Biodiversity and Conservation Science

Preliminary assessment of plastic infrastructure in the Swan Canning Riverpark

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GOVERNMENT OF WESTERN AUSTRALIA

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Executive Summary

The Swan Canning Riverpark is a culturally, recreationally, and environmentally significant attraction. Plastic is commonly used in shoreline infrastructure such as jetties, pontoons, and boardwalks within the Riverpark. The degradation of these structures is not well understood, despite the potential of plastic to contaminate and impact aquatic ecosystems as it degrades. Given the prevalence of these synthetic materials and the increasing desire from proponents to use them in the Riverpark, a greater understanding of how these structures degrade and impact the surrounding environment is required. This information will be used to inform policy development on the suitability of these materials in the Swan Canning Riverpark.

The aim of this study was to (i) compile an inventory of the types and prevalence of the different plastics used in the construction of shoreline infrastructure installed around the Swan Canning Riverpark; and (ii) to determine the types, severity, and potential causes of observed surface degradation by conducting rapid visual condition assessments of these structures at appropriate sites.

The most prevalent type of plastic used for infrastructure around the Swan Canning Riverpark was fibre reinforced plastic (FRP) for kick rails, substructure and grated decking on jetties, platforms, boardwalks, pontoons, and ramps. Recycled plastic (co-polymer of polyethylene and polypropylene) was also used for a variety of structures such as decking, kick rails, chafer posts and seats in the Swan Canning Riverpark. Other less common plastics included polyethylene composites, foam, and rubber, which were often used as fenders to prevent damage from boat strike. These plastic structures were often prone to surface degradation when continuously submerged or splashed by estuarine water and exposed to boat strike. Surface degradation was also sometimes noticed with increased structure age and poor installation.

It is recommended that plastic use is minimized in the Swan Canning Riverpark, where possible. Recommendations for the use of these plastics in the Swan Canning Riverpark have been made to assist with instances where avoidance is not possible. These recommendations were informed by the results from the inventory and the rapid visual condition assessments. Key recommendations included: installing edge protection on plastic panels where there was a potential for wear (i.e. jetties exposed to boat strike); avoiding dark coloured plastic in areas subject to high UV radiation; avoiding light coloured plastics in areas subject to staining (to avoid pressure washing); avoiding plastic use on the tide line or in more alkaline areas; and ensuring care is taken during transportation and installation of plastic products.

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1 Introduction

Plastics are durable, lightweight, and relatively low cost synthetically derived petroleum-based polymers (Andrady, 2011). These polymers can be supplemented with a suite of chemical additives to enhance their properties (e.g. increase flexibility) and resist degradation (e.g. ultraviolet stability, fire resistance). The diverse physical and chemical properties of plastic polymers make them an extremely versatile and accessible material, often favoured over naturally derived alternatives such as wood and metal.

However, plastic is now considered a major pollutant globally and is ubiquitous in terrestrial and aquatic environments with the potential to cause adverse impacts to the functioning of these ecosystems. Knowledge of the longevity and degradability of plastic and associated impacts is relatively limited and likely to vary in different spatial and temporal contexts.

The Swan Canning Riverpark is located entirely within the Perth Metropolitan Area, Western Australia (WA). The Riverpark is admired by residents and visitors due to its unique beauty and diverse ecosystems. The Swan and Canning rivers provide habitat for over 209 species of fish and 80 species of birds. Many crustaceans and mammals also inhabit the river and the surrounding foreshore environment. The Swan Canning Riverpark not only provides an opportunity for swimming, water sports and fishing but also offers a unique connection to the Whadjuk Noongar people with its abundance of food, water, and dreamtime stories.

Plastic is becoming frequently used over traditional materials for shoreline infrastructure along the Swan Canning Riverpark often because of its expected longevity and low maintenance requirements. The use of synthetic materials such as fibre reinforced polymer / plastic (FRP) in structures exposed to harsh environmental conditions is becoming increasingly popular in WA. Like other types of plastic, FRP is commonly chosen in shoreline infrastructure due to its favourable properties including high strength to weight ratio, rust and rot resistance, incombustibility, and low thermal conductivity. Despite the expected longevity of these plastics, early signs of degradation have been anecdotally reported by owners and users of such infrastructure. The degradation of plastic infrastructure and the resulting shedding of plastic presents a potentially significant risk of plastic pollution to sensitive environments such as the Swan Canning Riverpark. However, there is currently limited research and knowledge regarding the amount of degradation, deterioration and plastic shedding that occurs from these structures. The degradation of plastic infrastructure and their suitability in estuarine environments has not been studied in ecologically significant locations, such as the Swan Canning Riverpark.

The potential implications associated with specifying plastic to construct shoreline infrastructure is raising concerns among stakeholders including local and state government agencies. There is, therefore, an urgent need to investigate the prevalence of plastic infrastructure used along the shoreline of the Swan Canning Riverpark and determine the types of plastics used, and the level of degradation present to improve future material recommendations and maintenance schedules.

1.1 Aims

The primary aim of the project was to determine the extent and types of plastic shoreline infrastructure within the Swan Canning Estuary and explore the occurrence, severity and potential causes of degradation to this infrastructure to inform policy development on the use of these materials within the estuary. This was achieved by, firstly, developing an inventory of plastic infrastructure assets within the Swan Canning Estuary and secondly, assessing these assets for degradation using a rapid visual assessment method incorporating the following degradation categories: cracks, chips, deformation, material loss and other general signs of wear (e.g. fading in colour). The following types of shoreline infrastructure were assessed: jetties, boat and beach access ramps, piles / chafer posts / fenders, pontoons, boardwalks / raised walkways and viewing platforms. Any additional types of plastic infrastructure (e.g. park benches) present during site visits were also documented.

Additionally, the suitability of specific materials for future installations was explored and, when there are existing structures or there are no alternatives, recommendations were made to appropriate evidence-based management and maintenance schedules. If plastic degradation is evident, potential reasons for deterioration were examined and recommendations for improvements presented.

2 Background

2.1 Plastic Degradation Factors

The Swan Canning Riverpark experiences a wide range of environmental conditions that could exacerbate the degradation rate and shedding from plastic infrastructure. The literature examined is weighted towards FRP, as this likely represents most of the plastic infrastructure in the Swan Canning Riverpark.

2.1.1 High temperatures

Perth typically experiences an average maximum temperature of approximately 33°C in the summer months, with the highest recording of 44.5°C across 2020 / 21 and 2021 / 22 (Bureau of Meteorology, 2022). High temperatures increase plastic degradation and when the ambient temperature is higher than 40°C, the degradation rate of plastic will increase (Wu et al., 2023). When the ambient temperature is below 40°C, there will be minimal effect on the degradation rate (Wu et al., 2023). FRP decking can reach approximately 53°C when the ambient temperature is 25°C (Halabe et al., 2007). It is expected that the plastic surface will be approximately 15°C - 25°C hotter than the ambient temperature (Halabe et al., 2007). Some decking companies also reported the surface temperature of FRP decking higher than the ambient temperature (Trex, 2023). When the ambient temperature is 26°C, the surface of composite decking can reach over 49°C (Trex, 2023). An ambient temperature above 60°C, significantly increases the degradation rate of FRP (Wang et al., 2007). At the glass transition temperature (approximately 80°C), FRP loses the majority of its strength and will collapse in most cases (Wang et al., 2007). Temperature will only affect the degradation rate of plastic and not the way in which the plastic degrades (Feng et al., 2022). Resin types also influence the susceptibility of plastic structures to degradation. Polyester resins are the least resistant resin type to high temperatures. Vinyl ester and epoxy resins, however, are more resistant to deterioration from high temperatures (Kim et al., 2008). One study subjected FRP samples to 30 thermal cycles in an oven at 50°C for four hours before being reduced to room temperature (Aiello and Ombres, 2000). On average, the samples lost 4% of tensile strength indicating that degradation occurred. Further research suggests that FRP subjected to 60°C and alkaline conditions (pH 13.7) for 193 days shows the same amount of degradation as FRP that has been in standard conditions (i.e. no temperature extremes and neutral pH) for 50 years (Dejke and Tepfers, 2001). High temperatures in the Swan Canning Riverpark and the exposed nature of plastic shoreline infrastructure are likely to accelerate degradation.

2.1.2 Low temperatures

Perth experienced a minimum temperature of 0.1°C across 2021 and 2022 with the lowest temperature recorded being -1.3°C (Bureau of Meteorology, 2022). Thus, freeze-thaw effects are highly unlikely to occur in the Swan Canning Riverpark, however, this may be of importance in other regions in WA.

Numerous studies found that low temperature environments and freeze-thaw effects have negligible impact on the deterioration of plastic and FRP structures (Wu et al., 2023). Some studies have even found that the properties and modulus of FRP slightly increased in a low temperature environment (Wu et al., 2023). FRP bars subjected to 300 freeze-thaw cycles of -60°C to room temperature gained 4% in strength during one experiment (Chen et al., 2007). Another study found that freeze-thaw and low temperatures had negligible effect on FRP strength and deterioration after samples were exposed to 300 cycles of 20°C to -20°C (Tam, 2007). The tensile modulus of FRP increased by nearly 8% after the cycles and the samples displayed no defects such as cracking, delamination or porosity when analysed with a scanning electron microscope (Figure 1) (Tam, 2007). Low temperatures and freeze-thaw cycles have negligible effect on the degradation of plastic infrastructure and, therefore, it is expected that low temperatures would not likely impact the degradation of FRP and other plastic structures in the Swan Canning Riverpark.

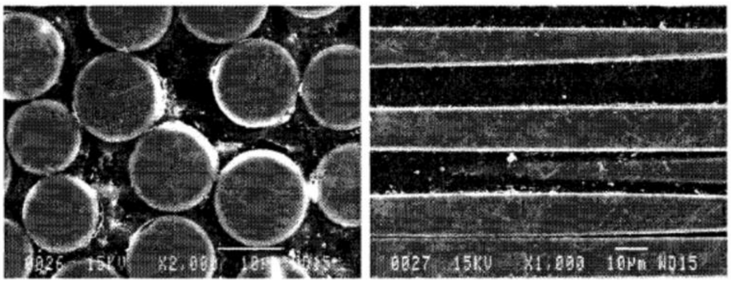


Figure 1. Scanning electron microscope images after fibre reinforced plastic was subjected to freeze-thaw cycles. Image source (Tam, 2007).

2.1.3 Ultraviolet radiation

Most polymeric substances undergo oxidative or degradative reactions when exposed to ultraviolet (UV) radiation and therefore, polymers are one of the most vulnerable to radiation damage among existing materials (Yu et al., 2016). UV radiation is well known to damage plastics such as FRP (Dong and Wu, 2019; Sasaki and Nishizaki, 2012; Zhao et al., 2017). Zhao et al. 2017 used FRP exposed to UV lamps (producing UVB radiation with a wavelength of 280nm – 315 nm) under accelerated conditions decreased the tensile strength as exposure time increased (Zhao et al., 2017). Some samples, however, increased in tensile strength when there was a low degree of volumetric shrinkage or hardening of the plastic resin (Zhao et al., 2017). Degradation may also be caused when long chained molecules, present in the plastic matrix, are damaged from UV radiation exposure (Wu et al., 2023). For FRP products, UV also affects the bonding between the resin matrix and fibre, which can also affect the mechanical properties and degradation rate of FRP (Wu et al., 2023). UV radiation may deteriorate plastic infrastructure over time around the Swan Canning Riverpark.

2.1.4 Moisture

Perth experiences annual rainfall of approximately 730 mm with the maximum recorded 24 hour rainfall since 2021 for Perth being 77 mm (Bureau of Meteorology, 2022). Additionally, moisture from humidity, fog, mist, or wave spray, may impact plastic and FRP structures in the Swan Canning Riverpark. The average humidity in Perth is 47% with the highest average being in July at 57%. Further, during peak floods and high tides, some plastic infrastructure will become inundated in water. Given the estuarine environment of the Swan Canning Riverpark, numerous shoreline structures would become partially submerged during high tides. The degradation of plastic from moisture and wet-dry cycling is likely to be more severe than degradation from high temperatures (Aiello and Ombres, 2000). The wet and dry cycle is known to significantly reduce tensile strength of FRP by 29%, causing deterioration and degradation (Aiello and Ombres, 2000). A reduction in strength can be caused by water molecules invading the plastic matrix through osmosis (Wu et al., 2023). The water molecules can then destroy and degrade the plastic matrix and fibre interface bonding (Wu et al., 2023). This could lead to material shedding / sloughing from plastic structures into the surrounding environment over time. Further, moisture can impact plastic by decreasing the tensile and compressive strength of FRP and show diminished fatigue performance (Shimamura et al., 2004). It is likely that moisture, particularly wet and dry cycling would influence the degradation of plastic infrastructure in the Swan Canning Riverpark.

2.1.5 Salinity

Salt levels in the Swan Canning Riverpark reflect those of the connected Indian Ocean. Saltwater moves gradually upstream with the assistance of tides until it reaches Kent Street Weir or Middle Swan. The estuaries typically become slightly less saline in the autumn and winter months due to freshwater runoff from rainfall (Department of Biodiversity, Conservation and Attractions, 2015). Previous studies suggest that there are no major effects from salty environments on the properties and degradation of plastic and FRP (Guo et al., 2022; Wu et al., 2023). Salt molecules can form a thin salt film on the surface of the plastic, which restricts the entry of molecules into the resin matrix and suggests an increased resistance of plastic to degradation from salt (Al-Salloum et al., 2013). The same study investigated the impact of salt on FRP when submerged for 540 days and found that although the tensile strength declined by 12.8%, the impact was significantly less than when subjected to tap water (24.48%) and alkaline (pH 12.5 - 13) (24.05%) solutions over the same period (Al-Salloum et al., 2013). The high salinity of the Swan Canning Riverpark combined with consistent sea spray from wind, exposes plastic infrastructure to highly saline conditions. Salt water and salty environments, however, may have less impact on the deterioration of plastic infrastructure in the Swan Canning Riverpark relative to other factors.

2.1.6 Abrasion and wear from human use

The Swan Canning Riverpark is accessible to the public and it receives an estimated one million visitors annually. This significant number of visitors would likely affect the surface wear rate of plastic infrastructure frequently used by the public. Human foot traffic could increase abrasion on the top surface of boardwalks and subsequently lead to increased degradation of the structure. FRP and other plastics have extremely intricate abrasion properties due to being anisotropic (Singh et al., 2022) and therefore, the rate of erosion from abrasion is dependent on fibre augmentation and fibre inclination (Sabry et al., 2022; Singh et al., 2022). The wear rate of glass fibre reinforced plastic (GFRP), for example, is 0.00033 grams / min for a 15N (equivalent to 0.654kg) applied load (Sabry et al., 2022). Further, samples of FRP with polyester resin exposed to a rubber abrasion wheel test with a sliding distance of 100 – 784 m and loads of 3 N to 6 N provided evidence of degradation (Figure 2a) (Chand and Neogi, 1998). Abrasive wear to FRP strongly depended on the size of abrasive particles, sliding distance and applied load, and degradation initially occurred by matrix removal followed by fibre removal (Chand and Neogi, 1998). The inclusion of fibres to a resin matrix of FRP provides an improvement of 60% in the wear rate caused by abrasion (Figure 2b) (Talib et al., 2021). Therefore, plastic structures not reinforced by fibre in the Swan Canning Riverpark may be more susceptible to degradation from human foot traffic and abrasion. This wear may be further exacerbated in sandy environments where the users' shoes have a 'sandpaper' like effect on the plastic surface.

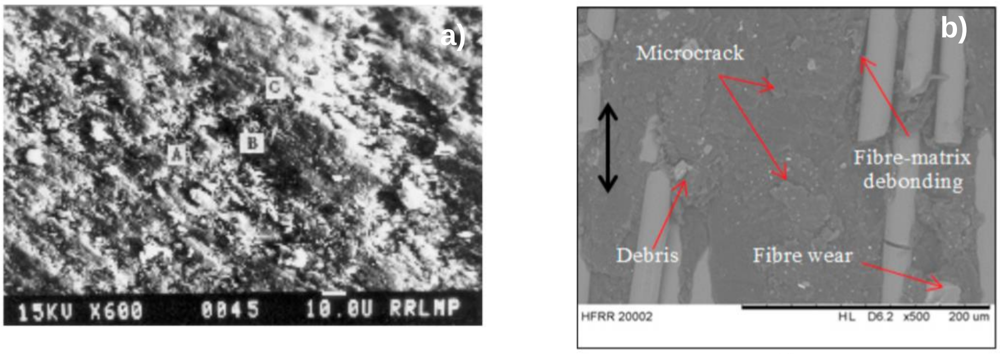


Figure 2. Scanning electron microscope images of degradation to fibre reinforced plastic when subjected to abrasion (a), Image sourced from: (Chand and Neogi, 1998) and (b) Image source (Talib et al., 2021). Formation of micro-pits (A), macro-pits (B) and microcracks (C) are evident (Chand and Neogi, 1998) in image a.

2.1.7 Acidity

The aquatic environment in the Swan Canning Riverpark is considered slightly alkaline with a pH typically ranging from 7.0 - 8.5. Acidic conditions are less impactful on the properties of plastics and its subsequent degradation relative to other factors (Wu et al., 2023). Given the Swan Canning Riverpark is predominantly alkaline, these environmental conditions would be unlikely to impact the degradation of plastic infrastructure.

2.1.8 Alkalinity

The pH levels in the aquatic environment of the Swan Canning Riverpark typically range from 7.0 and 8.5, which is within the Australian and New Zealand Environment and Conservation Council limits. Total alkalinity varies between 100-200 mg $CaCO_3$ (Baker and Cosgrove 2022). The alkalinity of the Swan Canning Riverpark can increase during algal blooms as a by-product of photosynthesis but it rarely goes above a pH of 10 (Department of Biodiversity, Conservation and Attractions, 2020). Degradation of plastic, such as FRP, is severely affected by alkalinity, which may be the most detrimental of all potential degradation factors (Wu et al., 2023). GFRP immersed in an alkaline solution (pH 12.4 - 13.7) had a 51% decrease in tensile strength and major flaking observed (Figure 3) after just 70 days at 60°C (Chen et al., 2007).

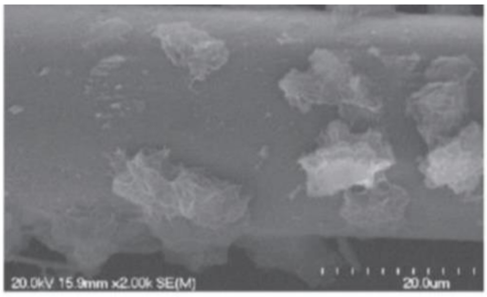


Figure 3. Microstructure Degradation of fibre reinforced plastic exposed to alkaline conditions. Image source (Chen et al., 2007).

After exposing FRP to alkaline conditions (pH of 12.7) for 120 days, 10% of tensile strength was lost (Chen Yi et al., 2006). A similar experiment where FRP was submerged in an alkaline solution of pH 13.6 for 147 days found that FRP lost 40% of its original tensile strength (Bazli et al., 2016). This loss in strength was worse than samples exposed to salt water, acidic solutions, and wet / dry cycles for the same period (147 days) (Bazli et al., 2016). In many of these studies it is difficult to discern if alkalinity is referring to high pH or high total alkalinity, as the terms appear to be used interchangeably. Infrastructure made from FRP in the Swan Canning Riverpark predominantly use polyester or vinyl ester resins (PermaComposites, 2024), which may be more susceptible to alkali ion invasion and likely to deteriorate faster than vinyl ester (Figure 4) (Abbasi and Hogg, 2005).

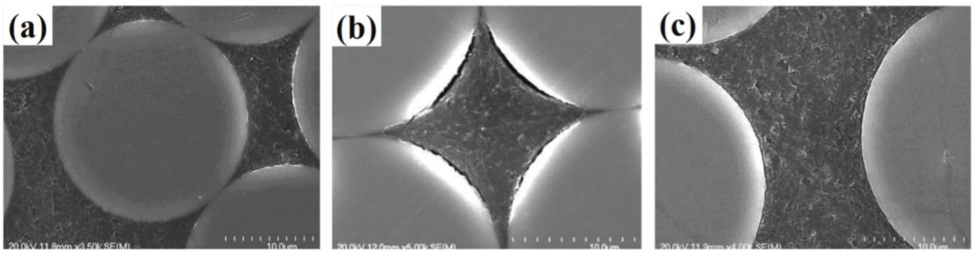


Figure 4. Deterioration of different fibre reinforced plastic resin (a - epoxy resin, b - polyester resin, c - vinyl ester resin) exposed to alkaline conditions. Image source (Feng et al., 2022).

The degradation from alkalinity is likely to be more severe than from salinity and moisture (Feng et al., 2022). The hydroxide ions present in alkaline conditions react with the resin matrix and can destroy the molecular chains through hydrolysis. This reaction can have a significant impact on glass fibres that undergo severe degradation due to hydroxide etching. The pH levels in the Swan Canning Riverpark, however, are not as extreme as those used in these experimental studies. Further investigation into the long-term exposure of the plastics used for shoreline infrastructure to mild alkaline conditions (pH 7 – 8.5), such as those in the Swan Canning Riverpark, are required.

2.1.9 Sustained Loading

Sustained loads are loads that influence a structure throughout its entire service life. This includes self-weight and super-imposed dead loads such as loading from handrails, chairs, bollards, and chafer posts, for example. Sustained loads can accelerate the degradation of plastic matrices by exacerbating existing cracks, fractures, or defective plastic matrices (Wu et al., 2023). These cracks are passageways for corrosive molecules and ions such as water, hydroxide and chloride, which further accelerates deterioration mechanisms (Feng et al., 2022). FRP retains its strength from sustained loads less than 20% of its design strength, however, when the sustained load is increased to 40%, the degradation rate can accelerate (Tu et al., 2020). Therefore, in the unlikely event that plastic infrastructure in the Swan Canning Riverpark is exposed to sustained loads above 40% of their design strength, degradation rates may increase. Further investigation into the impact of sustained loads on other types of plastic is required.

2.1.10 Summary of degradation factors

The degradation factors are summarized by their likelihood of degrading plastic infrastructure in Table 1. It should be noted that these likelihoods are based on scientific literature mostly relating to FRP, and that further investigation is required to understand environmental conditions in estuarine environments that diminish plastic shoreline infrastructure longevity.

Table 1. Likelihood of potential environmental conditions (i.e. degradation factors) degrading plastic infrastructure.

