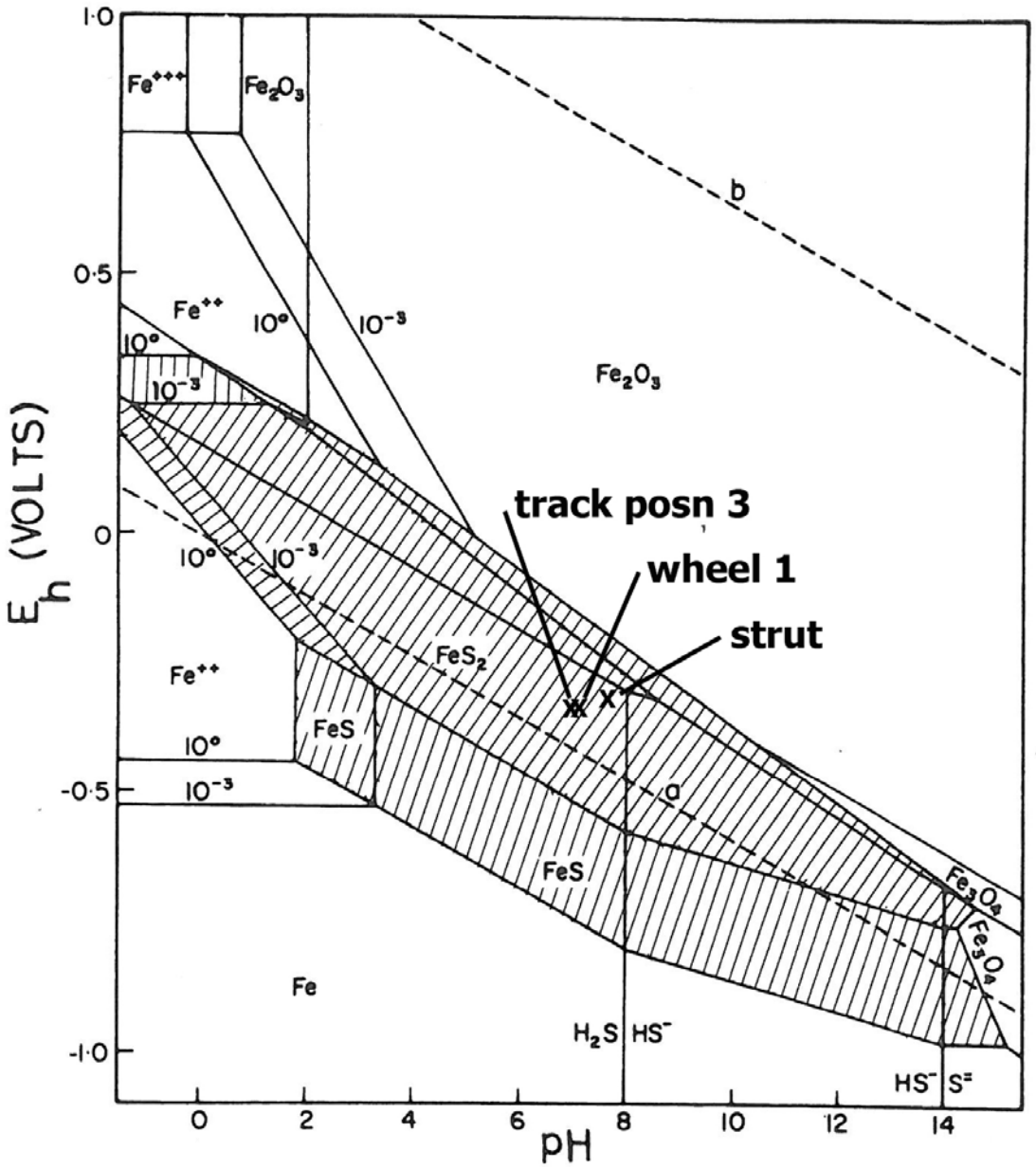

Figure 7-19 Pourbaix diagram for iron in anaerobic seawater at 25°C indicating the state of the buried iron artefacts on the Quindalup jetty site (Peters, 1977: 277).

The pH and the depth of penetration (25 mm) of position 1 on wheel 2 (Fig. 7-16) were higher in comparison to the other aerobic measurement points [wheel 2: position 2 (15 mm) and wheel 3 (16 mm)]. Position 1 had the typical aerobic

red/brown iron oxy-hydroxide surface corrosion products (Fig. 7-16), indicating that there was a breach in the concretion layer allowing direct access to oxygenated seawater, which subsequently increased corrosion in this area.

The corrosion parameters of the buried strut, railway track (position 3) and wheel 1 are plotted on the Pourbaix diagram for iron in anaerobic seawater (Fig. 7-19). The intercepts show that these iron artefacts were actively corroding, with pyrite being the major corrosion product. Corrosion of ferrous materials under deoxygenated conditions form very dense concretions combined with iron sulphides and iron oxides of lower oxidation state, which are black in colour. This was evident on the buried artefacts. In addition, the depths of penetration on the buried objects were significantly less than those measured on the other more exposed iron artefacts.

Although the corrosion mechanism for anaerobically corroded iron is similar to that for aerobically corroded iron, the corrosion rates of ferrous materials in less oxygenated environments are generally lower than for those exposed to more aerobic conditions.

Position 1 on the exposed section of the railway track had the least negative corrosion potential (-0.306), which indicates that this area (Fig. 7-15) suffers the most corrosion of the artefacts measured on the site. In addition, the track was broken between position 1 and 2 and not in direct electrical contact, which is confirmed by the 40mV difference in the corrosion potentials of these two points (Table 7-3). The corrosion potentials of positions 2 and 3 on the railway track were very similar, -0.347V and -0.344V, respectively, and about 40mV more negative than position 1. This suggests that this piece of track is in one section and is corroding at a slower rate than the exposed shoreward end (Fig. 7-16).

The depths of penetration measured on the exposed sections of the track, (1 and 4 mm, respectively) are considerably less than those measured on the exposed sections of wheels 2 and 3 (15 and 16 mm, respectively). This may indicate a different metal composition for the track, a different period of exposure and/or that the track was subjected to a different micro-environment prior to the survey. The first two aforementioned points cannot be supported through this limited conservation inspection without recourse to destructive sampling. However, on closer inspection of the surface of the exposed track sections, the concretion was thin and quite dense, with very little secondary marine growth, suggesting that the track was buried previously. This effectively would have slowed the corrosion rate, and could explain the lower depths of penetration observed on these track sections at the time of the survey. However, when buried artefacts are initially exposed to an aerobic marine environment, the corrosion rate will increase quite markedly until a quasi-equilibrium state is attained in the new micro-environment. Hence, if the track had been recently exposed, it is not surprising that the most exposed section (position 1) is suffering the highest rate of corrosion of all the artefacts.

Garratt (1993b) reported that the jetty remained in regular use until circa 1897. The standard corrosion rate for isolated iron in aerobic seawater is 0.1 mmy^{-1}. Therefore, if the exposed iron wheels 2 and 3 are corroding at this standard rate, then the depth of corrosion should have been about 11–12 millimetres at the time of the survey. Hence, based on the fact that the total depth of penetration was about 15–16 millimetres, which included the depth of the concretion layer, it may be safely assumed that this artefact was part of the original Quindalup jetty and the upper sections have been exposed to the aerobic marine environment for a considerable period of time.

Figure 7-20 Location of Jetty Pile 1 adjacent to the iron bogey (wheels 2 and 3). (Photograph: P. Baker, WA Museum)

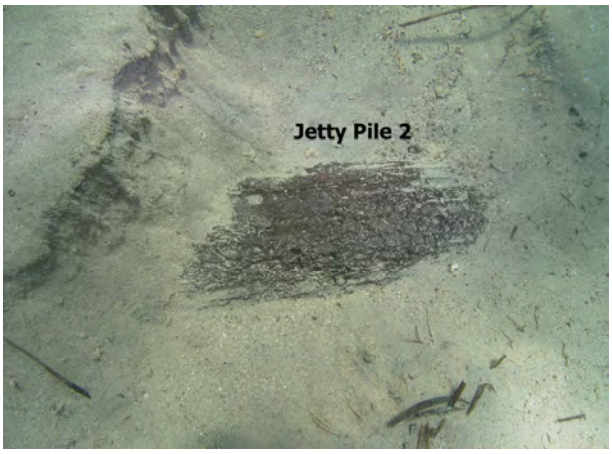

Figure 7-21 Buried jetty Pile 2 forward of the iron bogey (wheels 2 and 3). (Photograph: P. Baker, WA Museum)