	High	*Medium*	*Low*
Environmental conditions (“degradation factors”)	● Moisture and the wet-dry cycle ● Sustained loads (> 40% of design strength) ● High temperatures (> 40°C)	● UV radiation ● Abrasion from human traffic (more significant for plastic that is not reinforced with fibre) ● Alkaline conditions for a prolonged period ● Sustained loads (< 40% of ultimate strength)	● Low temperatures and the freeze-thaw cycle ● Salty environments ● Acidity

2.2 Potential impacts from degraded plastic in aquatic environments

The prevalence of plastic contamination in aquatic environments, such as estuarine ecosystems, and their associated impacts have been investigated for several decades (Cole et al., 2011). Impacts from entanglement, ingestion and transportation of invasive species adhered to the surfaces of plastics resulting from large plastic that are visually recognisable in waterways have been frequently documented. More recently, microplastics (hereafter MPs), defined as plastic less than 5 mm in diameter (Andrady, 2017), have been the focus of more recent research into plastic contamination (Vaid et al., 2021). MPs are often grouped into two categories:

1. Primary MPs are manufactured to be small particles (e.g. nurdles for plastic moulds or beads for cosmetics) (Cole et al., 2011).
2. Secondary MPs result from the breakdown of larger plastic (Cole et al., 2011) usually by photolytic or mechanical processes that can accelerate fragmentation.

The potential ecotoxicological effects from the chemical additives or adsorbed contaminants in plastics are also being considered in recent impact studies (Gallo et al., 2018).

2.2.1 Potential sources of microplastics

MPs entering estuarine environments, such as the Swan Canning Riverpark, are often secondary MPs fragmented from plastic waste originating from terrestrial sources including household activities, industrial waste, landfill, wastewater treatment plants, construction and agricultural activity (Figure 5). Other sources of MPs in riverine ecosystems may come from industrial abrasion, synthetic paints, and vehicle tyres (Napper and Thompson, 2016; Sarkar et al., 2021). Human users recreating or working within estuarine environments (e.g. boating, fishing, exercising, building, maintenance) may also contribute plastic waste (e.g. single-use packaging) that can degrade into secondary MPs.

Additional sources of secondary MPs rarely considered are those that may slough, crack or break off degrading plastic infrastructure commonly installed along the shoreline of rivers and estuaries (e.g. jetties, boardwalks, boat ramps, pontoons). Plastic infrastructure often interacts directly with the aquatic environment (e.g. jetties, pontoons) and may shed secondary MPs and larger plastic fragments, as the structure ages and becomes increasingly vulnerable to degradation factors. For example, storm events were found to damage pontoons, expose, and release encapsulated expanded polystyrene (EPS) producing ‘white spills’ along coastal Queensland (Xayachak et al., 2023). These types of structures are frequently installed along the Swan Canning Riverpark and the extent of the potential shedding of MPs and larger plastic into the local aquatic environment are unknown. While these plastics will impact the estuarine environment where they may slowly degrade and remain for long periods of time (van Emmerik et al., 2022), the plastic that originates from these inland waterways (e.g. rivers and estuaries) are major sources of plastic into the ocean (Jambeck et al., 2015). Therefore, an understanding of the magnitude of the contributions from these potential sources is critical for identifying ways to reduce plastic contamination in estuarine environments.

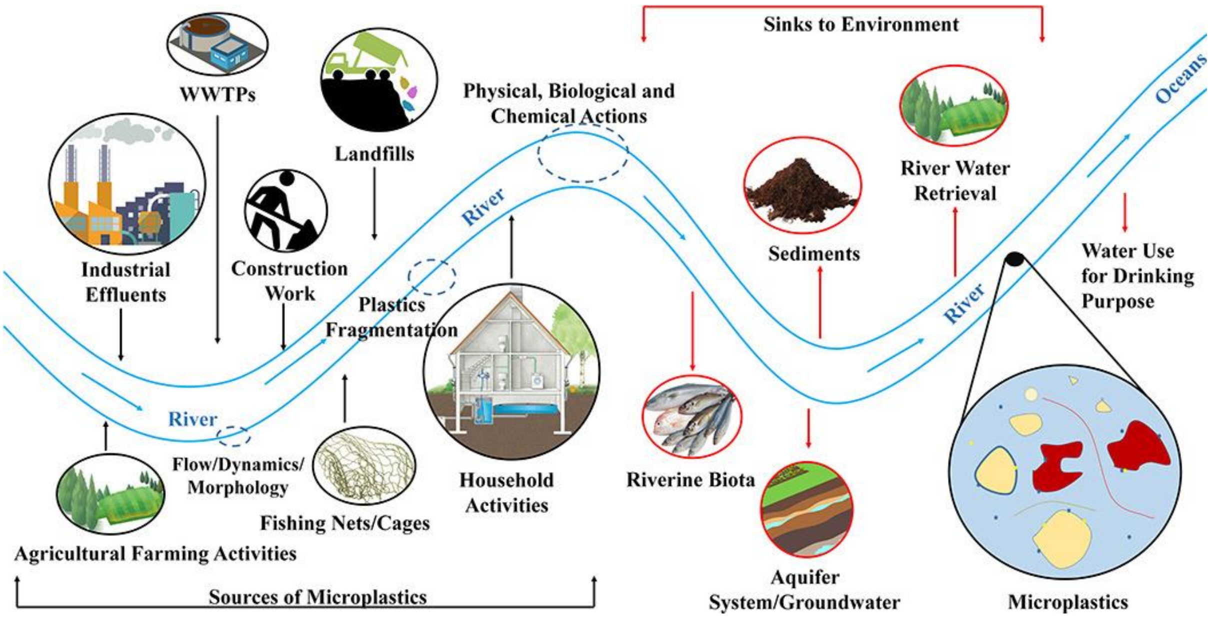


Figure 5. Major sources of microplastic pollution in rivers (WWTPs - wastewater treatment plants). Diagram source (Kumar et al., 2021).

2.2.2 Prevalence of microplastics in aquatic environments

MPs are evident in riverine water (Eriksen et al., 2013; Zhang et al., 2020) and sediments (Scherer et al., 2020; Singh et al., 2021) around the globe. The composition and prevalence of MPs varies spatially and temporally (Kumar et al., 2021), and is heavily dependent on the level of localised anthropogenic pressures from industrial activities and high population densities (Birch et al., 2020). Studies have found that a significant positive relationship exists between the abundance of plastic in rivers and the vicinity of urban land uses (Baldwin et al., 2016).

A higher abundance of secondary MPs are often evident in riverine systems (van Wijnen et al., 2019) with polyolefins (polypropylene, PP and polyethylene, PE) typically being the most prevalent polymer types (Vaid et al., 2021). MPs fibres are usually the most common form of plastic in surface waters and sediments of riverine systems, followed by fragments (Vaid et al., 2021). MPs that are less dense than seawater can float and be transported significant distances by water and wind currents (Maximenko et al., 2012). Other denser particles, and those biofouled, can sink and contaminate sediment (Andrady, 2011). Sediments act as a long-term sink for MPs in terrestrial, marine and freshwater ecosystems (Guerranti et al., 2017; Morét-Ferguson et al., 2010; Rasta et al., 2020).

Similar to many estuarine environments around the world, the Swan Canning Riverpark is surrounded by urban development, industrial activity and agricultural land uses that could all contribute to MPs contamination (Lutz et al., 2021). The sediments of stormwater drainage systems that may originate from these sources in the Swan Canning Riverpark, had 664 plastic particles per kg with the most prevalent polymers being PE and PP (Lutz et al., 2021). EPS and fragmented hard and soft plastics, often identified from single-use products, were among the most common plastic items found on shorelines in 2021 along the Swan Canning Riverpark (Novak, 2023). Filaments were the most dominant type of plastic in the surface waters of the Riverpark in 2021 (Novak, 2023). Other studies that assessed the concentration of plastic in surface waters in the lower Swan Estuary found, on average, 16,461 pieces (>333 μm in size) per km^2 in 2015, which were predominantly nylon fishing lines (Hajbane and Pattiaratchi, 2017). There is also recent evidence of MPs attaching to seagrass blades of *Halophila ovalis* in the Swan Canning Riverpark (Wright et al., 2023).

An adequate assessment of the types and abundance of MPs within the corridors of the Swan Canning Riverpark is required to benchmark regional variations and determine potential environmental and public health risks regarding the use of plastic in sensitive ecological areas. There is substantial uncertainty regarding the specific types, and the physical and chemical properties of MPs, that could fragment or slough from existing plastic infrastructure and contaminate the local estuarine environment.

2.2.3 Potential impacts from microplastics (physical)

The ubiquitous nature of plastic in estuarine environments, particularly microscopic sized particles, means they are now bioavailable to a greater range of aquatic organisms. The trophic-level transfer of MPs and chemical additives is now evident in several marine and freshwater organisms, including those consumed by humans (Carolina et al., 2019).

MPs are easily ingested by fish (Sanchez et al., 2014) and other aquatic organisms, including fish larvae (Steer et al., 2017), due to their size (i.e. < 5 mm). Therefore, digestive tracts are often the predominant part of the aquatic organisms examined for MPs (Jabeen et al., 2017; Rehse et al., 2016). Once ingested, plastic can translocate to other organs and tissue depending on their size, causing lipid accumulation and inflammation (Lu et al., 2016), immobilisation (Rehse et al., 2016), reduced growth (Au et al., 2015) and mortality (Jemec et al., 2016) (Figure 6). MPs can also accumulate in organisms via filter-feeding mechanisms through gills (Vaid et al., 2021). Molluscs and other benthic organisms may be more impacted from MPs due to their habitat and feeding behaviour (Kumar et al., 2021). MPs can also enter the cells of freshwater and marine microalgae species and reduce algal density and influence photosynthesis (Chen et al., 2020).

The surface of MPs promotes biofouling in aquatic systems which makes particles negatively buoyant and sink to the bottom (Dai et al., 2018). This may distribute MPs across layers of the water column and facilitate accessibility and availability to other types of aquatic organisms, including bottom dwellers (Vaid et al., 2021). Pathogenic microorganisms (e.g. *Vibrio sp*., *Pseudomonas sp*.) can inhabit the surface of biofouled MPs and potentially harm feeding organisms (Harrison et al., 2018). Other studies have found MP generation is directly proportional to the fouling load on macroplastic (>5mm) debris, since it can increase the susceptibility of feeding by detritivores (Hodgson et al., 2018).

The biological effects of MPs from FRP, a plastic commonly used for constructing shoreline infrastructure in the Swan Canning Riverpark, are relatively unknown (Ciocan et al., 2020). It can be assumed that FRP would break down into MPs and glass fibres when degraded (Ciocan et al., 2020). These fragments would have a higher density than sea water and concentrate near the shore adjacent to plastic infrastructure in the Swan Canning Riverpark. Similar to asbestos, human exposure to fibrous materials such as degraded FRP can cause lung cancer, fibrosis and mesothelioma by inhalation (Maxim and McConnell, 2001). Although precise data on the degradation of materials like FRP and the scale of contamination aren't available, it's assumed that the MPs released can potentially accumulate in food chains by zooplankton and filter feeders, and biomagnify into high trophic levels (Wright et al., 2013). Physiological and morphological impacts of FRP containing a polyester-based resin (poly diallyl phthalate) were assessed in a laboratory experiment on juvenile mussels, *Mytilus edulis* (Ciocan et al., 2020). Inflammatory features were observed after particulate glass and plastics were detected in the gastrointestinal tracts and gills of the mussels (Ciocan et al., 2020). Further, swimming impairment and sinking occurred in a species of water flea (*Daphnia magna*) after exposure to powdered FRP (Ciocan et al., 2020). The study concluded that there may be a significant localised impact from FRP on aquatic environments (Ciocan et al., 2020). Though the concentrations of FRP used in these laboratory conditions (Ciocan et al., 2020) would likely be higher than expected *in-situ* environmental conditions in the Swan Canning Riverpark.

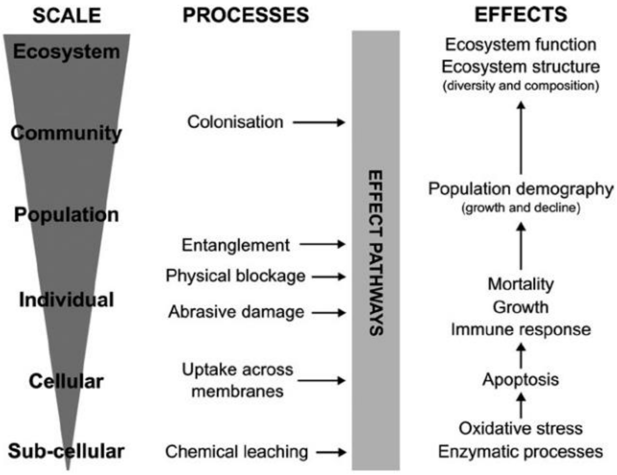


Figure 6. Scale, processes and predicted mechanistic effects from plastics in natural environments. Diagram source (Windsor et al., 2019).

2.2.4 Potential impacts from microplastics (chemical)

Chemicals that leach from plastic and exacerbate their toxicity include a range of additives such as lead based heat stabilisers, phthalate plasticisers and polybrominated diphenyl ethers (PBDEs) (Lithner et al., 2011). These additives can provide process-related or function-related properties and include catalysts, colourants, and flame retardants, for example.

Heavy metals (Brennecke et al., 2016), polychlorinated biphenyls (PCB) (Camacho et al., 2019), polycyclic aromatic hydrocarbons (PAH), organochlorine pesticides (OCP) and pharmaceuticals (Iqbal et al., 2017) can also be adsorbed by plastic in trace concentrations (Rochman et al., 2019). The sorption capacity of MPs is highly dependent on various physical (e.g. surface area, share, size) and chemical (e.g. polymer type, molecular weight, types of additives) properties (Oz et al., 2019). There is also evidence of sub-lethal impacts comprising inflammation and immunotoxin responses in oysters that ingested MPs associated with heavy metals like iron and nickel (Patterson et al., 2019).

UV inhibiting additives would likely be present in the plastics used to construct shoreline infrastructure in the Swan Canning Riverpark since they are exposed to harsh environmental conditions. UV inhibiting additives can include UV light absorbers (UVA) such as benzotriazoles and benzophenones, quenchers (i.e. light stabilisers) or base particle scavengers (i.e. hindered amine light stabilisers), which can be used individually or in blends. Benzotriazoles, for example, were found in the water, sediment and fish from Indian rivers and showed impacts in a range of organisms (Vimalkumar et al., 2018). Further investigation is required to understand the chemical additives in plastics used for shoreline infrastructure to determine their potential pollution impacts in the Swan Canning Riverpark.

3 Methods

3.1 Plastic infrastructure inventory

To determine the prevalence of plastic infrastructure installed throughout the Swan Canning Riverpark an inventory was conducted on potential plastic infrastructure used along the Swan Canning Riverpark. The 23 sites included in the inventory were prioritised over other sites based on their likelihood of containing plastic infrastructure with a range of types and ages. Given the time constraints of the project, additional sites (> 23) were not included in the inventory. The inventory included more sites in the Swan (*n* = 17) than the Canning (*n* = 6) because less sites with suitable plastic infrastructure were present in the latter.

Data collected for the inventory (Appendix 1: Inventory **Error! Reference source not found.**) were obtained from statutory assessment permit applications (if DBCA was involved), online resources (e.g. engineering and manufacturer websites detailing relevant projects, marina and yacht club websites), and contact with project officers / engineers at local councils (e.g. City of Gosnells for Thornlie Nature Trail boardwalk) and managers of yacht clubs and marinas.

The following information constituted the key components required for the inventory (Appendix 1: Inventory): ‘DBCA involvement’ (yes / no), ‘Application type / title’ (if applicable), ‘Suburb / City or council’, ‘Asset owner’, ‘Contributor’ (contact for inventory), ‘Structure type’ (e.g. jetty, boardwalk, pontoon, piles), ‘Plastic component’ (e.g. decking, kick rail, sub-structure), ‘Material’ (plastic polymer type), ‘Manufacturer of plastic’ (if known), ‘Additives’ (known chemicals added to the product; e.g. specific UV stabilizers), ‘Colour’, ‘Year of installation’ and ‘Structure age (years)’.

Information on the plastic component and material was readily available, however, it was often difficult to obtain details on the manufacturer and chemical additives. In particular, the specific chemical additives in plastic products were identified as intellectual property of manufacturers and usually generalized into chemical groups (e.g. fire retardants, UV stabilisers) in material safety data sheets.

The information collected for the inventory (Appendix 1, **Error! Reference source not found.**) w as required before sites most appropriate for visual assessments of degradation could be determined.

Table 2. Inventory summary table of plastic infrastructure assessed at sites along the Swan Canning Riverpark in May 2023. Site abbreviations (Section 7) are provided for sites assessed in rapid visual assessments. FRP: fibre reinforced plastic, PE: polyethylene. * Sites not included in rapid visual assessments.

Plastic component	Material (plastic type)	Site (abbreviation) / structure / age
Decking	FRP (grated)	1. Point Fraser / boardwalk / under construction* 2. University of Western Australia rowing club / boat ramp / under construction* 3. Melville (M-BVP) / bird view platform / < 1 year 4. Thornlie nature trail (T-NT) / boardwalk / < 1 year 5. South of Perth Yacht Club (SPYC) / jetty / 3 years 6. Swan Yacht Club (SYC) / pontoon / 4 years 7. Point Walter boat ramp (PW-BR) / jetty / 4 years 8. Deep Water Point boat ramp (DWP-BR) / jetty / 4 years 9. Kent Street Weir Bridge (KSW-B) / raised walkway / 5 years 10. Middle Swan Canoe Launch (MS-CL) / pontoon / 6 years 11. Millers Pool (MP-BW) / boardwalk / 6 years 12. Aquarama Marina (AM) / jetty / 7 years 13. John Tonkin Reserve (JT-R) / beach access ramp / 8 years 14. Perth Flying Squadron Yacht Club (PFSYC) / jetty / 1 & 8 years 15. Swan Yacht Club (SYC) / jetty / 9 years 16. Leeuwin boat ramp (L-BR) / jetty / 9 years 17. Applecross (A-BW) / boardwalk staircase / > 9 years 18. Pier21 Marina / jetty / 13 years*
	Recycled plastic	1. Rockwood Street (Esplanade) Jetty (RS-J) / jetty / 2 years 2. Applecross (A-BW) / boardwalk / 9 years 3. Pier21 Marina / jetty / 13 years* 4. Mt Henry (MH-J) / jetty / 15 years 5. Pollard Park (PP-J) / jetty / 15 years
	Composite	1. South of Perth Yacht Club (SPYC) / jetty / 6 years
	PP (unknown)	1. Perth Flying Squadron Yacht Club (PFSYC) / jetty / 8 years
Kick rails	FRP	1. Thornlie nature trail (T-NT) / boardwalk / < 1 year 2. Millers Pool (MP-BW) / boardwalk & platform / 6 years 3. John Tonkin Reserve (JT-R) / beach access ramp / 8 years
	Recycled plastic	1. Melville bird view (M-BVP) / platform / < 1 years 2. Rockwood Street (Esplanade) Jetty (RS-J) / jetty / 2 years 3. Applecross (A-BW) / boardwalk / 9 years 4. Mt Henry (MH-J) / jetty / 15 years 5. Pollard Park (PP-J) / jetty / 15 years
Substructure	FRP	1. Melville bird view (M-BVP) / platform / < 1 years 2. Thornlie nature trail (T-NT) / boardwalk / < 1 year 3. Rockwood Street (Esplanade) Jetty (RS-J) / jetty / 2 years 4. Matilda Bay interpretation node / boardwalk / 3 years* 5. Point Walter / boardwalk / 6 years* 6. Applecross (A-BW) / boardwalk / 9 years
	PE (float bricks)	1. Swan Yacht Club (SYC) / pontoon / 4 years 2. Middle Swan Canoe Launch (MS-CL) / pontoon / 6 years 3. Aquarama Marina (AM) / jetty / 7 years 4. Perth Flying Squadron Yacht Club (PFSYC) / jetty / 8 years
Pile sleeves + capping	PE	1. Pier21 Marina / jetty / > 2 years* 2. Swan Yacht Club (SYC) / pontoon / 4 years

		3. Middle Swan Canoe Launch (MS-CL) / pontoon / 6 years 4. Aquarama Marina (AM) / jetty / < 8 years 5. Perth Flying Squadron Yacht Club (PFSYC) / jetty / 8 years 6. Applecross (A-BW) / boardwalk substructure (no caps) / 9 years 7. South of Perth Yacht Club (SPYC) / jetty / 0 - 23 years
Chafer posts	Recycled plastic	1. Aquarama Marina (AM) / jetty / 2 - 10 years
	Other	1. Swan Yacht Club (SYC) / jetty / unknown
Fenders	Rubber / PE / foam	1. Point Walter boat ramp (PW-BR) / jetty / 4 years 2. Leeuwin boat ramp (L-BR) / jetty / 9 years 3. South of Perth Yacht Club (SPYC) / jetty / 0 - 10 years
Handrails	FRP / unknown	1. Melville bird view / platform / < 1 years 2. Middle Swan Canoe Launch (MS-CL) / pontoon / 6 years 3. Applecross (A-BW) / boardwalk staircase / > 9 years
Seats	Recycled plastic / composite	1. Pollard Park (PP-J) / park next to jetty / unknown 2. Rockwood Street (Esplanade) Jetty (RS-J) / jetty / 2 years 3. Millers Pool (MP-BW) / near boardwalk / 6 years
Posts	Recycled plastic	1. John Tonkin Reserve (JT-R) / beach access ramp / 8 years

3.2 Plastic infrastructure site assessments

3.2.1 Site selection

A total of 17 of the 23 sites in the plastic infrastructure inventory were assessed along the Swan Canning Riverpark in May 2023 (Figure 7). Site selection was based on the presence / types of plastic infrastructure and the installation date to ensure a broad range of potential degradation was assessed. Permission was obtained to visually assess infrastructure at private marinas and yacht clubs. Given time restrictions on site visits, some sites were excluded when the plastic infrastructure was similar in age or in a similar location to plastic infrastructure at another site. Some of the other 23 sites in the inventory were not included in site assessments because construction was due to commence the same year of assessments and there was no evidence that they had been built yet (e.g. Point Fraser playground, Wungong Brook, Swan Yacht Club floating jetty, University of Western Australia rowing club boat ramp upgrade). The only site where an assessment could not be arranged due to insufficient permissions was Pier21 Marina, which left 17 sites to assess.

Plastic infrastructure along the Swan Canning Riverpark was assessed based on structure type. Degradation of the following structure types were investigated:

- Decking – including FRP grated decking, recycled plastic decking and plastic composite decking.
- Kick rails – FRP and recycled plastic.
- Substructure – FRP and polyethylene (PE) float bricks.
- Piles / chafer posts / wharf fenders – including sleeves, and substructure.
- Miscellaneous items – including handrails, seats, and posts.

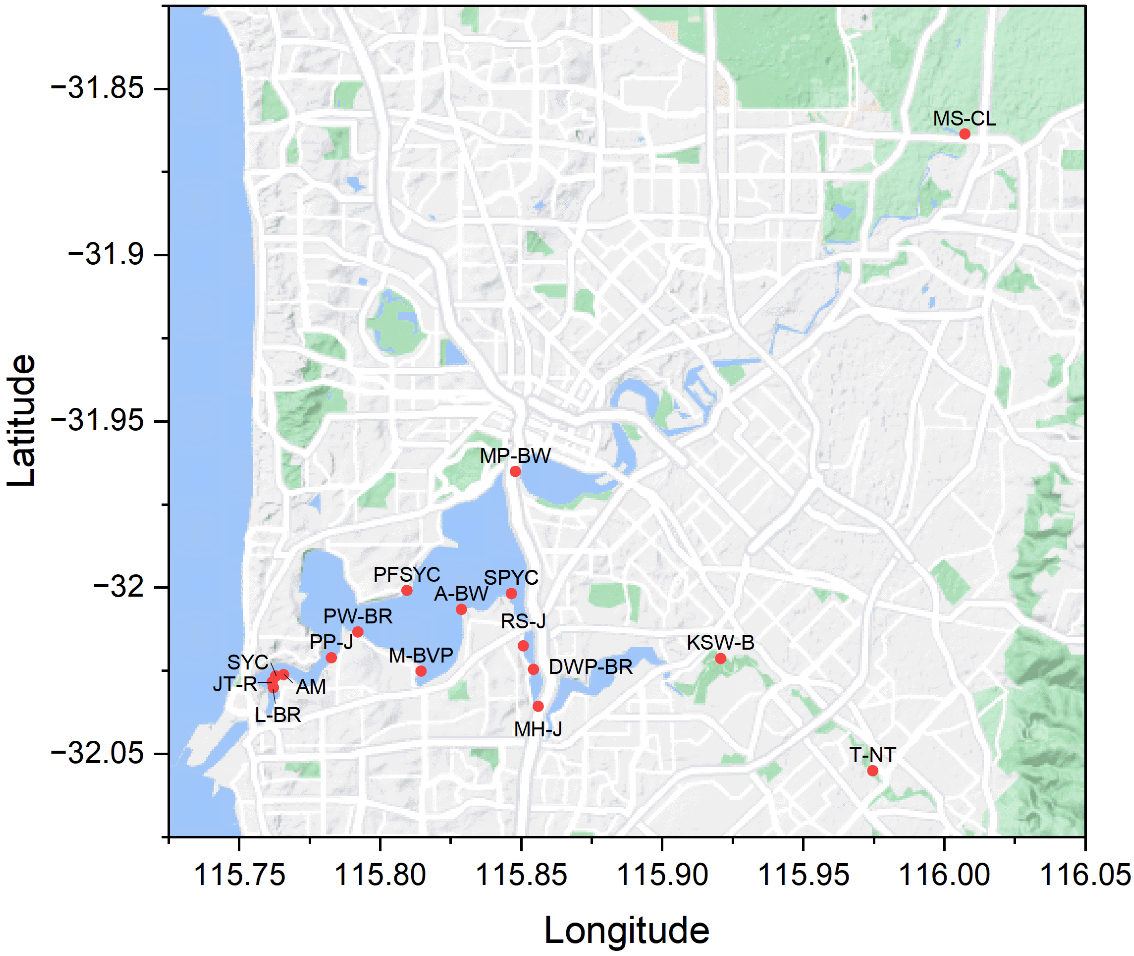


Figure 7. Sites selected for rapid visual assessments in the Swan Canning Riverpark. Refer to Section 7 for site name abbreviations.

3.2.2 Rapid visual condition assessments

A rapid visual condition assessment (RVCA) was conducted on plastic infrastructure at each site to determine the surface degradation of each plastic component (Appendix 2 & 3). Hereafter, degradation refers to surficial wear and breakdown of structures, not the structural integrity of plastics. For decking, the RVCA included a detailed assessment on three sections of 0.25 m^2 quadrat areas (Appendix 2). A section was analysed at either end of the structure (i.e. section closest to the shore and section most exposed on the water) and in the middle of the structure. The surface area of the structure was measured and estimated where possible, particularly for flat and large structures with decking. For piles, the RVCA included a detailed assessment on two sections of 1 m length, where possible. For most piles and other items (e.g. kick rails, seating), the entire structure was visually assessed in detail in a qualitative assessment (Appendix 3).

A general / qualitative assessment (Appendix 2) was also conducted for all structure types and any additional defects were noted. A plastic sample was also collected for future Fourier-transform infrared (FTIR) spectroscopy analysis and photographs were taken throughout the RVCA process to document all evidence of the current condition of structures.

For each quantitative assessment, the following criteria for degradation were considered (refer to Appendix 4 for a visual representation of these criteria):

- Cracks – a line on the surface that was split but was not broken apart (Appendix 4 Table 16)
- Chips - a fragment that was broken off the material (Appendix 4 Table 17)
- Deformation – change in the size or shape of the material (Appendix 4 Table 18). Examples included protruded panels, deflected decking and misaligned panels.
- Material loss – loss of material from users (e.g. abrasion) (Appendix 4 Table 19)

At each site and infrastructure type (i.e. decking, boardwalk), the level of damage for each criterion was rated as negligible, minor, moderate, or severe in the three selected areas along the structure and assigned the following 'points' (Appendix 2):

- Negligible = 0 points
- Minor = 1 point
- Moderate = 2 points
- Severe = 3 points

Ratings for the four criteria (listed above) were summed for every area to provide a degradation score out of 12 (highest possible score for each area). The three degradation scores (i.e. one per area) were averaged to give a degradation index for that specific type of plastic infrastructure (Appendix 2). This level of assessment (quantitative) was only completed for decking given it was the most prevalent and accessible component. Most of the other plastic structures were given an overall rating for each criterion (0 – 3) from the qualitative assessment (Appendix 3).

Quantitative: A mean, and standard error (SE) was calculated for plastic infrastructure where a detailed set of degradation ratings were collected across the structure (e.g. decking). This data was displayed using Origin, R statistical software and Microsoft Office Excel. The relationship between age (years) and degradation index was explored across all plastic materials used for decking using a Pearson correlation test in R studio (R Core Team, 2022). Other potential factors causing degradation of each plastic structure were described but not statistically confirmed given a multitude of factors were likely to affect these structures. The focus of this work was to provide a broad preliminary assessment of degradation in plastic infrastructure and therefore, it did not include any in-depth statistical analyses.

Qualitative: For structures that were less prevalent or more difficult to access and reliably observe, a qualitative set of observations (Appendix 3), accompanied by photographs and detailed descriptions, were collected to document the current conditions of the structure.

4 Results from rapid visual assessments

4.1 Summary

The most common type of plastic infrastructure in the Swan Canning Riverpark was decking used for boardwalks, raised walkways, viewing platforms, pontoons, jetties, and boat ramps featuring in 14 of 17 infrastructure assets (Figure 8). While 17 structures were assessed, some structures had decking of more than one type of material (i.e. composite decking and FRP decking), thus the total number of decking structures assessed was 20.

Plastic was also used to construct kick rails / edging often installed along decking, sub-structure used to support decking, and piles (i.e. sleeves and capping) / chafer posts / wharf fenders, other structures such as seating, and handrails (Figure 8). Kick rails and edging were a common feature on most jetties, boardwalks, raised walkways and pontoons. Piles / chafer posts and wharf fenders of various types occurred on all jetties.

The most common type of plastic covering the largest surface area was FRP used in grated decking. Other types of plastics that were used included recycled plastic for decking and chafer posts, composites for decking and PE for float bricks, pile sleeves and capping (Figure 8). Plastic that could not be identified during the RVCA included those used for fenders and paddings that were often present along jetties to protect siding, piles, or chafer posts exposed to boat strikes (Figure 8).

The type/s and level of degradation changed with structure type (e.g. jetty, boardwalk), component (e.g. decking, piles, wharf fenders) and plastic material (e.g. FRP, recycled plastic, PE). The severity of degradation for plastic decking significantly increased with the age of structure. Although not statistically confirmed, there were likely a multitude of other factors influencing degradation such as impact from boat strikes, wet and dry cycling with mildly alkaline estuarine water, and exposure to high temperatures in the Swan Canning Riverpark.

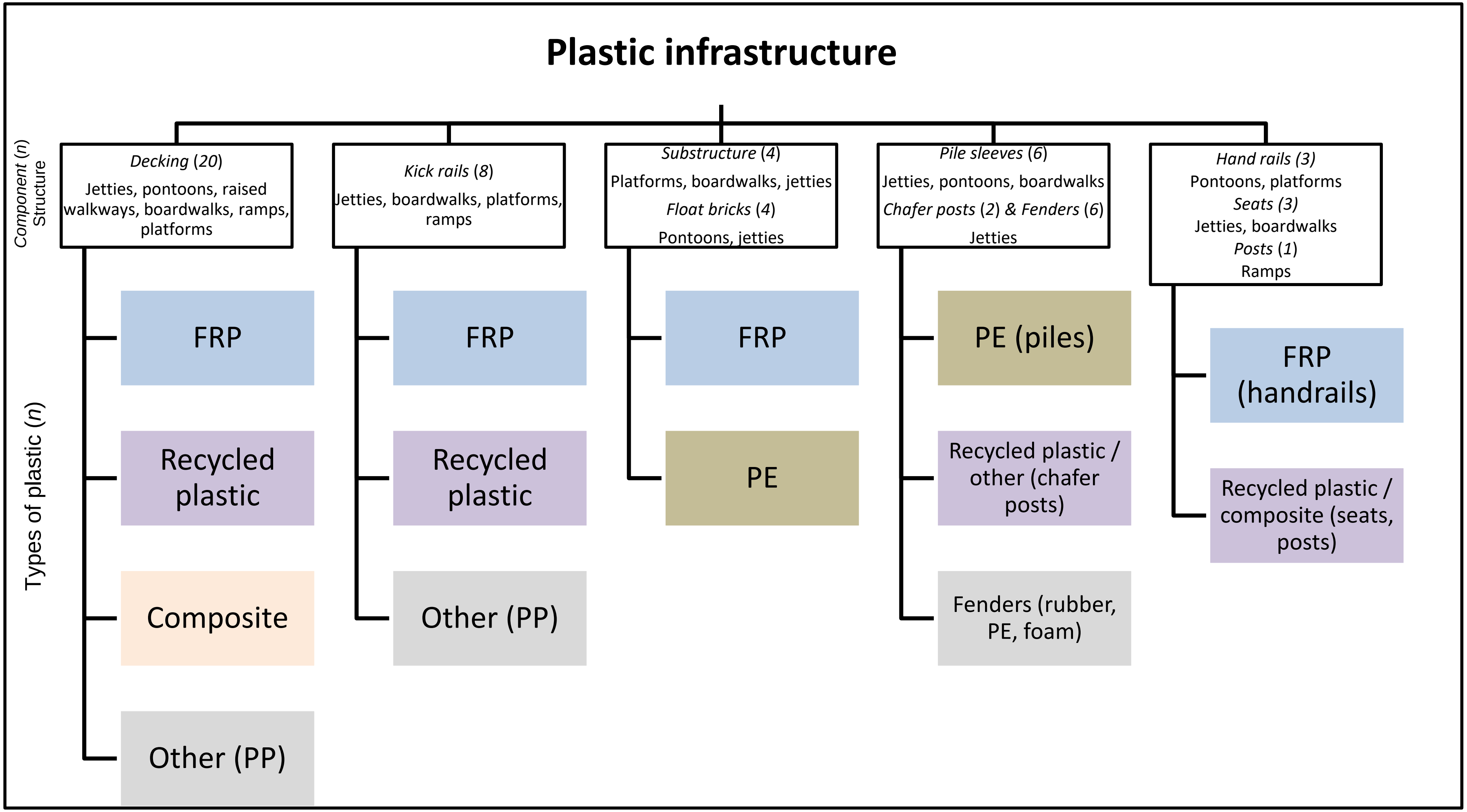


Figure 8. Summary of the plastic infrastructure (components are *italicised*) assessed in the Swan Canning Riverpark in May 2023 (FRP; fibre reinforced plastic, PP; polypropylene, PE; polyethylene).

4.2 Decking

4.2.1 Fibre reinforced plastic (FRP) decking

FRP was used to construct ~70% of all the decking (i.e. 14 of 20 decking) assessed in the Swan Canning Riverpark (Figure 9). A degradation rating was reported for all FRP decking (Figure 10).

All FRP decking was 'grated' (i.e. mesh / grid form) and categorised as either standard grating, mini mesh, micro mesh or solid top (all moulded grating; Appendix 5, Figure 37) with a different surface finish (e.g. flat and gritted, flat/smooth and no grit, concave and gritted; Appendix 5 Figure 38).

Of all the FRP decking assessed in this study 50% was used on jetties (e.g. South of Perth Yacht Club and Swan Yacht Club), ~14% on pontoons (e.g. canoe launch at Middle Swan and floating pontoon at the Swan Yacht Club), ~14% on raised walkways (e.g. Thornlie Nature trail and Kent Street Weir bridge), ~ 7% on ramps (e.g. beach access ramp at John Tonkin Reserve), ~7% for platforms (e.g. Melville bird view platform) and ~7% at board walks (e.g. Millers Pool).

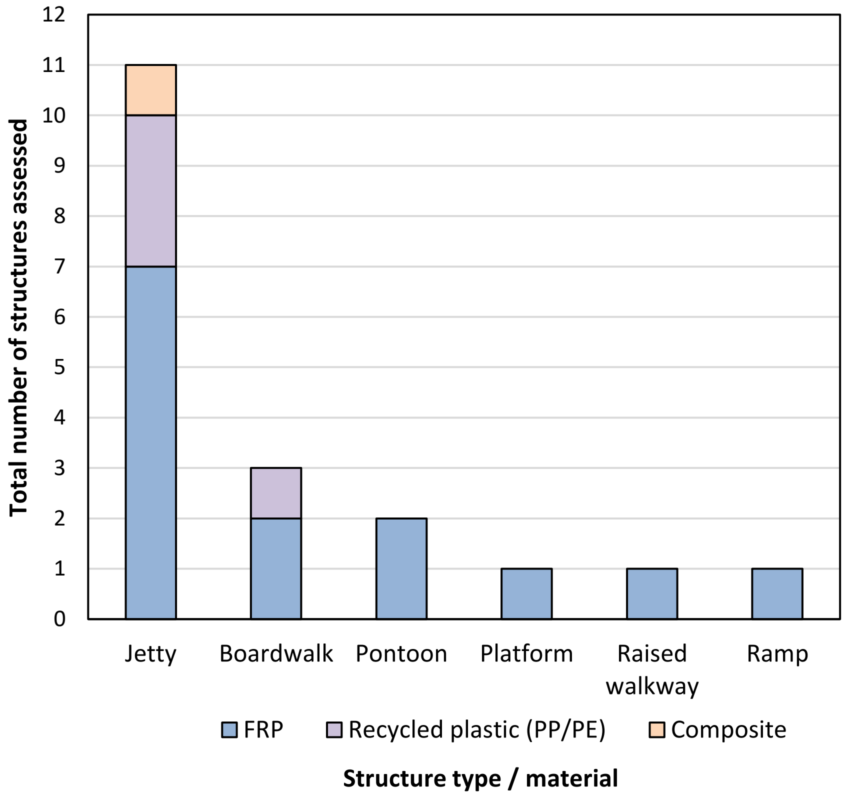


Figure 9. Structures made from fibre reinforced plastic (FRP), recycled polypropylene (PP) and polyethylene (PE) and composites observed in the Swan Canning Riverpark.

FRP decking: Cracks

The degradation score for cracking in FRP decking ranged between minor and moderate with a mean score of 0.81 (SE ± 0.51) (average rating 0 – 3; Figure 10). However, the micromesh grated decking on the ramp and pontoon at the canoe launch in Middle Swan Reserve had moderate to severe cracking (Figure 10). Cracks were prevalent (Figure 11a) and relatively deep (cracked through at least half of the depth of the grating; Figure 11b) across the grating on the pontoon, particularly at the end of the structure. Cracking was rated as 'severe' (rated as 3) on the pontoon in quadrat 3, which was closest to the water (Figure 11b).

The characteristics of the cracking present in most FRP decking structures was often perpendicular to the intersection of joins (Figure 12a, b, c) or inside the corners of the grating (Figure 12a). These cracks were present as surface wear for most structures and rated as minor (degradation score of 1), where few cracks were observed, or moderate if cracks were prevalent (degradation score of 2) (Figure 10).

The severity of cracks worsened towards the edges of the structures, particularly if it was not protected with a kick rail or another form of edging or exposed to other wear in addition to abrasion from foot traffic (e.g. boat strikes).

The only FRP decking where cracking was negligible was the decking with standard grating and a solid top (see Appendix 5 Figure 37) at the Swan Yacht Club (Jetty 2) installed in 2014 and the small beach access ramp with mini mesh grating at John Tonkin Reserve installed in 2015. The FRP decking on Jetty 2 at the Swan Yacht Club was only trafficked by boat users with swipe card access and closed to the public. Furthermore, the ramp at John Tonkin Reserve was shaded and relatively small (~17 m^2) and didn't appear to be used frequently.

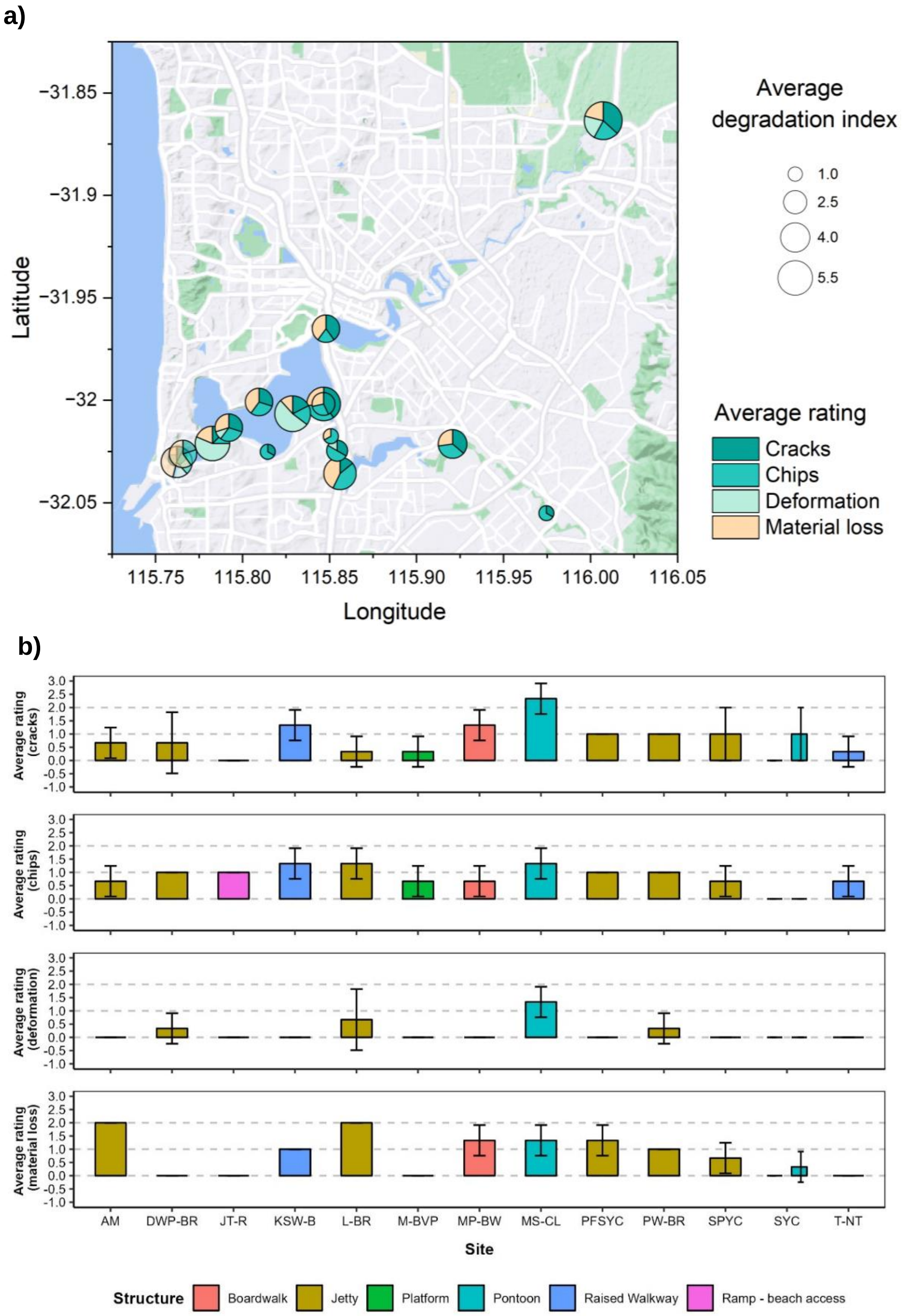


Figure 10. Average degradation rating with standard error from each assessment criteria (cracks, chips, deformation, material loss) across the three quadrats for structures where fibre reinforced plastic decking was used at different sites. Refer to Table 2 for site name abbreviations.

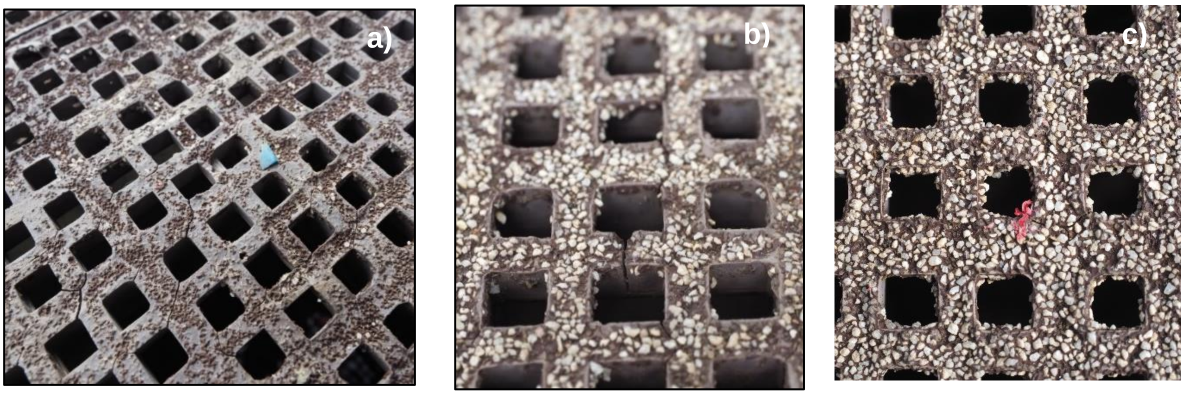


Figure 11. Moderate to severe cracking (a & b) and captured microplastics (c) on the fibre reinforced plastic grated decking used for the canoe launch at the Middle Swan Reserve.