Conservation survey results: Organic survey

Wood

The exposed, algae-covered remains of two wooden jetty piles were observed on the site. They both suffered from extensive from teredo-worm damage. In-situ pH profiles were measured on the exposed pile (Jetty Pile 1), which lies horizontally on the seabed about 1m south-east of the partially buried bogey (wheels 2 and 3) (Fig. 7-20), and on the buried pile (Jetty Pile 2) (Fig. 7-21), which is located about 1m north of the same bogey under 130 millimetres of sediment (it was found when our coring tube hit the upper face of the pile during sediment sampling). The length of the drill bit used in the wood coring procedure limited the maximum depth of penetration to about 100 millimetres. A sample of Jetty Pile 1, directly adjacent to the drill hole, was collected for species identification and maximum water content (U_{max}) determination. The results of the pH profiles are presented in Table 7-4 and shown diagrammatically in Figure 7-22.

Description	Depth of penetration (mm)	pH
Jetty Pile 1	0	8.33
	4	8.31
	6	8.29
	10	8.13
	16	7.66
	25	7.19
	31	7.30
	48	7.50
	98	7.48
	100	7.52
Jetty Pile 2	0	8.32
	22	8.32
	22	7.78
	32	7.42
	49	7.34
	62	7.12
	63	7.12
	93	7.09
	106	7.11

Table 7-4 Results of the pH profiles on the jetty pile remains on the Quindalup jetty site.

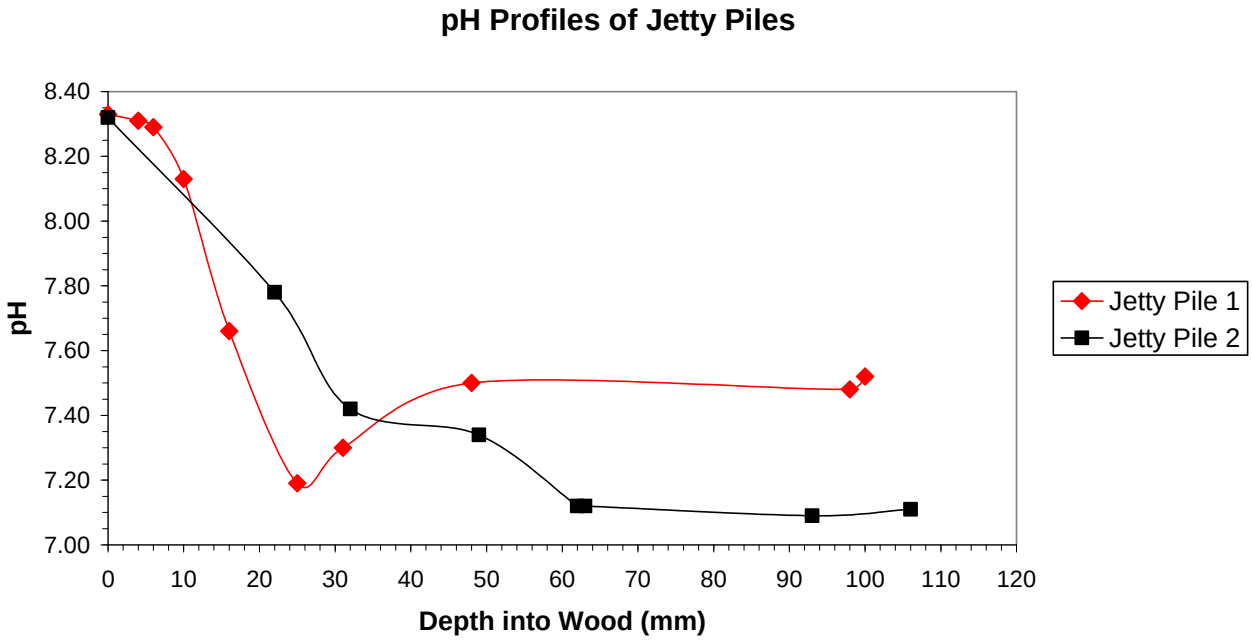

Figure 7-22 pH profiles of the jetty pile remains measured on the Quindalup jetty. (Graph: V. Richards, WA Museum)