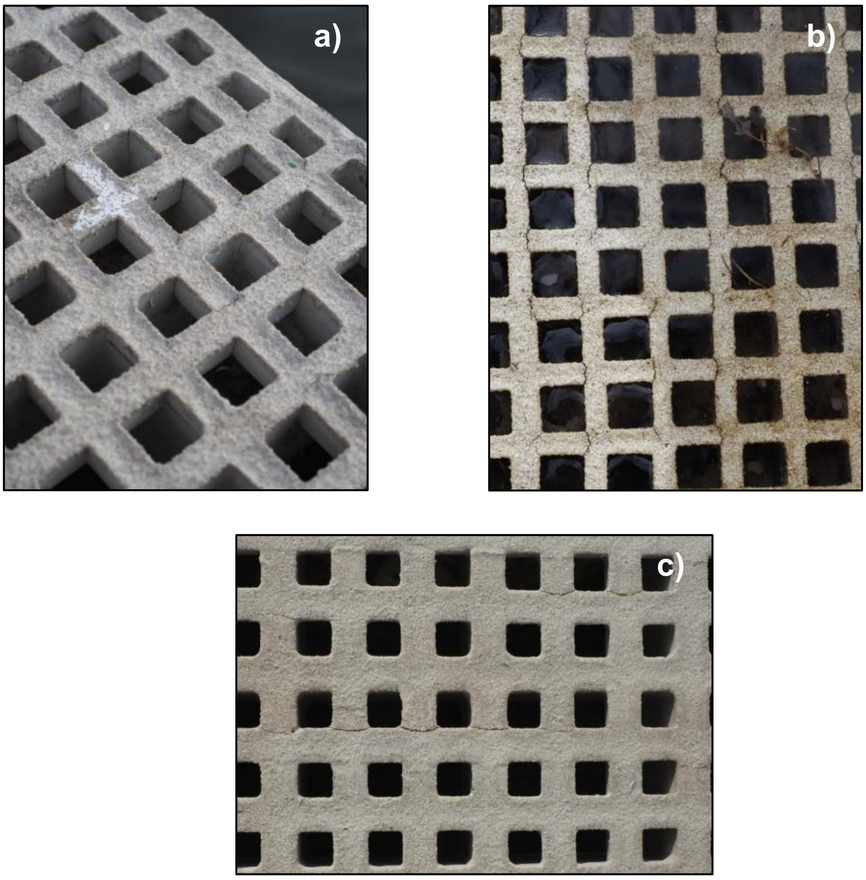
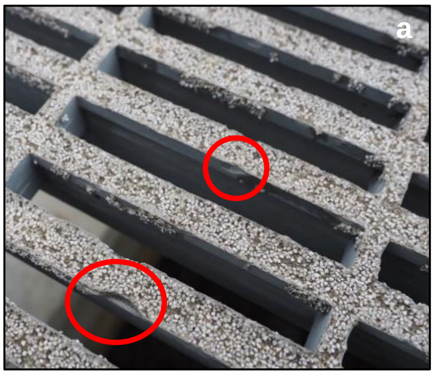


Figure 12. Fibre reinforced plastic (FRP) standard mesh with grit at Deep water Point finger jetty (a) and boat ramp (b) showing where cracking often occurs in grated decking; (c) cracking on FRP decking from quadrat 1 on the pontoon at South of Perth Yacht Club.

Some sites showed a high level of variability in the degradation score, particularly at the jetty and boat ramp at Deepwater Point. Severe cracking was observed in an additional quadrat assessed on the standard grating between the concrete boat ramp and finger jetty at Deep Water Point (Figure 12b). This part of the decking was semi-submerged in water with the cracking being most prominent at the tide line. This grating contrasted with the same type of decking installed at the same time (i.e. 2019) on the finger jetty that averaged negligible to moderate (0.67 ± 1.15 SE) cracking (Figure 12a).

FRP decking: Chips

The mean score for chips in FRP decking was 0.81 (SE ± 0.33) (Figure 10b & Figure 13). Chips were evident in almost all FRP grated decking at all sites, except the jetty at the Swan Yacht Club (Figure 10b). Cracks often led to chipping on the edges of structures such as along the grating at the Kent Street Weir Bridge (Figure 13a) and the beach access ramp at John Tonkin Reserve where FRP panels were joined at different angles (Figure 13b).



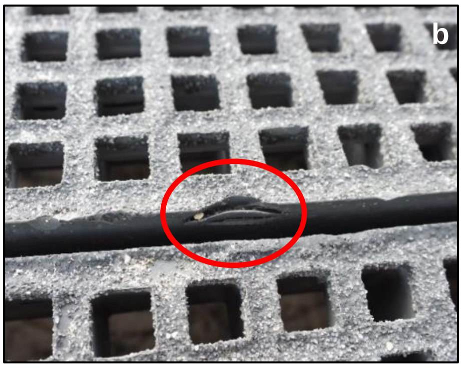


Figure 13. Chipping on grating at Kent Street Weir Bridge (a) and on edging of the beach access ramp at John Tonkin Reserve (b).

FRP decking: Deformation

The mean score for deformations in FRP decking was 0.19 (SE ± 0.21) (Figure 10b). The deformation was mostly negligible (0) to minor (1) for FRP decking except on the pontoon / access ramp at the Middle Swan canoe launch where minor to moderate deformation was evident (Figure 10).

FRP decking: Material loss

The mean score for material loss in FRP decking was 0.79 (SE ± 0.21) (Figure 10b). Most of the material lost from FRP decking was evident in the loss of the surface finishes on the grating, particularly the quartz sand used as the grit for anti-slip (Figure 14). The grit finish seems to protect FRP from initial wear until chipped, scratched or cracked. However, the grit was also abrasive with plastic adhered to gritted surfaces, particularly on the pontoon at Middle Swan canoe launch (Figure 11c). Some material loss caused exposure of fibres such as at an access staircase to the Applecross boardwalk (Figure 14c) and Millers Pool boardwalk (Figure 14d), which could further exacerbate degradation due to exposure of the fibre and resin interface.

The surface of the solid top decking installed at Kent Street Weir showed material loss in about a third of the panels (10 / 33 panels) (Figure 13a & Figure 14a).

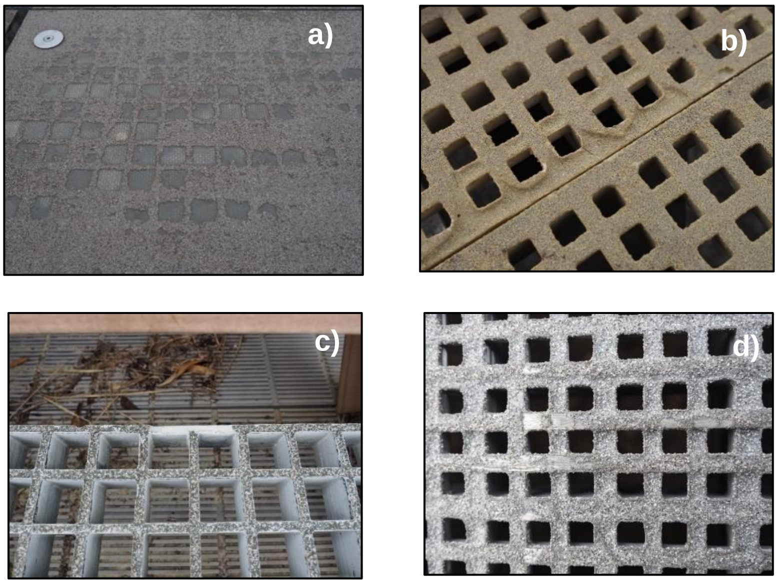


Figure 14. Material loss on the solid top section of the raised walkway at Kent Street Weir (a), the loading jetty at Aquarama Marina (b), an access staircase at Applecross boardwalk (c) and exposed fibres at Miller's Pool boardwalk (d).

FRP decking: Potential causes of degradation

It is worth noting that some owners reported that some panels of FRP had already been replaced due to excessive degradation or damage. It is likely that the degradation observed is not an accurate representation of the total amount of degradation that occurred over the lifespan of FRP structures (Figure 15).

Age: The severity of degradation significantly increased with the age of the structure across all types of plastic decking (Figure 16). Material loss and deformation became more common when structures exceeded five years of age.

Boat strike: FRP decking on the water-facing sides of jetties were particularly susceptible to boat strikes (Figure 17). The centre of the decking on these structures was much less damaged and often showed less exposed fibres than the outside margins of the FRP panels (Figure 17).

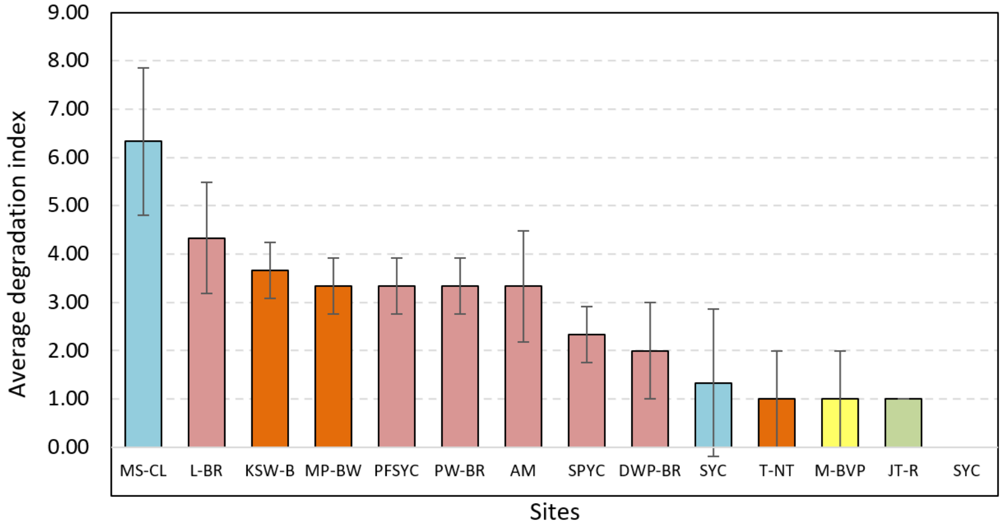


Figure 15. Average degradation index with standard error for structures with fibre reinforced plastic decking across sites. See Table 1 for site names. Pontoons (blue), jetties (pink), boardwalks (orange), platforms (yellow), ramps (green).

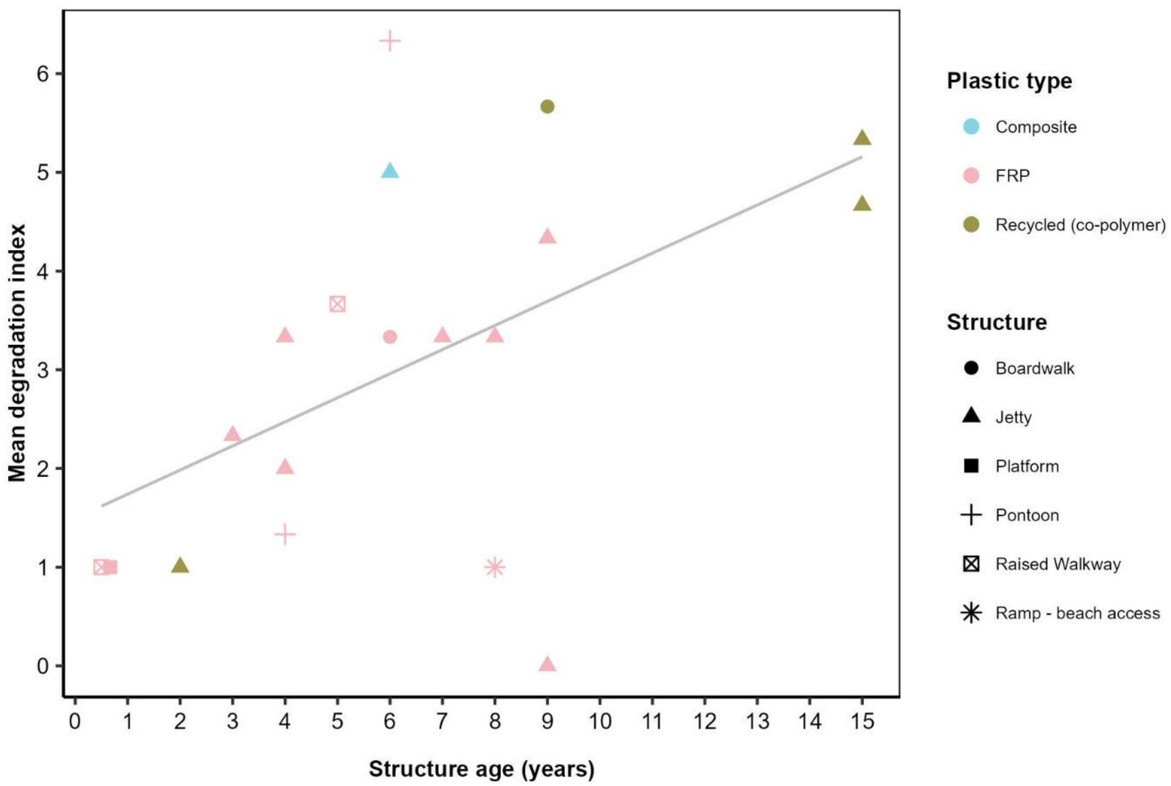


Figure 16. The relationship between the age of a structure (years) and the mean degradation index (FRP – fibre reinforced plastic) for plastic decking on different structure types with a linear trendline (grey).

Alkalinity: Alkalinity may be impacting structures upstream in the Swan River such as Middle Swan Canoe Pontoon. These areas are more susceptible to algal blooms, which are known to exacerbate alkalinity and potentially impact the integrity of FRP. More investigation is required to understand the impacts of mild alkalinity on FRP structures.

Foot traffic: Material loss from worn off grit was evident at sites where heavy foot traffic was reported by the owners of the structure or observed during site visits. Heavy foot traffic could expose the underlying plastic resin to other degradation such as UV radiation (e.g. Kent Street Weir raised walkway).

Wet-dry cycling: Cracks were prevalent on FRP decking when used at boat ramps exposed to wet-dry cycling (e.g. Deep Water Point boat ramp and Point Walter boat ramp).

Structure type and finish: More wear was evident on the edges of grated FRP decking with a larger grid size (e.g. standard grid versus micro-grid) (Figure 17). More wear was also

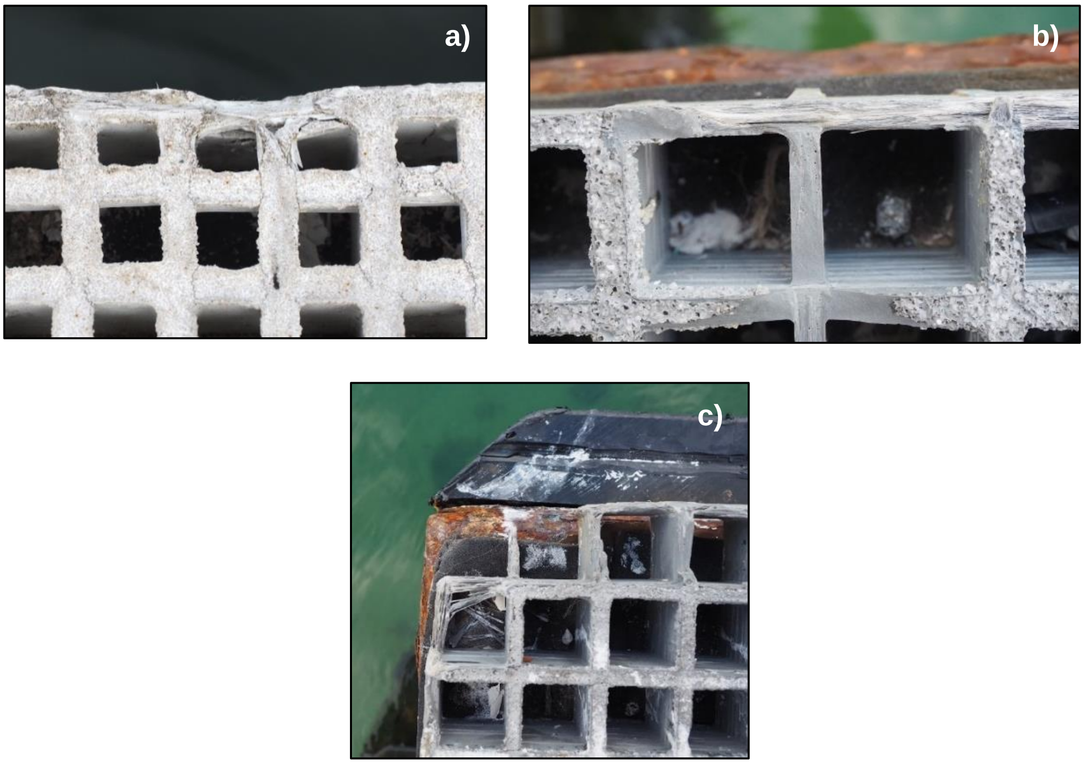


Figure 17. Examples of degradation from boat strikes on edges of grated fibre reinforced plastic decking at Deep Water Point finger jetty (a) and Leeuwin boat ramp finger jetty (b) and (c) end of Leeuwin boat ramp.

observed on FRP decking with a concave (rather than flat) surface finish (e.g. Melville bird view platform) (Figure 18b).

Installation: Scuffing on the edges of newer structures may have been caused from installation and transport of materials to site (Figure 18a).

Figure 18. (a) Fibre reinforced plastic (FRP) kick rail (top), FRP mini mesh edging (middle dark grey layer) and FRP substructure (bottom layer) along board walk at Thornlie nature reserve; (b) FRP decking joins at Melville bird view platform.

4.2.2 Recycled plastic decking

Recycled plastic decking was used to construct 25% of all the decking (i.e. 5 of 20 decking sampled) assessed in the Swan Canning Riverpark. The four sites with recycled plastic decking included: Mount Henry jetty, Rockwood Street jetty, Applecross boardwalk and Pollard Park jetty. All recycled plastic decking appeared to be manufactured by the same company but may contain different compositions and ratios of different plastic types (mostly PP and PE). The majority (75%) of recycled plastic decking was used on jetties (e.g. Pollard Park, Mt Henry and Rockwood) and 25% on boardwalks (e.g. Applecross) (Figure 19 and Figure 20). The mean total degradation index was calculated as 4.2 (SE ± 1.1) out of a possible 12, which was higher than FRP decking at 2.6 (SE ± 0.45), indicating that recycled plastic decking structures were, on average, more degraded than FRP decking structures.

Recycled plastic decking: Cracks

The mean score for cracking in recycled plastic decking was 0.467 (SE ± 0.23). Only minor cracking was observed on recycled plastic decking structures (Figure 19). These cracks were predominantly around the edges of the panels and parallel to the ridges on the panels (Figure 19).

Cracking was more severe on the older structures such as the jetties and boardwalks at Mount Henry (Figure 19a), Applecross (Figure 19b), and Pollard Park (15 years in service). No cracking was observed at Rockwood Street jetty.

Overall, cracking was not a major issue resulting from degradation of recycled plastic decking, as most structures showed negligible cracking.

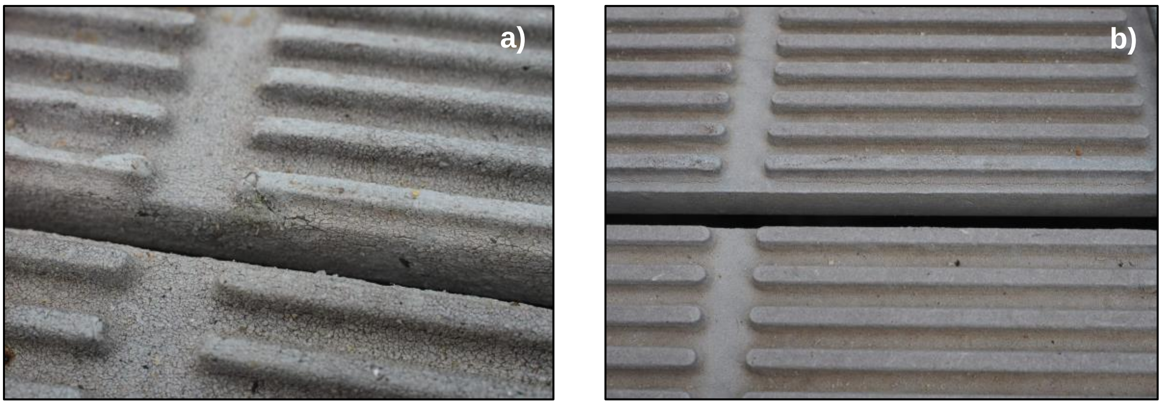


Figure 19. Cracking of recycled plastic decking observed at the Mount Henry jetty (a) and the Applecross boardwalk (b).

Recycled plastic decking: Chips

The mean score for chipping in recycled plastic decking was 1.17 (SE ± 0.57). Major chips were observed in all recycled plastic decking, except for Rockwood jetty, which was built less than three years ago. These chips mostly occurred on the edges of the recycled plastic decking panels (Figure 20).

Minor chipping was also consistently observed in the quadrats on most structures. Severe chipping was recorded in the third quadrat at the Mount Henry jetty where 27 chips were counted, and colourful plastic was exposed from underneath the outer coating (Figure 20a). Some large chips were noted at Pollard Park finger jetty on the outer edges of the panels likely from boat impact. Worn surfaces were evident at the Applecross boardwalk where large chunks of plastic decking had broken off (Figure 20c).