Wood is degraded in the marine environment by physical (water movement, sand impingement), chemical (chemical reactions in the wood and hydrolysis reactions with seawater) and biological (marine borers, fungi and bacteria) processes. Degradation commences on exposed surfaces and, under the right environmental conditions, continues into the wood until it is totally destroyed. As wood deteriorates, pore space size and accessibility increase, allowing alkaline seawater to penetrate into farther into the wood structure. Therefore, in general, plots of pH versus depth of penetration follow a typical sigmoidal relationship, where the pH of the wood near the surface is high, but sharply and rapidly decreases as core depth increases, eventually plateauing. The higher pH measured on the wood surface, slightly more acidic than seawater, is indicative of the pH being controlled by the buffering capacity of the sea water. More importantly, this maximum pH denotes the area of greatest deterioration. Degradation occurs from the outer, more exposed areas in the initial instance. Hence, the normally acidic nature of the wood becomes progressively more alkaline with increasing degradation due to the inward diffusion of seawater. The rapid decrease in pH into the wood indicates a decrease in the extent of degradation. The pH will eventually reach a minimum, denoting the area of least deterioration, where the wood is least waterlogged. The overall decrease in the pH of the wood core reflects the inherent acidity of wood. The innermost wood is still waterlogged, albeit to a lesser extent than the outer surfaces, and therefore the pH will be more alkaline than the standard pH of seasoned, modern, non-degraded wood of the same species.

The pH profiles for the exposed Jetty Pile 1 and the buried Jetty Pile 2 are typical of wood with a relatively thin outer layer (<20 mm) of extensively degraded wood overlying a less degraded inner core. However, the more acidic pH measurements noted for Jetty Pile 2, beyond a depth of about 50 millimetres, indicate that the inner region of this buried pile is in better condition than the exposed pile. This is not unexpected, as it is well known that wood recovered from deoxygenated environments is usually better preserved because the wood is better protected from extensive physical and biological deterioration. However, the extent of protection is directly related to the depth of burial, so, generally speaking, the deeper the burial

depth, the less degraded the wood. The majority of surface degradation on the buried pile would have occurred before the remains became buried. However, slow biodeterioration of the wood may continue under anoxic conditions due to the presence of erosion bacteria, which only survive in anaerobic environments.

Maximum moisture content is an easily measured quantity which may be related to specific gravity and, thus, to the extent of degradation of the wood. It is universally used as an indicator of wood deterioration and is the basis of a classification scheme. Waterlogged timbers may be classified as follows: Class I (>400%)—an extremely degraded, extensive surface with very little solid core; Class II (185–400%) —a degraded surface with a thin, partially degraded area and a considerably larger solid core; Class III (<185%)—a very thin degraded surface layer, overlying an extensive non-degraded core (Pearson, 1987).

Unfortunately, no core sample was collected from Jetty Pile 2, but core sample 1 taken from Jetty Pile 1 was 10 millimetres thick and possessed a very soft, degraded surface (2 mm), after which the wood was in relatively good condition, although there was evidence of teredo worm damage throughout the entire length of the core. The maximum water content of the wood core sample is 89%, indicating that the wood of this pile is Class III and corroborating the results of the pH profiles.

The pile wood is tentatively identified as a Eucalyptus species, most probably jarrah (pers. comm. Godfrey 4 May 2009). Eucalypt species were a preferred choice for jetty piles because of their durability in the marine environment, especially in the cooler waters of the Western Australian south-west coast.

Sediment

The pH of the sediment at a depth of 70 millimetres was 8.25. This is slightly more acidic than the surrounding aerobic seawater (pH 8.34_{av}), which is to be expected, due to the oxidation of organic detritus by aerobic and facultative bacteria that produce acidic metabolites and by-products. However, this pH difference is not particularly significant and there was very little organic detritus observed on the seabed, which could explain the relatively higher pH of the sediment due to less aerobic oxidation of organic material. It is more likely, however, that there was some ingress of the surrounding seawater into the measurement hole. This would effectively increase the pH of the interstitial water more than would normally be expected at these depths for sediments of this finer particle size.

The redox potential of the sediment at 130 millimetres was –0.110V, indicating that the sediment is mildly reducing at this depth. These redox potential and pH measurements indicate that the zero-E_h interface lies somewhere between 7 to 13 centimetres under the seawater/sediment interface. This implies that the overlying sediment above this depth range will be more alkaline and oxidising in nature.

One sediment core sample was collected approximately 4 metres north of Jetty Pile 1 at a water depth of 2.4 metres. The total length of the core sample (QJ 55) was 240mm (Fig. 7-23). The core sample revealed a thin layer (19 mm) of dark grey, fine-grained sand overlying 12 millimetres of very black fine sand. Below this depth there was a 70-millimetres layer of grey, fine-grained sand overlying 139 millimetres of lighter grey, fine sand, with coarser grained particles distributed evenly throughout this lower layer. The typical grey to black colouration of sediment is indicative of anaerobic conditions, but it is important to note that when the sediment was first recovered, the upper sediment layers (100 mm) were white to light grey in colour and

slowly turned darker over a period of a few weeks. This colour change was caused by bacterial degradation of the organic material present in these sediment layers. The bacteria utilise dissolved oxygen in the sediment for their metabolic processes and, therefore, the layer becomes deoxygenated over time, causing this black discolouration. Alternatively, there was very little colour change in the lower core section (>100 mm), with the exception of some oxidation of reduced iron species to a typical red/brown colour, indicating that there was very little organic matter present in these lower depth layers. Hence, in order to avoid possible misinterpretation of the sediment data, the core samples should be photographed as soon as possible after recovery.