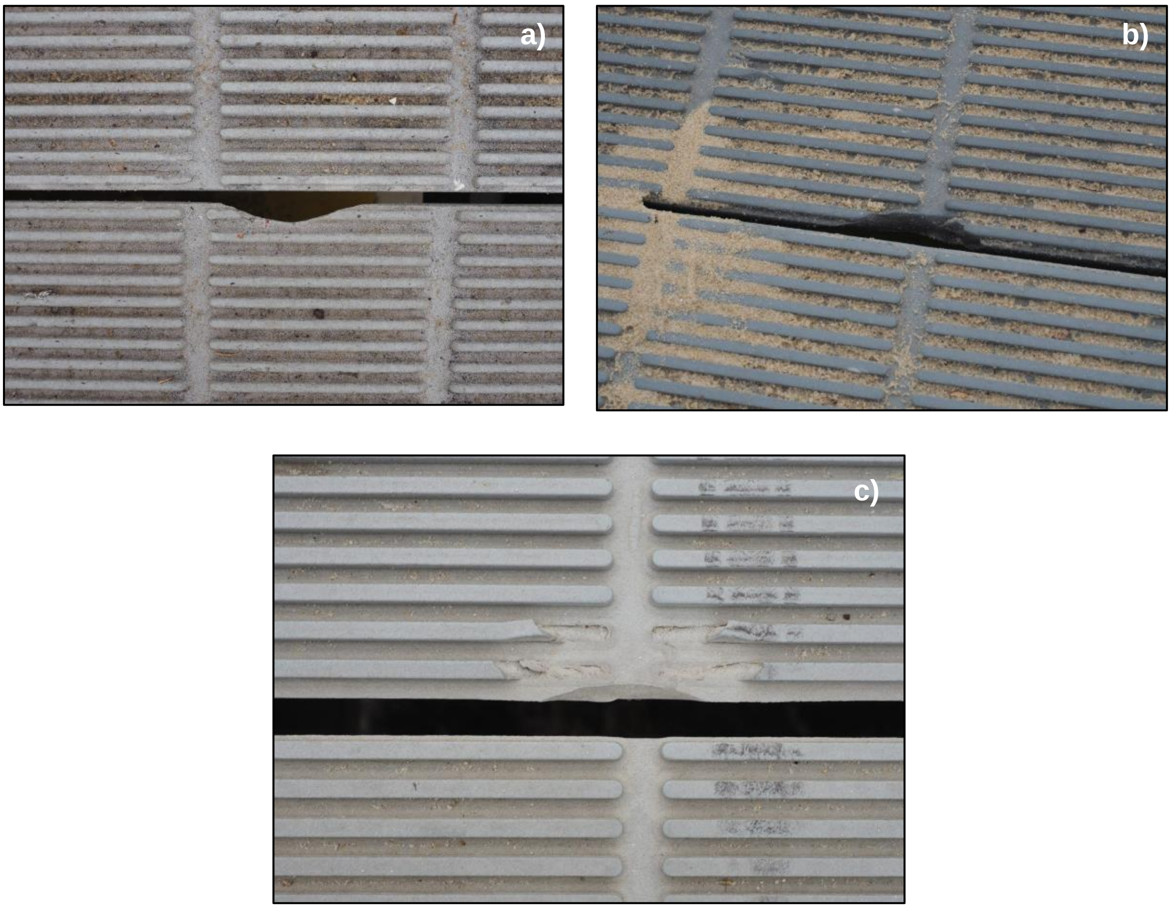


Figure 20. Chipping present on recycled plastic decking at the Mount Henry jetty (a), Pollard Park jetty (b) and the Applecross Boardwalk (c).

Recycled plastic decking: Deformation

The mean score for deformations in recycled plastic decking was 1.5 (SE ± 1.5). Most recycled plastic decking structures showed negligible deformations except for Pollard Park finger jetty

(Figure 21a) and the Applecross Boardwalk (Figure 21c). Deformations at Pollard Park jetty were 8 mm, 6 mm, and 5 mm over a 300 mm section for quadrats one to three, respectively. These large deformations may be attributed to the timber substructure or poor installation methods (Figure 21b). Multiple panels were misaligned and of different colours indicating poor workmanship and / or previous replacement of panels (Figure 21). The recycled plastic decking at Applecross boardwalk was 'dipping' in the middle on some panels (Figure 21) creating deformation that ranged from 5-6 mm across the sampled quadrats.

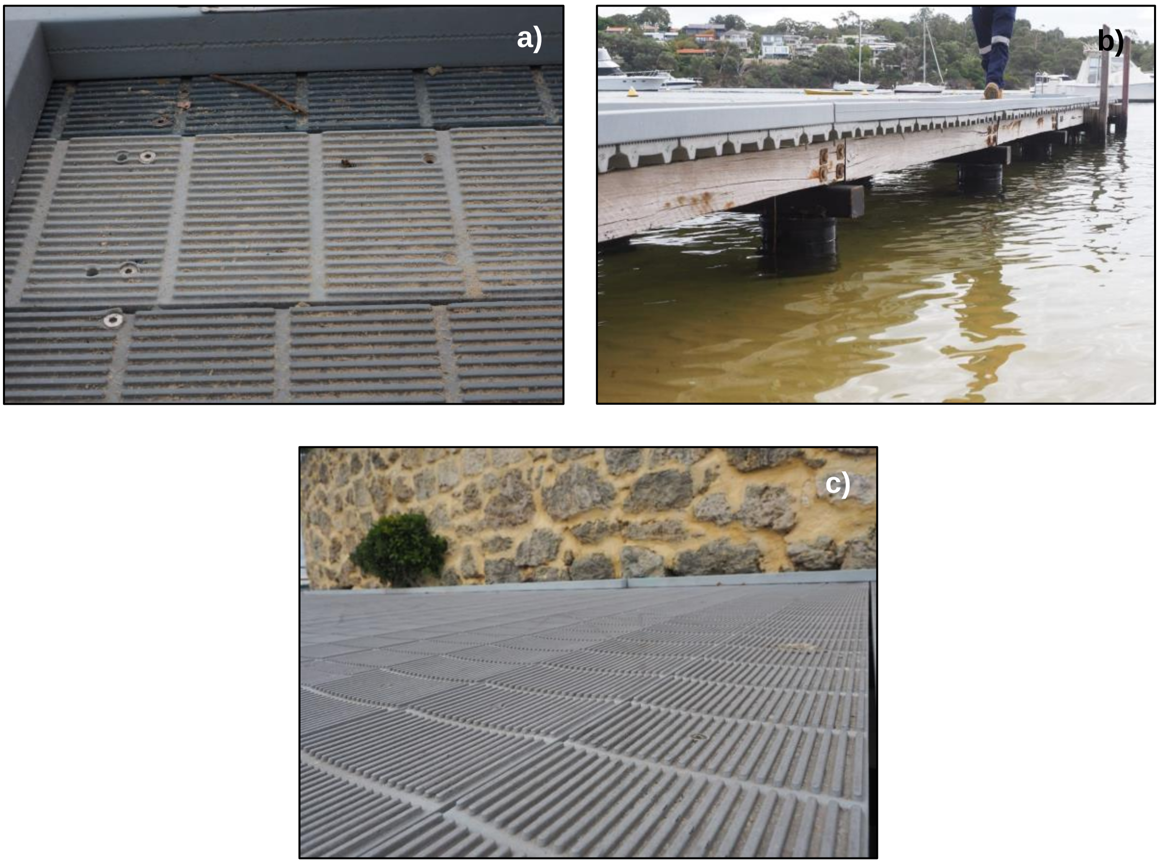


Figure 21. Deformation of recycled plastic decking observed at Pollard Park jetty (a, b) and Applecross boardwalk (c).

Recycled plastic decking: Material loss

Material loss was evident in most recycled plastic decking structures with a mean degradation score of 0.8 (SE ± 0.55). One quadrat on the Mt Henry jetty received a 'severe' rating for material loss due to significant chemical / fire burns causing the top layer to completely disintegrate (Figure 22a).

Exposed plastics (including MPs) were observed on all worn recycled plastic decking structures (Figure 22b). Further degradation of this material could result in the release of plastic fragments breaking off and entering the aquatic environment.

The surface of the recycled plastic decking at Mount Henry jetty and Applecross boardwalk were 'powdery' or 'chalky' and the surface could easily be scratched or rubbed off by hand causing exposure of plastics below the outer surface layer.

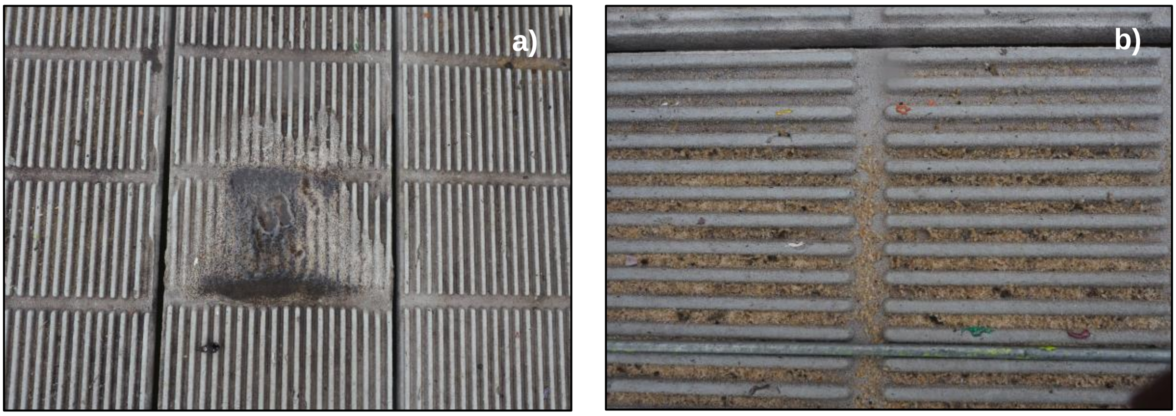


Figure 22. Material loss observed on recycled plastic decking at the Mount Henry jetty (a – chemical or fire damage, b – exposed plastics of different colours).

Overall, the degradation observed at Mt Henry Jetty, Applecross boardwalk and Pollard Park finger jetty were similar (Figure 23). The lowest degradation index was observed at Rockwood Street Jetty, which was the most recently installed asset, in 2021.

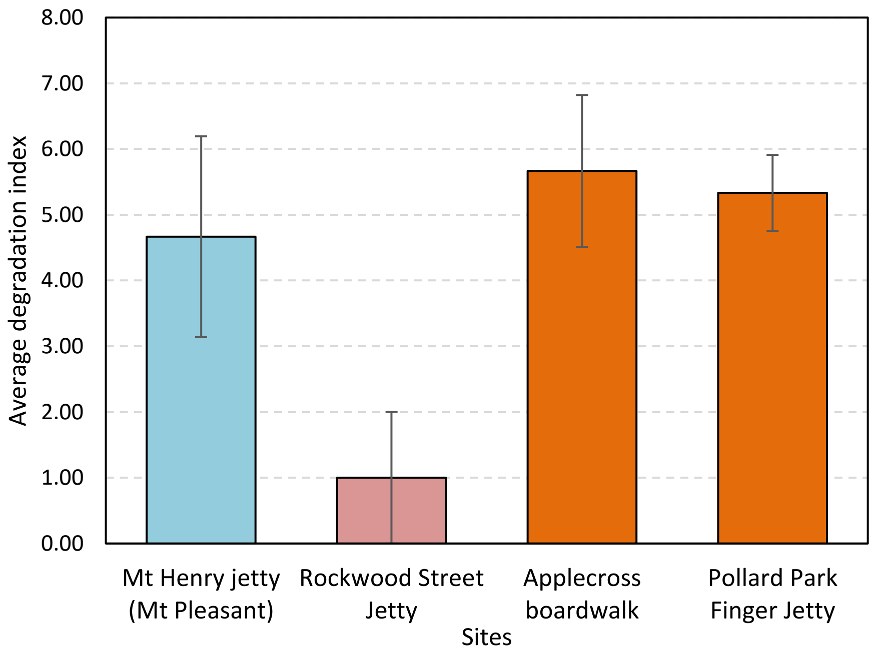


Figure 23. Average degradation index and standard error for structures with recycled decking. Colours indicate structure type; pontoons (blue), jetties (pink), boardwalks (orange).

Recycled plastic decking: Potential causes of degradation

Age: The severity of degradation significantly increased with the age of the structure across all types of plastic decking (Figure 16). Material loss and deformation became more common when structures exceeded five years of age. Rockwood street Jetty was the most recently installed and had the lowest degradation index (Figure 23)

Installation: Evidence of incorrect drilling and preparation for screws (e.g. Rockwood Street jetty) may promote early wear and plastic shedding on younger structures (Figure 24) versus those appropriately installed (Figure 25).

High temperatures / UV radiation: The chalky / powdery texture evident on most of the observed recycled plastic decking is likely caused from high temperatures and UV radiation that may be weakening the surface of the structure.

Boat strike: Similar to FRP, the outer edges of recycled plastic decking used on jetties prone to boat strike were often the most damaged part of the structure.

Abrasion from human traffic: Material loss and exposure of the recycled plastic fragments were observed where human foot traffic was evident.

Timber substructure: Deformation and warping was evident when a timber substructure was used under recycled plastic decking (e.g. Pollard Park jetty).

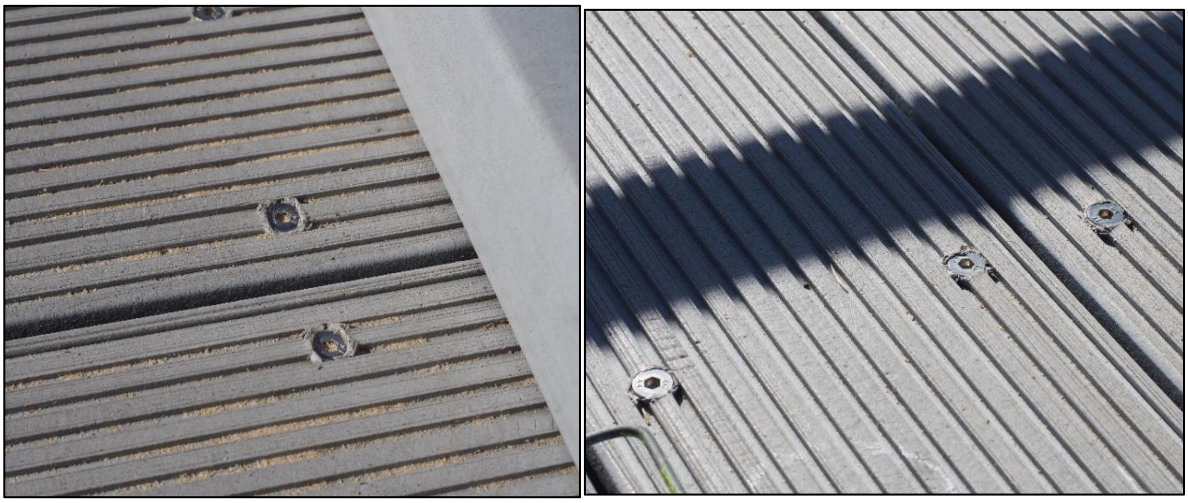


Figure 24. Poor installation of screws to install recycled plastic decking at Rockwood Street (Esplanade) jetty.

Figure 25. Correct installation of screws to install recycled plastic decking at Mt Henry Jetty.

4.2.3 Other decking material

Composite decking

The only composite decking observed during the site visits were found on one jetty at the South of Perth Yacht Club (Figure 26a). Severe chipping and cracking, and moderate material loss was noticed in some quadrats assessed along the jetty (Figure 26a) resulting in an overall degradation rating of 5 for this structure. This was likely an underestimate of the overall degradation of the structure as severe deformation was also noticed along the jetty outside of quadrats. 47 panels had also already been replaced on this jetty. This type of composite decking has since been discontinued. It is expected to be replaced with FRP decking by the end of 2023 from warranty claims.

Polypropylene decking

Decking ‘tiles’ most likely made from PP, were installed on one jetty at the Perth Flying Squadron Yacht Club (Figure 26b). Fading was noticed across the structure and peeling of plastic where panels were joined with a circular disc was also evident (Figure 26b). PP is usually a more rigid type of plastic and may perform differently when exposed to degradation factors that are impacting structures at other sites. More investigation of this material is required before reliable recommendations can be made.

Figure 26. Other types of plastic decking observed including composite plastic at the South of Perth Yacht Club (a) and hard plastic decking (most likely polypropylene) at the Perth Flying Squadron Yacht Club (b).

4.3 Other plastic structures

4.3.1 Kick rails

Plastic kick rails were present on the edges of most boardwalk / platforms and some jetties (Figure 27). Qualitative assessments suggest degradation was relatively minor (Table 3 and Table 4) across all of the observed plastic kick rails (mean degradation rating from visual assessment ~1 or minor). Kick rails were more common on smaller finger jetties (e.g. Pollard Park, Mount Henry and Rockwood Street), which represented ~ 30% of the jetties that were assessed (Figure 27). Half of the kick rails assessed were made from recycled plastic and ~ 37% from FRP. The remaining plastic was a type of composite that was used along a jetty (Rockwood Street jetty) and a platform (Melville Bird View platform) (Figure 27, Table 3, Table 4). Marinas and yacht clubs tended to use aluminium or wooden kick rails instead of plastic.

Aluminium kick rails seemed to wear better than wooden kick rails that required greater maintenance.

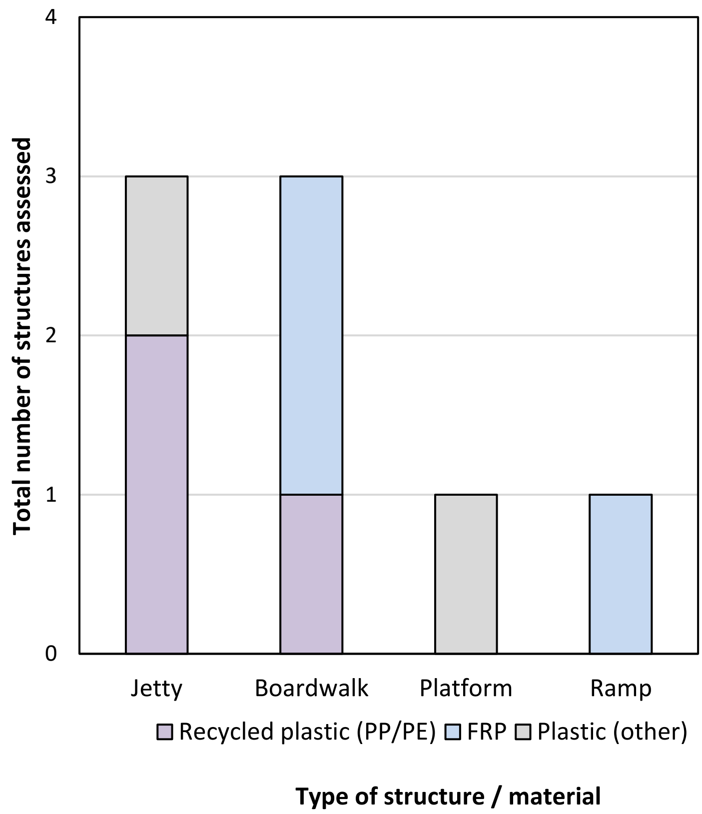


Figure 27. The total number of kick rails by structure and material type (PP: polypropylene, PE: polyethylene, FRP: fibre reinforced plastic).

Table 3. Qualitative visual assessments of fibre reinforced plastic (FRP) kick rails used on different structures in the Swan Canning Riverpark from May 2023.

Material	**Fibre reinforced plastic**		
Structure type	*Boardwalk*		*Ramp (beach access)*
Site name	Thornlie Nature Reserve	Miller's Pool boardwalk	John Tonkin Reserve
Structure age (years)	< 1	6	8
Observations	Scuffing evident from installation or transport.	Peeling of dark blue paint along structure exposed FRP material.	Good condition. Very narrow FRP kick rail but seemed to protect decking well.
Degradation index from observations	1 (minor)	1 (minor)	0 (negligible)
Images from May 2023	 	 	 

Table 4. Qualitative visual assessments of recycled and other plastic kick rails used on different structures in the Swan Canning Riverpark from May 2023.

Material	**Recycled plastic**		**Other**		
Structure type	*Jetty*		*Boardwalk*	*Jetty*	*Platform*
Site name	Mount Henry jetty	Pollard Park jetty	Applecross boardwalk	Rockwood Street jetty	Melville Bird view platform
Structure age (years)	15	15	9	2	< 1
Observations	Chalky / powdery texture. Solid integrity of structure for age.	Chipping and scuffing evident along edges. Powdery texture. 5mm deformation evident.	Relatively good condition with some chalky texture evident on surface.	Likely composite plastic with some minor wear (scuffing) otherwise in good condition.	Thick plank of hard brown plastic (most likely PE / PP), timber look finish which made it look etched and rough. Good condition and looked like it was installed properly.
Degradation index from observations	1 (minor)	2 – 3 (moderate – severe)	1 (minor)	1 (minor)	0 (negligible)
Images from May 2023	 	 		 	 

Plastic kick rails: Potential causes of degradation

Boat strike: A greater number of cracks and chips were noticeable on the outer edges of kick rails used on jetties that were exposed to boat strike. Plastic kick rails installed on structures mostly trafficked by pedestrians (i.e. boardwalks) showed less signs of degradation from chips and cracks.

Installation: There was moderate to severe deformation and warping of the recycled plastic kick rails at the Pollard Park finger jetty, which was most likely caused by incorrect installation particularly evident from the deformation in the rest of the jetty (i.e. recycled plastic decking). The FRP kick rail along the boardwalk on the Thornlie Nature Trail was in good condition except for some 'scuffing' along the sides of the structure (Table 3). Given it was less than one year in age at the time of the RVCA and didn't look like it could be exposed to this kind of wear in its present location, it was most likely caused during installation or transport.

High temperatures / UV degradation: The 'chalky' or 'powdery' surfaces of recycled plastic kick rails likely resulted in material loss from high temperatures and UV degradation. In all cases where this chalky texture was evident, the surface material could easily be rubbed off by hand with minimal pressure. The degraded MP particles from the chalky surface of the kick rails are likely to shed from these structures and enter the surrounding environment. The dark paint on the FRP kick rail at Miller's Pool was severely peeling in multiple places. Paint is often prone to UV degradation from sun exposure and given this site was fully exposed, it could be causing the paint to peel (Table 3). Toxic chemical components in paint could also be contaminating the local environment from painted structures. Further FRP would be more exposed to other types of degradation once the paint peels from these structures.

Manufacturing: Porosity was noticed in some kick rails, particularly recycled plastic, which is likely due to imperfections during manufacturing. This porosity may lead to an increase in degradation due to the ingress of water if plastic is submerged.

4.3.2 Sub-structure and float bricks

All plastic sub-structures observed were made from FRP on fixed structures such as jetties (e.g. Rockwood Street jetty), boardwalks (e.g. Thornlie Nature Trail and Applecross boardwalk) and platforms (e.g. Melville bird view platform) (Figure 28). Only ~ 10% (1 / 10) of jetties observed had FRP sub-structure since most were steel. It was difficult to thoroughly assess the degradation of FRP sub-structure because they were mostly inaccessible. The Applecross board walk, which had the oldest FRP sub-structure observed (nine years), was in the worst condition but it could not be quantitively assessed (Table 5). The degradation of this structure was likely a result of exposure of the boardwalk to salt spray from water and wind forces due to its aspect and location.