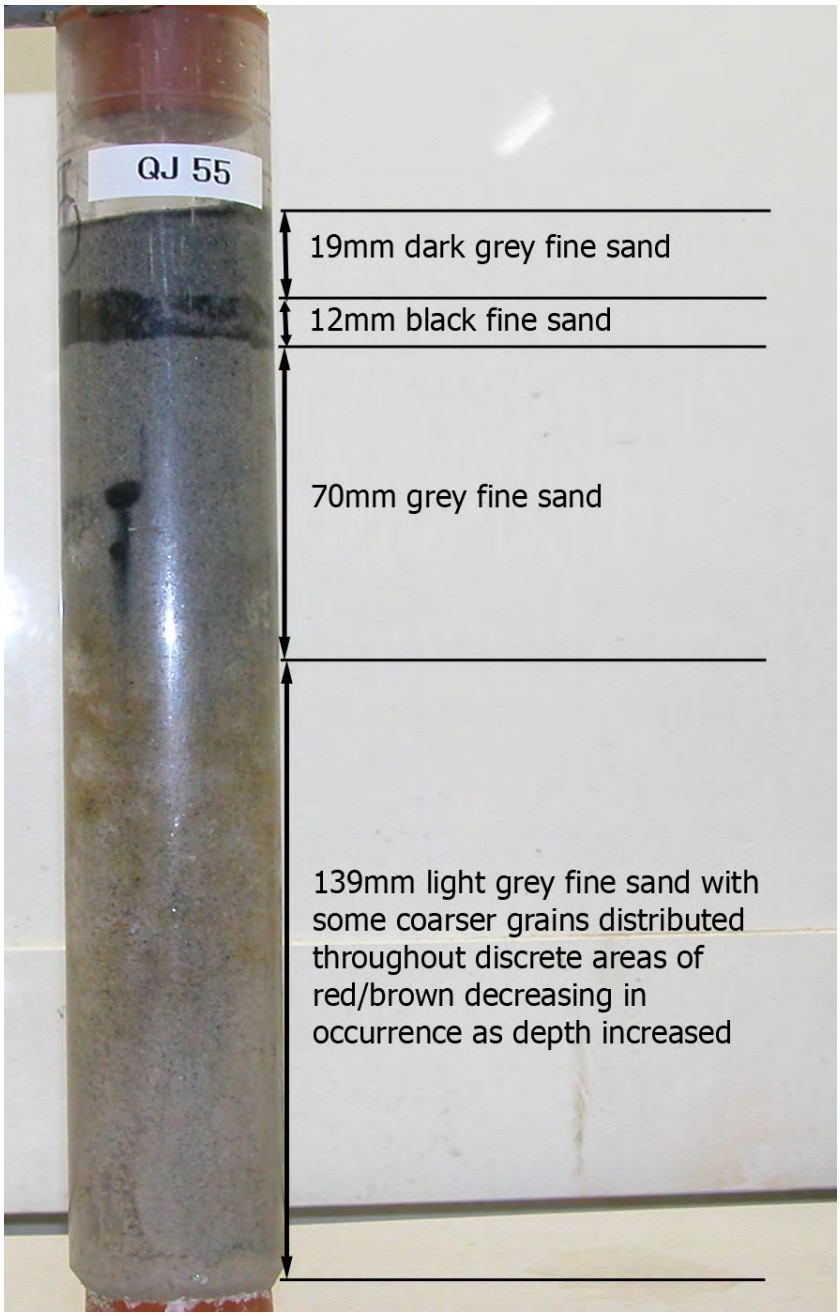

Figure 7-23 Sediment core sample (QJ 55) from the Quindalup jetty site. (Photograph: V. Richards, WA Museum)

Despite these colour changes in the sediment core sample, the visual observations imply that the depth to stable sediment is approximately 10 centimetres, which supports the electrochemical measurements that indicated that the zero-E_h interface also occurs around this depth.

The results of the sediment survey indicate that the sand in the upper 10 centimetres of the sediment column is fine-grained, relatively oxygenated and thus more oxidising in nature, and contains appreciable quantities of organic material to support bacterial activity. However, below this depth, the sediment becomes more stable, less oxygenated and therefore more reducing in nature, and contains considerably less organic content. The conservation implication of these observations for the site is that artefacts in the upper sediment layers would be subjected to more deterioration than those materials buried at depths greater than about 10 centimetres.

Discussion

The Quindalup jetty site is an open circulation, well oxygenated, oxidising marine environment, typical of the Geographe Bay area. The Quindalup jetty remains lie approximately 100 metres offshore and about 100 metres north-west from the seaward end of the contemporary jetty. The remains were aligned on a roughly north-south transit covering an area approximately 10 metres^2 and consisted of a few iron wheels and jetty pile remains and an iron railway track.

The surrounding shoreline had a gentle sloping bathymetry towards the north with the depth to the jetty remains about 2.5 metres. The survey area was relatively level, comprising of fine grained calcareous sand with little organic detritus and epiphytes evident on the seabed surface, with the exception of dead seagrass fronds. There were extensive seagrass beds surrounding the survey area, however there had been some scouring of the seagrass in close proximity to the exposed iron wheels probably caused by the contemporary mooring located on-site.

The results of the sediment survey indicate that the sand in the upper 10 centimetres of the sediment column is fine grained, relatively oxygenated and thus, more oxidising in nature containing appreciable quantities of organic material to support bacterial activity. However after this depth the sediment becomes more stable, less oxygenated and therefore, more reducing in nature with considerably less organic content. The conservation implications of these observations is that artefacts in the upper sediment layers would be subjected to more deterioration than those materials buried at depths greater than about 10 centimetres on this site.

The corrosion survey indicated that all ferrous artefacts on the Quindalup jetty site were actively corroding; however the buried iron artefacts were in better condition than those materials constantly exposed to the aerobic marine environment. The corrosion survey of the exposed iron bogey suggested that it was part of the original Quindalup jetty and had been exposed for a considerable period of time. There was also some evidence of recent exposure of the iron track, indicating that some sediment movement does occur on the site, however the overall amount of sediment movement was minimal.