Black float bricks made from high density polyethylene (PE) filled with polystyrene for buoyancy were used under floating jetties and pontoons (Figure 28). Floating jetties are becoming more popular than fixed jetties given they are more flexible in changing environmental conditions (e.g. storm surges) and more (safely) accessible to users. Algal growth was evident on bricks and therefore, they often required pressure washing (e.g. six monthly for the Swan Yacht Club pontoon; Table 5). Float bricks were also used under floating jetties at the Perth Flying Squadron Yacht Club and Aquarama Marina, but these were not visually assessed and therefore not included in the summary table (Table 5).

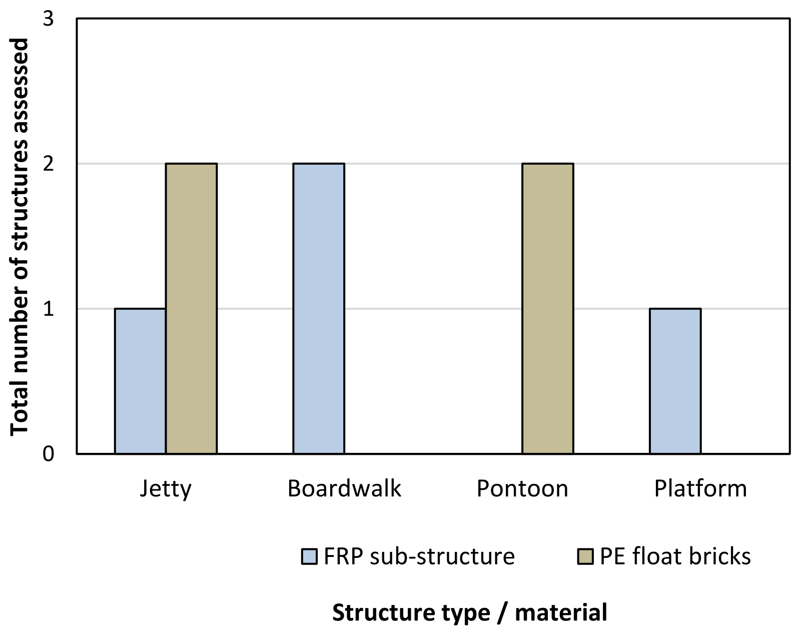


Figure 28. The total number of fibre reinforced plastic (FRP) sub-structure and polyethylene (PE) float bricks used for different structure types.

Table 5. Qualitative assessments of fibre reinforced plastic (FRP) sub-structure and polyethylene (PE) float bricks used on different structures in the Swan Canning Riverpark (May 2023). PE float bricks were also present at the Perth Flying Squadron Yacht Club and the Aquarama Marina but were not assessed.

Material	**FRP sub-structure**				**PE float bricks**	
Structure type	*Jetty*	*Boardwalk*		*Platform*	*Pontoon*	
Site name	Rockwood Street jetty	Thornlie nature trail	Applecross boardwalk	Melville bird view platform	Swan Yacht Club	Middle Swan canoe pontoon
Structure age (years)	2	1	> 9	< 1	4	6
Observations	Good condition as evident from shoreline.	Some light wear (e.g. scratches) possibly from installation.	Fading in colour and wear on surface that was most exposed.	Good condition from side view of structure.	Good condition according to asset owner. Algae present on all bricks.	Bricks used for access ramp in good condition as evident from shoreline.
Degradation index from observations	*Not assessed (limited accessibility)*					
Images from May 2023			 			

Plastic sub-structure and float bricks: Potential causes of degradation

Wet and dry cycling: Most sub-structure and float bricks were constantly exposed to water that may influence the integrity of the structure over time given the likely impacts associated with exposure to wet and dry cycling, particularly for FRP.

Installation: Damage likely occurred during transport and installation, particularly when care was not taken to properly install the structure according to design specifics.

Maintenance: Pressure washing to remove algal growth could degrade plastic over time and shed MPs into the surrounding environment.

UV radiation: The edges of the structure could be more prone to degradation from UV radiation (particularly black float bricks) than surfaces underneath the structure, but they would likely be less impacted than other more exposed plastic structures (e.g. decking).

4.3.3 Pile sleeves and capping / chafer posts / fenders

Piles

Piles are steel pillars of variable lengths wrapped in thick black high-density polyethylene (PE) called a 'sleeve' often topped with a white high-density PE cone shaped cap. The piles can be rewrapped with plastic when the sleeves degrade to prevent the steel from rusting. The sleeves are generally very thick to absorb and dampen dynamic and impact loads from waves and boats. Piles were mostly used on jetties and pontoons to minimise impact from boat strike (Figure 29, Table 6). They were particularly common at marinas and yacht clubs to delineate boat pens and prevent damage to boats (Table 6). Piles were also used as substructure (e.g. Applecross boardwalk) (Figure 29, Table 6). It is likely they were used in more substructures than included in this assessment due to the limited visibility of substructures at some sites. Piles showed minor to moderate surface degradation across structures evident by scuff marks, scratching and gouges most likely from boat impact in most instances, except for damage caused from installation (e.g. high on piles at Middle Swan canoe pontoon).

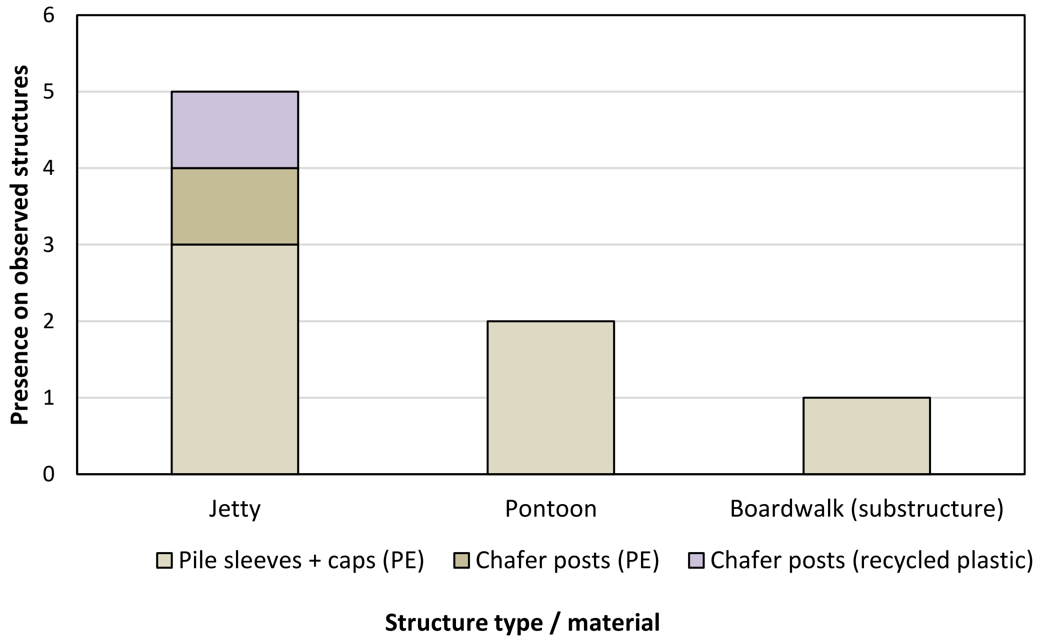
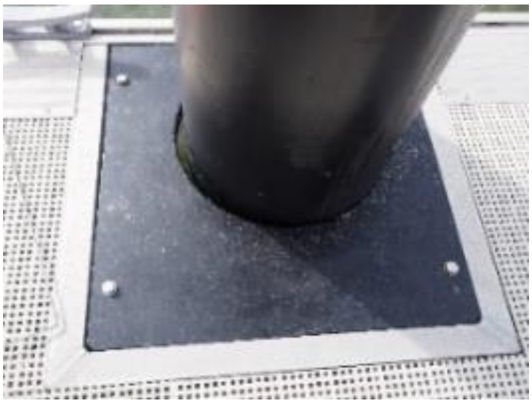
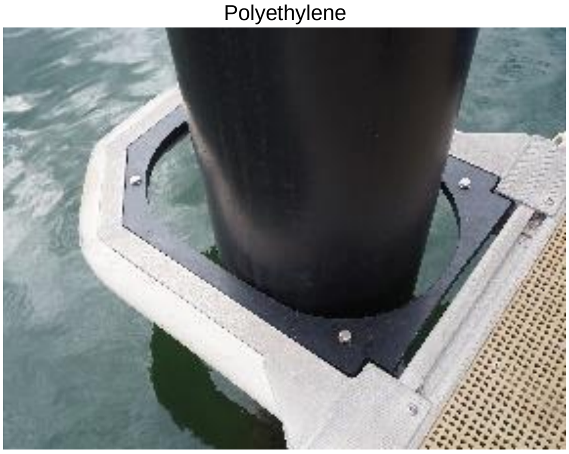


Figure 29. The presence of polyethylene (PE) pile sleeves / caps and PE and recycled plastic chafer posts on different structures.

Pile capping was in relatively good condition; however, it was difficult to assess most caps properly given the height of some piles. Caps did not appear to get as damaged from boat strike as the sleeves themselves. The white colour used for all capping could help reduce UV degradation. Rollers and edging used to allow movement of floating structures around piles resulted in material loss from chaffing (Table 6). Rollers and edging were installed in various ways (Table 6) and were necessary for preventing wear to other plastic structures, such as decking.

Table 6. The materials used to allow movement around piles at various sites around the Swan Canning Riverpark.

South of Perth YC	**Middle Swan canoe pontoon**
Bricks (stone) 	Nylon rollers 
Swan Yacht Club pontoon Polyethylene 	**Aquarama Marina** Polyethylene 

Chafer posts

Chafer posts were made from PE (rigid black plastic) or aluminium with recycled plastic (grey co-polymer of PE and PP) in different sizes (Figure 29, Table 8). Most chafer posts were protected by additional plastic padding or 'fenders' to further absorb impact from boats whilst protecting them from damage. Chafer posts were present along jetties, particularly at marinas and yacht clubs. Most wear was caused by boat strike and evident by scuff marks and scratches. Plastic sloughing and shedding into the river environment was evident in some cases (e.g. Swan Yacht Club). The most damaged chafer posts were relatively tall (~ 2m) and made from recycled plastic at the fuelling station at Aquarama Marina where they were prone to frequent boat strike (Table 8).

Fenders

Fenders provided additional cushioning on chafer posts along jetties prone to boat strike and, therefore, were generally more degraded (Table 9). The softer fenders made from rubber and foam (Figure 30) also meant they were very prone to sloughing of plastic into the water under jetties. A harder unknown type of plastic was used for protecting the corners of the canoe pontoon at Middle Swan. This plastic was faded and severely damaged with larger pieces missing along the edge of the water (Figure 31).

Table 7. Qualitative visual assessments of polyethylene pile sleeves and caps used on different structures in the Swan Canning Riverpark (May 2023). Degradation index applies to sleeves only since capping was often out of reach and could not be reliably assessed.

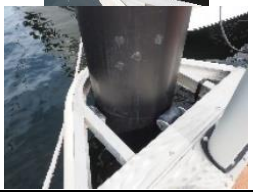
Material	**PE (Pile sleeves + caps)**					
Structure type	*Jetty*			*Pontoon*		*Boardwalk substructure*
Site name	Aquarama Marina	Perth Flying Squadron Yacht Club	South of Perth Yacht Club	Swan Yacht Club	Middle Swan Canoe launch	Applecross boardwalk (no cap)
Structure age (years)	< 8	8	0 - 23	4	6	9
Observations	Slowly replacing wooden piles from 1985. Used in boat pens (not assessed) and loading jetty. Some did not have white PE caps. Scratches from boat strikes evident. Drill tailings evident from capping installation.	Only observed on central floating jetty and were in good condition with minimal scuffing and scratches evident.	Wear evident from boat strike and repairs in some places. Some wear from rollers at base of piles.	Scratches evident on pontoon piles, particularly near table settings and where boats dock. Otherwise in good condition. Could not assess piles used for boat pens.	Very damaged at the top of the piles (far out of reach) possibly from installation. Large chunks of plastic missing along the pile, particularly >2m on piles.	Roughly cut piles with metal and fibre reinforced plastic substructure. Vandalism and damage evident but difficult to assess whole structure as it was mostly inaccessible.
Degradation index from observations	1 (minor)	1 (minor)	1 – 2 (minor to moderate)	1 (minor)	2 (moderate)	1 – 2 (minor to moderate)
Images from May 2023	 		 			

Table 8. Qualitative visual assessments of plastic (recycled plastic and polyethylene; PE) chafer posts used on jetties in the Swan Canning Riverpark (May 2023).

Structure type	*Jetty (chafer posts)*	
Material	**Recycled plastic**	**PE**
Site name	Aquarama Marina	Swan Yacht Club
Structure age (years)	2 – 10	> 4
Observations	Newer grey REPLAS posts (~ 2 years) showed minimal wear. Most degradation (chipping, scratches) were evident on large chafer posts used in the most exposed location at the fuelling station. Most posts had additional plastic padding on outer sides.	Black plastic attached to aluminium posts were used along smaller access jetties for boats. They were scuffed in places with plastic sloughing off.
Degradation index from observations	1 – 2 (minor – moderate)	1 – 2 (minor – moderate)
Images from May 2023		

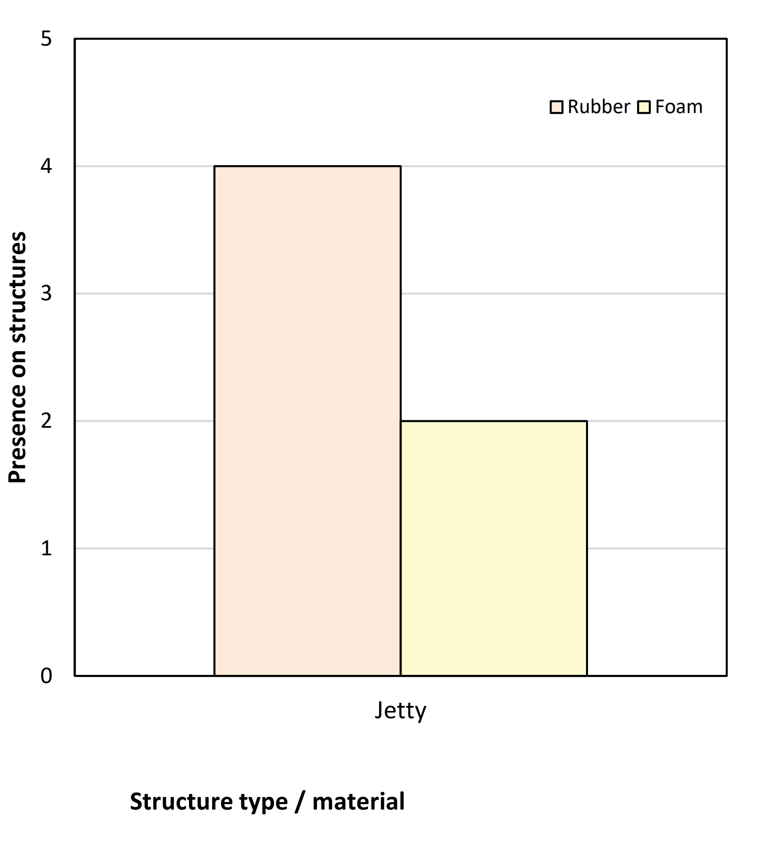
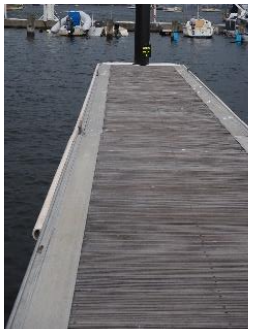
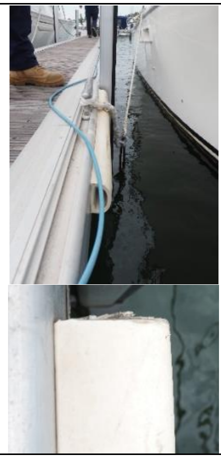
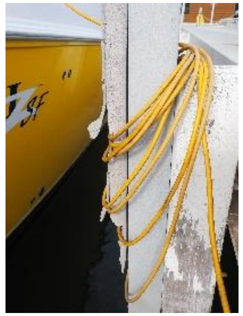


Figure 30. The different kinds of materials used as wharf fenders on jetty structures.

Figure 31. Damaged rigid capping used on corners of the pontoon at Middle Swan Reserve.

Table 9. Qualitative visual assessments of plastic fenders used on jetties in the Swan Canning Riverpark (May 2023). The specific type of rubber and foam are unknown.

Structure type	*Jetty*					
Material	**Rubber (polymer unknown)**				**Foam (polymer unknown)**	
Site name	South of Perth Yacht Club	Perth Flying Squadron Yacht Club	Swan Yacht Club	Point Walter	South of Perth Yacht Club	Aquarama Marina
Structure age (years)	*Uncertain*					
Observations	Faded and shedding noticed at the ends cut roughly during installation.	Faded with mild wear.	General scuffing and wear evident.	Faded with black scuff marks and chunks missing. Powdery texture.	Example in image of foam fender severely damaged with chunks of foam falling off into the river.	Faded and plastic peeling and shedding into river. Huge pieces of plastic found loose on structure.
Degradation index from observations	2 (moderate)	1 (minor)	1 (minor)	2 (moderate)	3 (severe)	3 (severe)
Images from May 2023						

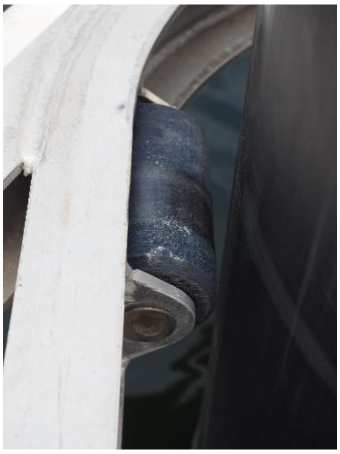
Plastic piles / chafer posts / fenders: Potential causes of degradation

Boat strike: Given the usual purpose of piles, chafer posts and fenders are to minimise impact from boats on jetties and pontoons, most physical damage (e.g. scuffing, scratches, scrapes) was likely caused from boat strike. Fenders were the most impacted plastic structure of all assessed given they are often the first point of contact with boats and a much softer material than the high-density PE and recycled plastic used for piles and chafer posts, respectively.

Wet and dry cycling: Piles and chafer posts were often partially submerged in water and may be more prone to degradation from interacting with estuarine water. Rubber and foam fenders would also be constantly wet from being close to the water. Degraded piles, chafer posts and fenders (i.e. damaged from boat strikes) could be more susceptible to degradation from wet and drying cycling.

Installation: Large scuff marks evident high on the piles at the Middle Swan canoe pontoon suggest damage was possibly caused when they were lowered for installation. Further drill tailings were present where screws were used to install pile caps (Table 10). Peeling PE was observed where edging was cut into shape around the bases of piles. Rigid edging installed around the base of piles could be causing more wear on piles than rollers (Table 6).

Table 10. Other signs of degradation evident on piles in the Swan Canning Riverpark (May 2023).

Site name	Aquarama Marina	South of Perth Yacht Club
Observations	Drill tailings falling out under screws.	Wear noticed on nylon rollers from friction with polyethylene pile sleeve.
Images (May 2023)		

4.3.4 Handrails / seats / posts

Other plastic infrastructure observed during site assessments included: handrails, seats and posts (Figure 32, Table 11 and Table 12). Handrails were likely made from FRP given the fibrous texture observed (Figure 32 and Table 12). Peeling was evident on the end of the rail when it was not capped (e.g. Applecross boardwalk) (Table 12). The handrail at the Middle Swan canoe pontoon was reportedly replaced in 2022 but it was already looking rusted and the plastic on the top (likely FRP) was degrading. Most of the railing was submerged in water at this site (Table 12). Seating (most likely recycled plastic) was installed along some jetties and boardwalks (e.g. Millers Pool) (Figure 32 and Table 11). Most of the seats were in relatively good condition and did not show many signs of degradation, except from some vandalism (etchings) (Table 11).

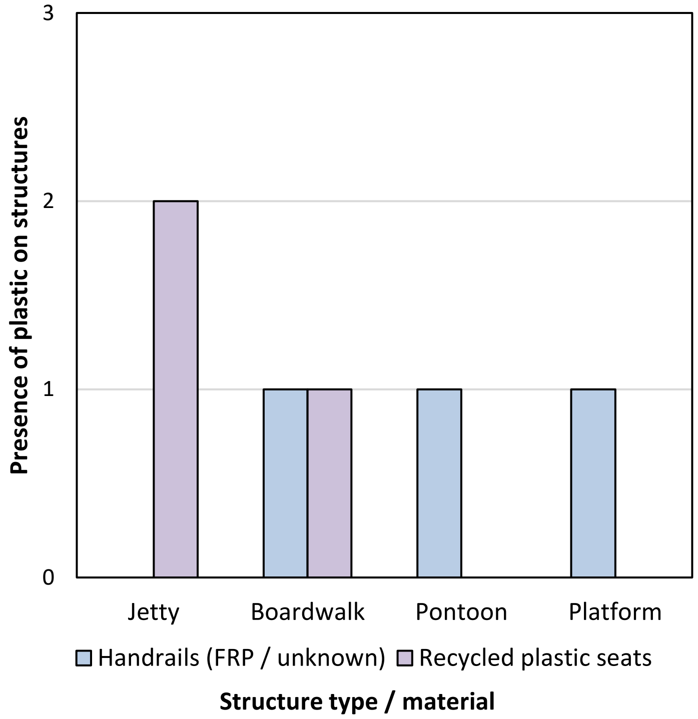


Figure 32. The total number of fibre reinforced plastic (FRP) sub-structure and polyethylene (PE) float bricks used for different structure types.

Plastic handrails, seats and posts: Potential causes of degradation

High temperatures / UV degradation: Fades plastic over time and creates weaknesses in structures, particularly handrails. Not as evident in seats and posts.

Vandalism: Obvious etchings present on structures causing additional degradation, particularly on seats.

Age: Older handrails showed more signs of degradation (e.g. material loss at ends) but this would also depend on the frequency of their use.

Table 11. Qualitative visual assessments of handrails made from fibre reinforced plastic (FRP) on different structures in the Swan Canning Riverpark (May 2023).

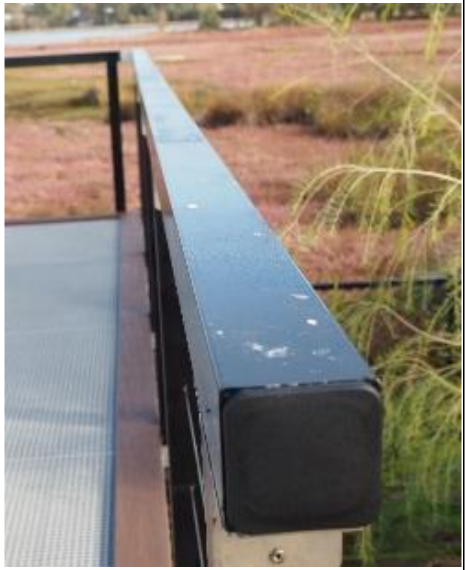
Material	*Unknown*	FRP	
Structure type	*Handrails*		
Site name	Melville bird view platform	Middle Swan canoe pontoon	Applecross boardwalk access staircase
Structure age (years)	< 1	6	>9
Observations	Plastic type needs confirming. Black handrail with no damage present. Plastic capping on ends.	Severely degraded handrail submerged in water and attached to algae covered FRP decking. Partially metal.	Surface layer peeling on end of rail (no capping). Faded brown colour.
Degradation index from observations	0 (negligible)	3 (severe)	2 (moderate)
Images from May 2023		 	

Table 12. Qualitative visual assessments of seats and posts on different structures in the Swan Canning Riverpark (May 2023).

Material	Recycled plastic			
Structure type	*Jetty seats*		*Boardwalk seats*	*Beach access ramp posts*
Site name	Rockwood street jetty	Pollard Park Street Jetty	Miller's Pool boardwalk	John Tonkin Reserve
Structure age (years)	2	Unknown	Unknown	Unknown
Observations	Some chipping and scraping evident likely from vandalism.	Metal frame with plastic seat and backing. Cracking evident from screws. Some scratches present.	Black plastic seat in good condition but not thoroughly assessed.	Plastic posts observed in shaded position along the access ramp and shore front. Good condition.
Degradation index from observations	1 (minor)	1 - 2 (minor - moderate)	0 (negligible)	0 (negligible)
Images from May 2023	 	 		

5 Recommendations

5.1 Conclusions & recommendations

Degradation was evident across nearly all plastic infrastructure assessed in the Swan Canning Riverpark. All types of degradation (except deformation) observed on plastic infrastructure during the RVCA could shed plastics into the surrounding environment and act as a source of local plastic contamination. This plastic contamination could result in negative long-term implications for the Swan Canning Riverpark, given the physical and chemical impacts from plastic that are now well documented in marine and estuarine ecosystems (see Section 2).

The types and severity of degradation observed on each structure were likely influenced by various factors, most notably from boat strikes, age of the structures, wet-dry cycling, exposure to high air temperatures and UV radiation (see Section 2), and poor installation and / or design. The prevalence and mixed effects of these plastic degradation factors suggests that the environment of the Swan Canning Riverpark is not conducive with the properties and therefore, longevity of plastic (particularly FRP exposed to high temperatures and wet-dry cycling). Although degradation increased with structure age (years) for decking, most structures showed premature wear well before their minimum specified design life (e.g. 25 years for some decking).

The use of plastic infrastructure should be carefully considered given there is particular concern with degradation and plastic shedding from structures that directly interact with water and contribute to plastic contamination in the estuary. Plastic infrastructure should only be installed when deemed absolutely necessary, and its use should be subject to a routine maintenance schedule (e.g. biannually) to ensure any damaged or worn components are replaced to minimise material loss, where possible. Further, plastic components that are often replaced during maintenance and / or decommissioning should be repairable or recyclable, where possible.

The use of alternative materials such as timber, concrete, and metal should be prioritised for structures in direct contact with estuarine water. These plastic-free alternatives are often simpler to recycle (e.g. metal) and, in some cases have a greater lifespan (e.g. concrete) or are less toxic to the environment when degraded (e.g. untreated timber). It is recognised that plastic-free alternative materials may not always be suitable or feasible for infrastructure in the Swan Canning Riverpark and their use will strongly depend on the context of an application. The recommendations below provide strategies to minimise impacts in the case where there are existing plastic structures or there are no plastic-free alternatives available.

5.2 Minimizing the impact of Plastic Infrastructure

5.2.1 Decking

If no alternative is available and plastic material must be used for decking, the following recommended use preference is provided in Table 13.

General recommendations for application of plastic decking

1. Edging

Install edge protection on plastic decking, particularly on jetties, to prevent chipping from boat strikes (Figure 33a & b). This defect was noted at all jetties with boat ramps such as Deep Water Point, the Leeuwin boat ramp and Point Walter.

Table 13. Recommended order of use of plastic decking, where use is necessary.

Plastic structure	Material	Order of recommended use	Justification
Decking	FRP solid top	1	• FRP solid tops where grating is fully covered generally wore better than other FRP decking with exposed grating. This may be because of the reduced number of edges of the structure exposed to degradation. The exception was surface wear noticed at Kent Street Weir where the sand grit was lost from high foot traffic. • More plastic material is used in solid top decking relative to grated only, however, solid top decking seems to be a more durable structure overall.
	FRP micro/mini mesh	2	• Grating grids that were tighter seemed less exposed to cracking and chipping on their edges.
	Recycled plastic	3	• Generally, recycled plastic was found to be in worse condition than FRP decking (note: not assessed as thoroughly as FRP decking due to limited sites with recycled plastic decking). • Recycled plastic may release microplastics when small fragments of the recycled plastics are exposed (e.g. colourful embedded plastics evident from surface wear). • Recycled plastic appeared to wear more with age. • Use of darker colours could be absorbing more heat and degrading faster at exposed sites. • More maintenance is required with recycled plastic than jarrah jetties. Decking screws become loose under lots of foot traffic and as the boards move, they bore out the hole (according to Pollard Street contributor).
	FRP standard grating	4	• Least favourable type of FRP grated decking, as the edges of the grid are more exposed to wear (e.g. chips and cracks) and appear generally weaker when impacted by boat strike. • Avoid a concave finish where possible as the upper thinner edges were more easily chipped.
	Composite	5	• Difficult to make recommendations based on one observation (South of Perth Yacht Club jetty) that was severely degraded. This example was a poorly designed product that was discontinued. It showed severe cracking and breaking along panels after only six – seven years of use.

Metal transition plates and rollers are also recommended between adjoining panels to ensure the decking is protected and to guarantee the longevity of the decking itself (Figure 33c). Ensure plastic panels have edge protection where the gradient changes or where there is a large gap between panels. This was a noticeable defect at John Tonkin Reserve (Figure 33d).

Figure 33. Aluminum edging used on Jetty 2 at the Swan Yacht Club (a), South of Perth Yacht Club (b), and Swan Yacht Club pontoon (c) protected fibre reinforced decking from wear in comparison to an example where edging is recommended (d - John Tonkin Reserve beach access ramp).

2. Prevent damage during installation

Ensure that screw / bolt holes are countersunk (where applicable) in the workshop to prevent ‘fraying’ around the screw / bolt head. This defect was noticed at Rockwood Street jetty due to poor workmanship and quality (Figure 24).

3. Positioning

Avoid using plastic on the tide line to avoid exposure to wet and dry cycling. FRP presented significant cracking at Deep Water Point (Figure 34a) and Point Walter jetty boat ramp (Figure 34b) when used on the tide line. Nearly every grid in the FRP was cracked in the tide line area and greater than 100 cracks were counted in a 0.25m^2 area. Potential impacts from wet and dry cycling on other types of plastic infrastructure requires further investigation.

4. Colour

Avoid using dark grey or black decking in areas prone to high air temperatures and UV exposure, as the heat absorbed may make it unsuitable for pedestrian use and potentially contribute to degradation (particularly fading of colour and weakening of structure).

Figure 34. Examples of fibre reinforced plastic exposed to wet and dry cycling at Deep Water Point (a) and Point Walter boat ramps (b).

Fibre reinforced plastic specific recommendations for decking

Avoid installing FRP in potentially alkaline environments such as freshwater sections of the Canning River and upstream in the Swan River. This alkaline environment, which may increase during algal blooms, could exacerbate degradation causing premature wear or failure of the plastic infrastructure, however, more investigation into impacts from mild alkalinity are necessary.

Ensure plastic panels are adequately protected and care is taken during transport and installation to prevent plastic chipping around the edges of the structures. According to FRP engineering, an epoxy sealer should be used to coat all cut or sanded surfaces before installation to prevent corrosive chemicals from reaching exposed glass fibers. Premature chipping and wear will promote early wear of these structures by exposing fibers and degrading the matrix-fibre interface. This was a common defect noted in plastic structures that were less than a year old, such as the Melville bird view platform and the Thornlie Nature Trail boardwalk. A transport design or transport procedure could be included in applications to avoid this issue.

Further avoid using white / light grey decking in areas prone to staining (e.g. jetties; Figure 35), as they may require more cleaning (e.g. pressure washing) that could potentially wear away the surface grit and expose the structure to premature degradation.

Figure 35. Staining of solid top fibre reinforced plastic decking on jetty at Swan Yacht Club.

Fabrication should occur offsite (where possible). ‘FRP engineering’ recommends that fabrication should occur onsite to improve accuracy, however, it’s recommended that any cutting or sanding of plastics should occur away from the edge of the water where possible and cleaned up immediately.

Panels with grating should be cut so bars of adjoining panels are aligned and leave a solid bar or ‘banding’ on all sides (i.e. not cut on diagonals). This did not always occur for the infrastructure assessed, particularly when decking was sometimes cut at angles at the end of jetties (e.g. Deep Water Point finger jetty; Figure 36). Though even when the FRP decking is cut on the banding at the end of jetties, damage cannot be prevented from boat strike (e.g.

finger jetties at Leeuwin boat ramp Figure 17c) and therefore, additional durable edging is required.

A maintenance schedule should be developed for FRP products. This maintenance schedule should include tightening of all bolts or screw on all panels to avoid vibrations induced by people walking on the structure. The maintenance schedule should also include reapplying surface protective coatings or top grit to prevent further wear and degradation of FRP. The FRP structure should be inspected approximately every six months and any panels that are degraded or damaged should be replaced.

During FRP decking decommissioning, care should be taken to avoid any damage to the FRP that may result in material loss and plastic shedding. Any material resting on the substructure (i.e. soil or sand) should be carefully cleaned and disposed of, as it may contain MPs. All waste from FRP panels should be disposed of as per local council requirements.

Figure 36. Fibre reinforced plastic decking cut on an angle and showing chipping at the end of Deep Water Point finger jetty.

5.2.2 Plastic structures other than decking

Table 14. Recommendations for the use of plastics for structures other than decking.

Structure	Plastic material	Recommendations
Kick rails Recommended to protect edges of plastic structures (particularly decking)	Recycled plastic	• Lighter colours recommended to minimise UV degradation. • Do not install where it can become submerged in water. • Structure needs to be properly installed to avoid warping.
	FRP	• Extra care needs to be taken when transporting and installing this material. • Good protection for edges prone to degradation on decking when not exposed to boat strike. • Painting not an effective means of protection unless applied properly, maintained, and used where UV exposure is less intense.
	Other plastics	• Hard plastics (including composites) could be useful for structures such as viewing platforms and jetties but more of these structures need to be observed before recommendations can be made. • Textured surface (rough timber finish) finishes may lead to increased wear and microplastic shedding.
Substructure + float bricks Difficult to evaluate given lack of thorough assessments	FRP sub-structure	• May not be suitable for structures submerged in alkaline water (e.g. jetties, boardwalks) that experience continual wet and dry cycling where FRP appears to be more susceptible to degradation.
	PE float bricks	• Require ongoing maintenance schedule to clean algal build up. • Should be checked every ~five years for cracks or any other wear that could expose polystyrene that is encapsulated in the high-density polyethylene. More investigation is required.
Piles	PE piles with PE caps	• Piles are necessary for structures prone to boat strike. • Steel piles with PE were often used to replace degraded wooden piles. • Damage should be prevented during installation from bracing pile sleeves. Drill tailings should be collected and not be left behind after installation. • Rollers and edging are necessary around the base of piles when used on floating structures to prevent wear to decking and kick rails. Degradation to pile sleeves and sloughing of plastics into water from friction with all types of rollers and edging could be possibly prevented with a greater gap from sleeves. Rollers may cause less wear to the sleeves over time than rigid edging but this needs to be investigated further.
Chafer posts	Recycled plastic	• Do not recommend. Investigate alternative materials. • Constant shedding of plastics into the water given their purpose is to 'chafe' means an alternative less prone to sloughing is required. • Both materials showed similar signs of degradation, but use of recycled plastic chafer posts is more common.
	PE	
Fenders	Rubber	• Do not recommend. Investigate alternative materials. • Worst structure observed for plastic sloughing and showed worst signs of UV degradation. • One of the most impacted structures from boat strikes. • Rubber recommended over foam as the latter seemed more brittle and prone to degradation. • Do not recommend hard plastic capping on edges of pontoons and jetties. Particularly plastic that is prone to brittleness with UV exposure. Aluminium or stainless steel may be a more suitable material to be used as capping.
	Foam	
Handrails	FRP	• Do not use when structure is prone to becoming submerged in water. • Capping recommended at end of rails, where applicable.

5.3 Study limitations and future assessments

Some results were likely skewed for plastic components where ongoing replacement occurred (e.g. piles, decking panels, chafer posts). For example, the composite decking at the South of Perth Yacht Club was in very poor condition, however, scored a total degradation index of 5 since 47 panels were already replaced.

The substructure and underside of decking could not be studied for most structures due to safety, access, and time limitations. Further surveys of substructure are recommended, as this is where the highest tensile forces are likely to exacerbate cracking. This area is also subjected to more severe degradation mechanisms such as wet-dry cycling (e.g. Applecross boardwalk). Piles could also not be safely accessed at most sites, and it is recommended that further research is undertaken to gain a more accurate understanding of their current condition and degradation mechanisms.

Quantitative assessments were mostly done on decking since this structure contributed to most of the plastic infrastructure assessed and was the most accessible. Other structures that were only qualitatively assessed (e.g. fenders, piles) should be more thoroughly assessed in the future before alternatives are recommended.

The study was limited by the maximum age of the infrastructure assessed (i.e. 15 years). Older structures should be surveyed to gain a greater understanding of the performance of plastic infrastructure over the full design life (25 years). Damage and degradation were often noticed well before (< 15 years) the manufacturers recommended design life (25 – 30 years).

It would be beneficial to increase the sample size and repeat assessments at sites over an extended temporal period (e.g. five years) to observe degradation over time whilst measuring degradation factors and allow any relationships between degradation ratings and influencing factors to be statistically analysed.

6 Glossary

Fibre reinforced plastic	FRP is a composite material consisting of a plastic/polymer resin that is reinforced with fibres. Glass fibres with ester resins are the most common material combination in the Swan and Canning rivers.
Recycled plastic decking	A material consisting of various ratios of recycled plastic. The recycled plastic majorly being polyethylene (PE) and polypropylene (PP)
Composite plastic	A composite plastic material consisting of various ratios of plastic. Majorly being polyvinyl chloride (PVC) and polyethylene (PE) and may contain additives.

7 Notations, Abbreviations & Definitions

FRP	Fibre Reinforced Polymer / Plastic
GFRP	Glass Fibre Reinforced Polymer / Plastic
WA	Western Australia
MP	Microplastics
PP	Polypropylene
PE	Polyethylene
HDPE	High Density Polyethylene
PS	Polystyrene
PVC	Polyvinyl Chloride
RVCA	Rapid Visual Condition Assessment

Site abbreviations

MS-CL	Canoe pontoon Middle Swan
T-NT	Thornlie Nature Trail
KSW-B	Kent Street Weir Bridge
MH-J	Mt Henry jetty
DWP-BR	Deep Water Point Boat boat ramp
RS-J	Rockwood Street Jetty
SPYC	South of Perth Yacht Club
A-BW	Applecross boardwalk

MP-BW	Millers Pool
PFSYC	Perth Flying Squadron Yacht Club
M-BVP	Melville bird view platform
SYC	Swan Yacht Club
PP-J	Pollard Park Finger Jetty
L-BR	Leeuwin Boat Ramp
PW-BR	Point Walter jetty / boat ramp
JT-R	John Tonkin Reserve
AM	Aquarama Marina

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9 Appendices

9.1 Appendix 1: Inventory

Table 15. Plastic infrastructure inventory for sites along the Swan Canning Riverpark. May 2023.

Site number	Site name	Swan / Canning	Owner of the asset (location / lease holder etc)	Structure	Plastic component	Material (polymer)	Colour	Wear type 1	Wear type 2 (if any)	Evidence of degradation	Year installed	Structure Age (years)
1	Point Fraser	Swan	City of Perth	Boardwalk	Grated decking	FRP	Unknown	Pedestrian	Playground	No	2023	Under construction
2	Melville bird view platform	Swan	City of Melville	Platform	Grated decking	FRP	Grey	Pedestrian		Yes	2022	<1
					Kick rail	Co-polymer (Ethylene-1-octene copolymer < 50%) + PP (>50%)	Brown			No	2022	<1
					Handrail	Unknown	Black			No	2022	<1
					Substructure	FRP	Black			Unknown	2022	<1
3	Wungong Brook	Canning	City of Armadale	N/A	N/A	N/A	N/A			N/A	N/A	-
4	Mt Henry jetty replacement (Mt Pleasant)	Canning	City of Melville	Jetty	Decking	Co-polymer (Ethylene-1-octene copolymer < 50%) + PP (>50%)	Grey	Pedestrian	Boat strike	Yes	2008	15
					Kick rail	Co-polymer (Ethylene-1-octene copolymer < 50%) + PP (>50%)	Grey			No	2008	15
5	Swan Yacht Club proposals	Swan	Town of East Fremantle	N/A	N/A	N/A	N/A	Boat strike		N/A	N/A	-

	Swan Yacht Club			Pontoon	Grated decking	FRP	White	Boat strike	Pedestrian	Yes	2019	4
					Float bricks	HDPE	Black			Unknown	2019	4
				Jetty	Grated decking	FRP	Grey			Yes	2014	9
				Piles	Sleeves	HDPE	Black			Yes	2019	4
					Capping	HDPE	White			Yes	2019	4
				Jetty	Chafer posts/wharf fenders	HDPE	Black			Yes	Unknown	
6	Thornlie Nature Trail project - Homestead Park	Canning	City of Gosnells	Boardwalk	Grated decking	FRP	Grey	Pedestrian		No	2022	<1
					Substructure	FRP	White			Yes	2022	<1
					Kick rail	FRP	White			Yes	2022	<1
7	Middle Swan canoe pontoon	Swan	City of Swan	Canoe launch	Ramp	FRP	Brown	Pedestrian		Yes	2017	6
				Pontoon	Grated decking	FRP	Brown			Yes	2017	6
				Canoe launch	Handrail	FRP	Yellow			Yes	2022	<1
				Piles	Sleeves	HDPE	Black			Yes	2017	6
					Capping	HDPE	White			Unknown	2017	6
				Pontoon	Float bricks	HDPE	Black			Unknown	2017	6
8	UWA rowing club boat ramp upgrade	Swan	City of Perth	Boat ramp	Grated decking	FRP	Unknown			No	2023	<1
9	Pollard Park Finger Jetty	Swan	City of Melville	Jetty	Decking	Co-polymer (Ethylene-1-octene copolymer < 50%) + PP (>50%)	Grey	Pedestrian	Canoe launch	Yes	2008	15
		Swan			Kick rail	Co-polymer (Ethylene-1-octene copolymer < 50%) + PP (>50%)	Grey			Yes	2008	15
				N/A	Seats	Co-polymer (Ethylene-1-octene copolymer < 50%) +	Grey			Yes	Unknown	

						PP (>50%)						
10	Applecross boardwalk	Swan	City of Melville	Boardwalk	Grated decking	Co-polymer (Ethylene-1-octene copolymer < 50%) + PP (>50%)	Grey	Pedestrian	Cyclists	Yes	2014	9
					Kick rail	Co-polymer (Ethylene-1-octene copolymer < 50%) + PP (>50%)	Grey			Yes	Unknown	>9
					Substructure	HDPE	Black			Yes	Unknown	>9
					Substructure	FRP	Grey			Yes	Unknown	>9
				Staircase	Grated decking	FRP	Grey			Yes	Unknown	>9
					Handrail	FRP	Brown			Yes	Unknown	>9
11	Leeuwin Boat Ramp	Swan	Town of East Fremantle	Boat ramp	Grated decking	FRP	Grey	Pedestrian	Boat strike	Yes	2014	9
				Jetty	Chafer posts/wharf fenders	HDPE	Black			Yes	2014	9
12	Millers Pool	Swan	City of South Perth	Boardwalk	Grated decking	FRP	Black	Pedestrian	Cyclists	Yes	2017	6
					Kick rail	FRP	Blue			Yes	2017	6
				Platform	Grated decking	FRP	Black			Yes	2017	6
				Boardwalk	Seats	Composite	Black			No	2017	6
13	Point Walter boardwalk	Swan	City of Melville	Boardwalk	Substructure	FRP	Unknown	Pedestrian		Unknown	2017	6
14	Point Walter jetty / boat ramp	Swan	City of Melville	Jetty	Grated decking	FRP	White	Boat strike	Pedestrian	Yes	2019	4
					Chafer posts/wharf fenders	Unknown	White			Yes	2019	4
15	John Tonkin Reserve	Swan	Town of East Fremantle	Ramp - beach ramp	Grated decking	FRP	Black	Pedestrian		Yes	2015	8
					Kick rail	FRP	Grey			No	2015	8
					Post (misc)	Composite	Black			No	2015	8

16	Matilda Bay Interpretation Node	Swan	DBCA Regional Parks Unit	Boardwalk	Substructure	FRP	Unknown	Pedestrian		Unknown	2020	3
17	Perth Flying Squadron Yacht Club	Swan	Lease Holder	Jetty	Grated decking	FRP	Yellow	Boat strike	Pedestrian	Yes	2015	8
					Grated decking	FRP	White			Unknown	2022	<1
					Decking	PP	Yellow			Yes	2015	8
					Float bricks	HDPE	Unknown			Unknown	2003	20
				Piles	Sleeves	HDPE	Black			Yes	2015	8
18	Aquarama Marina	Swan	Lease Holder	Jetty	Chafer posts/wharf fenders	Co-polymer (Ethylene-1-octene copolymer < 50%) + PP (>50%)	Grey	Boat strike	Pedestrian	Yes	2013	2-10
				Piles	Sleeves	HDPE	Black			Yes	2015	<8
				Jetty	Grated decking	FRP	Sand			Yes	2016	7
					Float bricks	HDPE	Unknown			Unknown	2016	7
19	Pier 21 Marina	Swan	Lease Holder	Jetty	Grated decking	FRP	Unknown	Boat strike	Pedestrian	Yes	2010	13
					Decking	Co-polymer (Ethylene-1-octene copolymer < 50%) + PP (>50%)	Grey			Unknown	2010	13
				Piles	Sleeves	HDPE	Black			No	Unknown	>2
					Capping	FRP	White			No	Unknown	>2
20	South of Perth Yacht Club	Swan	Lease Holder	Jetty	Grated decking	FRP	Grey	Boat strike	Pedestrian	Yes	2020	3
					Decking	Composite	Brown			Yes	2017	6
				Piles	Sleeves	HDPE	Black			Yes	2000	0 - 23
					Capping	HDPE	White			No	Unknown	0 - 10
				Jetty	Fender	Unknown	White			Yes	Unknown	0 - 10
21	Kent Street Weir Bridge	Canning	City of Canning	Raised Walkway	Grated decking	FRP	Grey	Pedestrian		Yes	2018	5
22	Rockwood Street Jetty	Canning	City of Melville	Jetty	Decking	Co-polymer (Ethylene-1-octene copolymer	Grey	Pedestrian	Boat strike	Yes	2021	2

						< 50%) + PP (>50%)						
					Kick rail	Co-polymer (Ethylene-1-octene copolymer < 50%) + PP (>50%)	Grey	Boat strike		No	2021	2
					Substructure	FRP	Grey			Unknown	2021	2
					Seats	Co-polymer (Ethylene-1-octene copolymer < 50%) + PP (>50%)	Grey	Pedestrian		Yes	2021	2
23	Deep Water Point Boat ramp	Canning	City of Melville	Jetty	Grated decking	FRP	Grey	Boat strike	Pedestrian	Yes	2019	4
					Chafer posts/wharf fenders	Unknown	White/grey	Boat strike		Yes	2019	4

9.2 Appendix 2: Rapid visual condition assessment (Quantitative)

Site Name: ____________________________ **Assessors:** _______________

Date of Assessment: ___________________ **Area of decking:** __________

Structure (circle one): jetty / pontoon / raised walkway / boardwalk / ramp / platform

Component: ___________________

Site Description (i.e. shoreline aspect, contact with water, structure use):

____

____

<u>Assessment Procedure:</u>

1. Place 3 x 0.25m^2 quadrats on each component for a quantitative assessment. Place one quadrat on the component centrally and closest to shore (1), on the middle of the component (2) and at the end / furthest from shore (3).
2. Rate each quadrat according to the assessment criteria below.
3. Sum the ratings to get a degradation index for each quadrat.
4. Average all quadrats to get a degradation index for the component.
5. Conduct a general inspection of the component noting and photographing additional defects.