Exposed jetty pile remains were covered with algal mats with very few higher marine organisms evident on the surfaces but exhibited extensive marine borer damage. The pH profiles for the exposed Jetty Pile 1 and the buried Jetty Pile 2 were typical of wood with a relatively thin outer layer (<20 mm) of extensively degraded wood overlying a less degraded inner core. However, the more acidic pH measurements

noted for Jetty Pile 2 after a depth of about 50 millimetres indicated that the inner region of this buried pile was in better condition than the exposed pile. This is not unexpected, as it is well known that wood recovered from deoxygenated environments is usually better preserved because the wood is predominantly protected from extensive physical and biological deterioration.

APPENDIX A

Date: 26 February 2009
Location: Busselton town jetty
Dive Platform: *Seaspray*
Dive Supervisor: Ross Anderson
Activity: Training—conservation surveys

Diver 1	**Diver 2**	**Total dive time (min)**	**Maximum depth (m)**
V. Richards	J. Carpenter	6	8.5
W.Hassapak	C. Wijamunige	6	8.5
V. Richards	J. Carpenter	55	8.5
W.Hassapak	C. Wijamunige	55	8.5

APPENDIX B

Date: 27 February 2009
Location: Quindalup town jetty
Dive Platform: Shore
Dive Supervisor: Ross Anderson
Activity: Conservation survey

Diver 1	Diver 2	Total dive time (min)	Maximum depth (m)
V. Richards	J. Carpenter	84	2.8

REFERENCES

Australian Heritage Commission

1990, *Australian Heritage Commission Amendment Act 1990*.

http://www.comlaw.gov.au/Details/C2004A04092

Cumming, D.A., Garratt, D., McCarthy, M. & Wolfe, A.

1995, Port Related Structures on the Coast of Western Australia. Report no. 98, Department of Maritime Archaeology, Western Australian Museum, Fremantle.

De Kerchove, R.

1961 (2nd edition), *International Maritime Dictionary*. Original publication, 1948. Van Nostrand, New Jersey.

Drew, P.

1994, *The Coast Dwellers: Australian living on the edge*. Penguin books, Ringwood, Victoria.

Fahrner, C.K. & Pattiaratchi, C.B.

1995, The Physical Oceanography of Geographe Bay, Western Australia in *Geographe Bay Summary Report: Wastewater 2040 strategy for the South West region*, ed. D.A. Lord, pp. 3–12. Water Authority of Western Australia, Perth.

Garratt, D.

1993a (December), Wonnerup Jetty. Report no. 73, Department of Maritime Archaeology, Western Australian Museum, Fremantle.

Garratt, D.

1993b (December), Quindalup Jetty. Report no. 74, Department of Maritime Archaeology, Western Australian Museum, Fremantle.

Gerritsen, R.

1995, An Historical Analysis of Wrecks in the Vicinity of the Deadwater, Wonnerup, Western Australia. Report no. 97, Department of Maritime Archaeology, Western Australian Museum, Fremantle.

Gibbs, M.

1994, *An Archaeological Conservation and Management Study of 19th Century Shore-Based Whaling Stations in Western Australia*. Report to the National Trust of Australia, Australian Heritage Commission, Perth.

Guidelines to the Burra Charter

1988, *Guidelines to the Burra Charter: Cultural significance.* Australia ICOMOS Inc. http://australia.icomos.org/publications/charters/

Henderson, G.

2007, *Unfinished Voyages: Western Australian shipwrecks 1622–1850*. University of Western Australia Press, Crawley.

Pearson, C. (ed.)

1987, *Conservation of Marine Archaeological Objects*. Butterworths, Sydney.

Peters, E.

1977, The Electrochemistry of Sulphide Minerals, in *Trends in Electrochemistry,* eds J. O'M. Bockris, D.A.J. Rand & B.J. Welch, p. 277. Plenum Press, New York.

Staniforth, M.

2008, Australia: Flinders University, South Australia, *SHA Newsletter* **41**.3 (Fall): 69–70.

Walter, H.

1979, *Vegetation of the Earth in Relation to Climate and the Eco-Physiological Conditions*. Springer-Verlag, New York.

Worsley, J., and Worsley, P.

(In Prep*), Capes of Sunset: Western Australia¹s Maritime Heritage between Peel Inlet & Flinders Bay.* Department of Maritime Archaeology, Western Australian Museum, Fremantle.