<u>Degradation Criteria:</u>

Cracks* - a line on the surface of the component that appears as a split but is not broken apart.

Severe (3)	Crack width > 2mm & n < 30 OR Crack width 1 - 2mm & n > 30
Moderate (2)	Crack width 1 - 2mm & n < 30 OR crack width < 1mm & n > 30
Minor (1)	Crack width < 1mm & n 15 – 30 OR Crack width 1 - 2mm & n < 15
Negligible (0)	No cracks evident

Chips* - a fragment broken off the material.

Severe (3)	Chip width > 10mm & n < 30 OR Chip width 5 - 10mm & n > 30
Moderate (2)	Chip width 5 - 10mm & n < 30 OR Chip width < 5mm & n > 30
Minor (1)	Chip width < 5mm & n = 15 - 30 OR Chip width 5 - 10mm & n < 15
Negligible (0)	No chips evident

Deformation – change in size or shape of the component.

Severe (3)	Deformation > 5mm
Moderate (2)	Deformation 2 – 5mm
Minor (1)	Deformation < 2mm
Negligible (0)	No deformation evident

Material Loss - loss of material from abrasion.

Severe (3)	Material loss > 5mm
Moderate (2)	Material loss 2 – 5mm
Minor (1)	Material loss < 2mm
Negligible (0)	No material loss evident

** Rating may vary with structure and component and specified widths and counts may not always apply.*

Quadrat 1

Photo/s taken: Yes ☐ No ☐ N/A ☐

Number of: Cracks ___________ Chips __________ Maximum Deformation (mm) ____________

Description:____
____
____
____

	Cracks	**Chips**	**Deformation**	**Material Loss**	**Sum of rating (Degradation index)**
Rating (0 – 3)					

Quadrat 2

Photo/s taken: Yes ☐ No ☐ N/A ☐

Number of: Cracks ___________ Chips __________ Maximum Deformation (mm) ____________

Description:____
____
____
____

	Cracks	**Chips**	**Deformation**	**Material Loss**	**Sum of rating (Degradation index)**
Rating (0 – 3)					

Quadrat 3

Photo/s taken: Yes ☐ No ☐ N/A ☐

Number of: Cracks ____________ Chips ___________ Maximum Deformation (mm) _____________

Description:____

____

____

____

	Cracks	**Chips**	**Deformation**	**Material Loss**	**Sum of rating (Degradation index)**
Rating (0 – 3)					

Average degradation index

	Quadrat 1	**Quadrat 2**	**Quadrat 3**
Degradation Index			

Average Degradation Index = _____________

Comments:

____

____

____

____

____

General Assessment:

- Note any additional significant defects or deterioration that were not noted in the above assessment.

Degradation Criteria	Comments
Cracks	
Chips	
Deformations	
Material Loss	
Other Decolourisation, plastic in soils, chalking, exposure of fibres, top grit condition etc.	

9.3 Appendix 3: Rapid visual condition assessment (Qualitative)

Site Name: ____________________________ Assessors: __________________

Date of Assessment: ____________________ Quantity: ____________________

Structure (circle one): jetty / pontoon / raised walkway / boardwalk / ramp / platform /

Other ___________________

Component: _____________________

Site Description (i.e. shoreline aspect, contact with water, structure use):

____

____

General Assessment

General degradation index (0 – 3): _________________________________

Degradation Criteria	**Comments**
Cracks (a line on the surface of the component that appears as a split but is not broken apart)	
Chips (a fragment broken off the material)	
Deformations (change in size or shape of the component)	
Material Loss (loss of material from abrasion)	
Other comments (e.g. colour changes, plastic in soils, chalking etc.)	

9.4 Appendix 4: Images of example degradation criteria

Table 16. Visual representations of the rating system used for 'cracking' during site assessments. See Appendix 2 for descriptions of each degradation criteria rating.

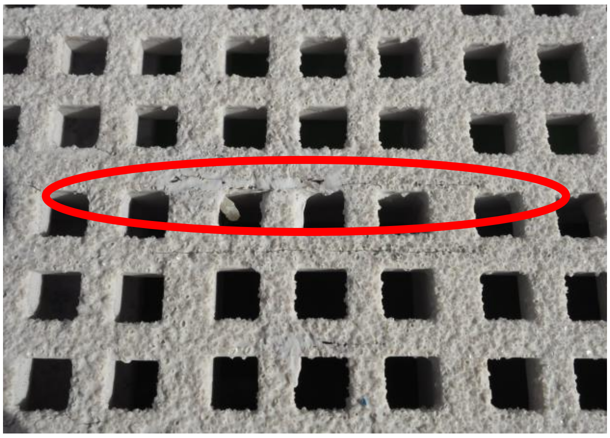
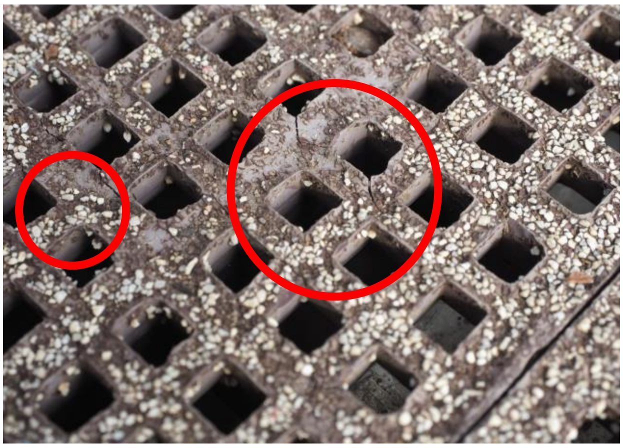
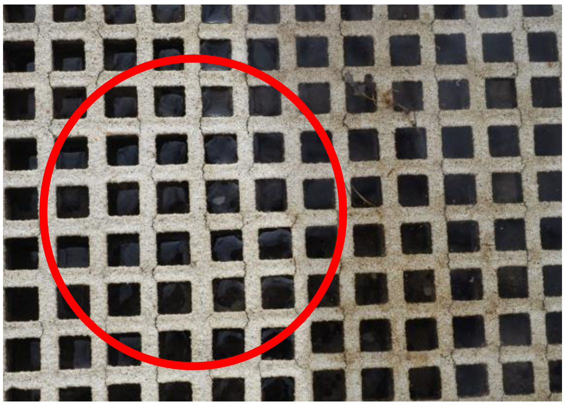
	Rating	Degradation criteria (cracking) examples
Degradation Rating	Negligible (0)	No cracking observed
	Minor (1)	
	Moderate (2)	
	Severe (3)	

Table 17. Visual representations of the rating system used for 'chipping' during site assessments. See Appendix 2 for descriptions of each degradation criteria rating.

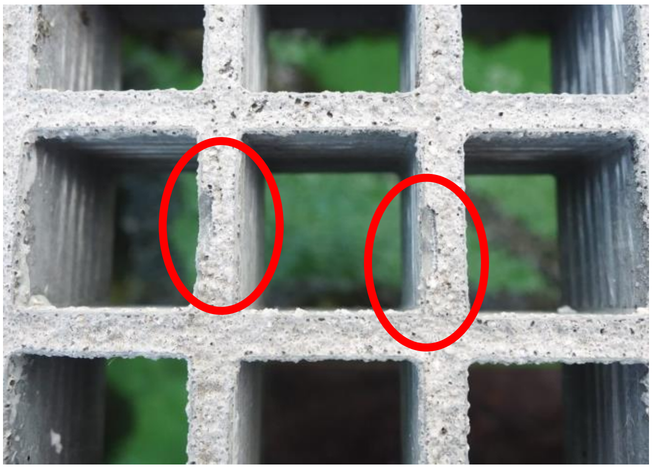
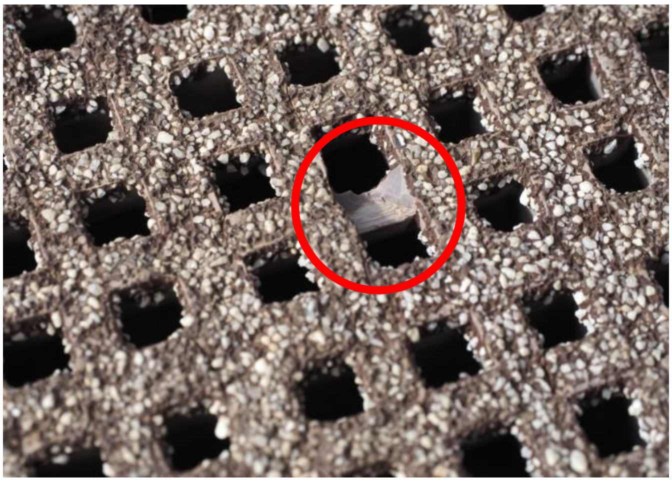
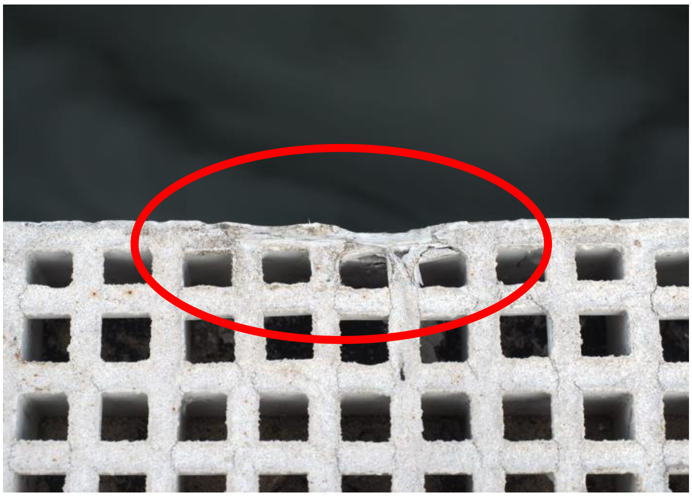
	Rating	Degradation criteria (chipping) examples
Degradation Rating	Negligible (0)	No chipping observed
	Minor (1)	
	Moderate (2)	
	Severe (3)	

Table 18. Visual representations of the rating system used for 'deformations' during site assessments. See Appendix 2 for descriptions of each degradation criteria rating.

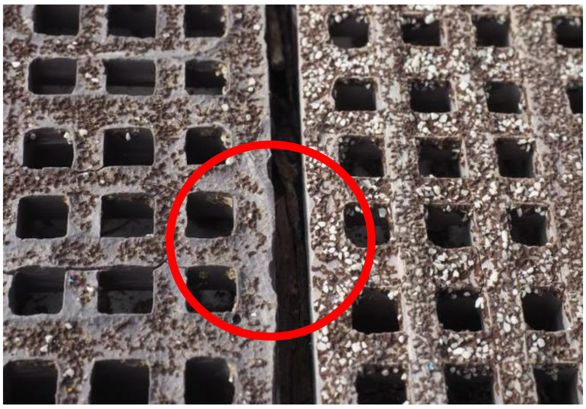
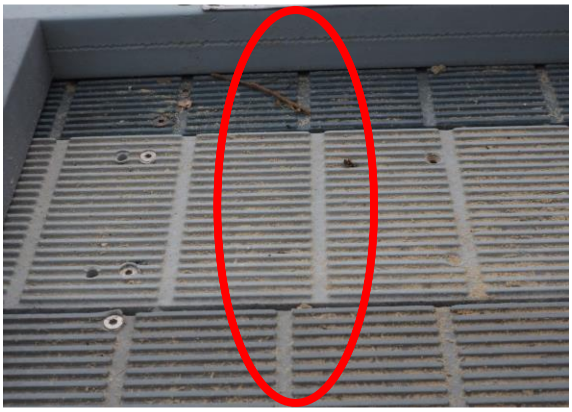
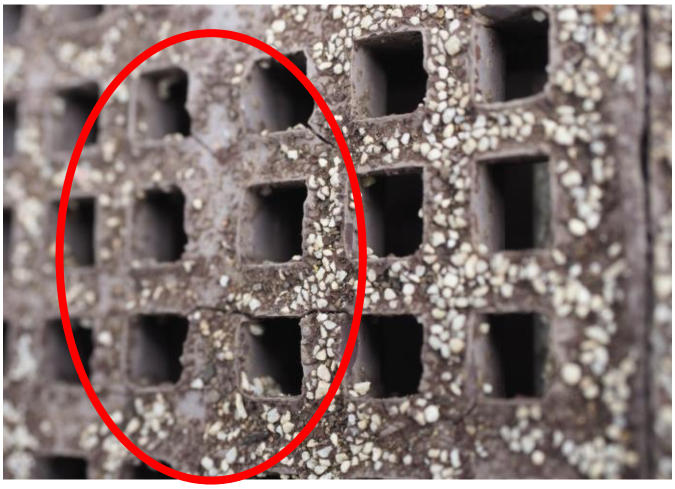
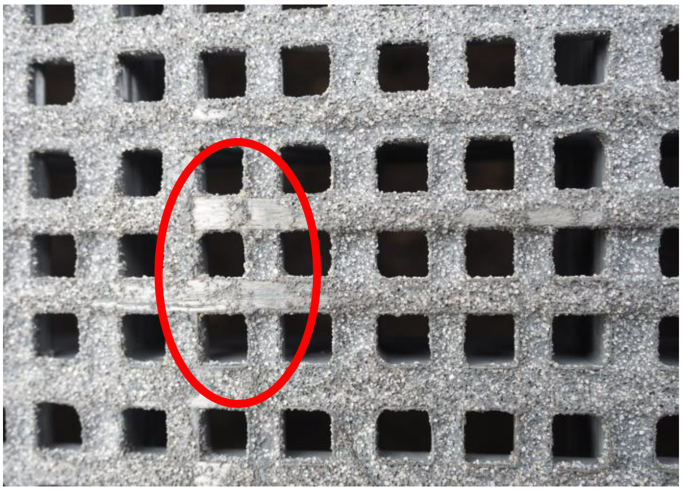
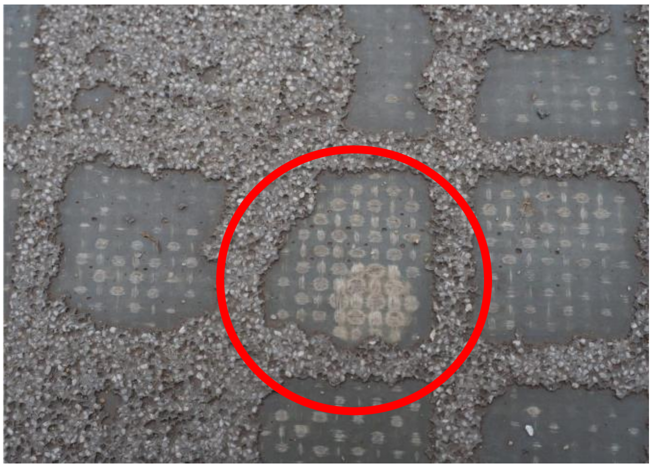
	Rating	Degradation criteria (deformation) examples
Degradation Rating	Negligible (0)	No deformations observed
	Minor (1)	
	Moderate (2)	
	Severe (3)	

Table 19. Visual representations of the rating system used for ‘material loss’ during site assessments. See Appendix 2 for descriptions of each degradation criteria rating.

	Rating	Degradation criteria (material loss) examples
Degradation Rating	Negligible (0)	No material loss observed
	Minor (1)	
	Moderate (2)	
	Severe (3)	

9.5 Appendix 5: Types of FRP grated decking

Types of FRP grated decking

Figure 37. The different types of grating types used in plastic infrastructure in the Swan-Canning Riverpark (*https://www.permacomposites.com/frp-grating/*).

Figure 38. Surface finishes for fibre reinforced plastic grated decking. Includes 'rectangular' grid type (*chrome-extension://efaidnbmnnnibpcajpcglclefindmkaj/https://frpengineering.net/wp-content/uploads/2020/11/FRP_Moulded-Grating.pdf*)

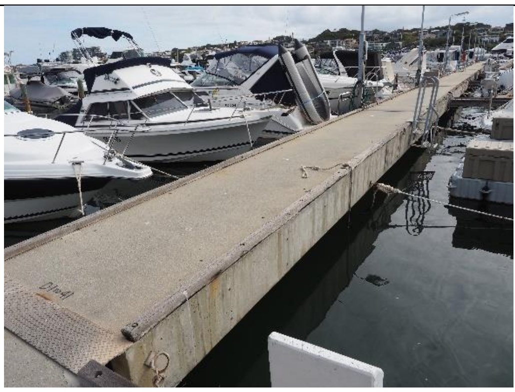
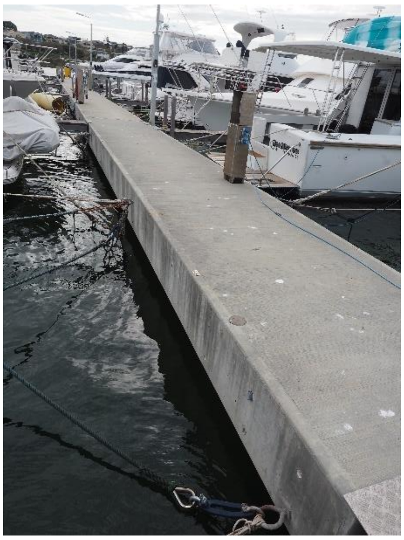
9.6 Appendix 6: Recommendations for alternative materials

Recommendations for alternative materials requires further investigation.

Table 20. Potential alternatives for plastic infrastructure.

Potential alternatives to plastic	**Comments**
Timber (general)    *Wooden pile removed at Aquarama Marina to be replaced with steel pile and polyethylene sleeve (top) and wooden jetty to be replaced (middle) and side boat access jetty (bottom) at Swan Yacht Club.*	• Resource shortages (not a long-term sustainable alternative). • Requires ongoing maintenance and repair. • Observed as being replaced at some locations (e.g. Swan Yacht club is replacing a fixed wooden jetty with plastic floating jetty in 2023; wooden piles from 1985 at Aquarama have almost all been replaced). Aquarama Marina GM comments: switched to plastic chaffers eight - 10 years ago because timber was difficult to source. Timber pylons obsolete now so they use steel pen piles covered with HDPE black plastic sleeve.

Timber (Softwood and Hardwoods - Accoya)	• Can be used in marine environments but it has not been trialled under Western Australian weather conditions. • Only a 10-year service life has been established for the oceans of Northern Europe. • Significant transport costs (and associated environmental impacts) for this product. • The Accoya warranty covers use in saltwater splash zones, for instance marina decking. Accoya is suitable in full saltwater immersion though the warranty does not cover attack by marine organisms. Includes a 50-year warranty above ground and 25 years in ground contact and freshwater immersion. • Provides a 10-year service life but a 50-year warranty. • Degradation material is natural (timber fibres)
Wood Plastic Composites (WPC)	• Not recyclable. • Needs more investigation.
Metal (steel)   *Steel jetty built in 1985 that needs replacing at Aquarama Marina.*	• Long lasting when maintained but can rust over time. • Energy intensive to manufacture. • Probably not feasible to use for marine infrastructure but can potentially be used for edge protection.
Metal (aluminium) *Edging example Figure 7-1.*	• Lightweight and ideal for jetty edging. • Can be used in jetty construction (e.g. https://www.poralu.com/en/products/ floating jetties) • Many floating pontoons are made of marine-grade aluminium frames.
Concrete	• Expensive upfront costs but with very low maintenance necessary.

<table>
<tr><td>

Concrete jetty at Aquarama Marina (top) and Swan Yacht Club (bottom)</td><td>• Concrete is the recommended material from multiple yacht club managers.
• Negligible signs of degradation after a 25+ year service life. Low maintenance.
• High embodied carbon but this may be offset by an increased service life, reduced maintenance cost and eliminating the possibility of plastic fragments ending up in the Swan and Canning rivers.
• Concrete float example (https://www.poralu.com/en/products/). The construction of a concrete dock float meets concrete standards IN 206-1. They are encapsulated and reinforced by a layer of galvanized steel, ensuring optimal protection and resistance regardless of site conditions. They are filled with high-density expanded polystyrene foam which ensures their unsinkability.</td></tr>
<tr><td>Compcrete</td><td>• Example https://www.permacomposites.com/compcrete-decking/</td></tr>
</table>

Other considerations for potential alternatives:

• Life cycle assessments
• Recyclability or reuse potential (Vaid et al., 2021)
• Embodied energy (Halliwell, 2010)
• “International clean marina accreditation” (achieved by some marinas and yacht clubs – e.g. Aquarama Marina https://aquarama.com.au/blog-articles/clean-marina-accreditation-renewed/)