Mitigating the 2022 Queensland "White Spill" Event: strategies to prevent similar incidents

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Photo credit: Sharyn Kerrigan

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Tangaroa Blue Foundation

Tangaroa Blue Foundation is an Australian registered charity focused on the health of our marine environment and coordinates the Australian Marine Debris Initiative, an on-ground network of volunteers, communities, organisations and agencies around the country monitoring the impacts of marine debris within their local environment.

Ten Little Pieces

Ten Little Pieces is raising awareness of and advocating solutions to plastic pollution through sustainability education, community activism & corporate environmental impact consultancy.

Tangaroa Blue Foundation and Ten Little Pieces acknowledge the First Nations people as Traditional Owners and Custodians of Country across Australia, including the Land and Sea Country on which we live and work.

We pay our respects to Elders past and present and acknowledge their continuous relationship to this land and the ongoing cultures of Aboriginal and Torres Strait Islander peoples across Australia.

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Executive Summary

The South-east Queensland rains and Flooding Event of February–March 2022 was caused by prolonged, severe rains. Several locations recorded rainfall totals of more than one metre between February 22 and March 1, 2022. These floods caused fatalities, destruction of houses, businesses, and transportation systems and infrastructure, and led to the environmental catastrophe known as the "White Spill" event.

Extreme volumes of marine debris flowed into open water across the Eastern Seaboard of Australia as flood waters began to drain from the inundated landmass. The force of the flood waters dislodged land damaged infrastructure including marine pontoons from river systems and marinas.

37 pontoons, weighing in excess of 16 tonnes each, subsequently disintegrated along a 250-kilometre stretch of coastline, from Mulgumpin (Moreton Island) northeast of Brisbane, across Noosa Eastern Beaches and Northern Shore, to K'gari (Fraser Island) expelling their large volume of polystyrene contents into the globally recognised and highly sensitive coastal ecosystems of the Southern Queensland. A further 300 pontoons were reported by Maritime Safety Queensland to have been retrieved from open water with an unknown number lost or sunk during the event. The presence of polystyrene poses significant challenges for environmental clean-ups due to its fragility, buoyancy and toxicity with long-lasting impacts on marine and coastal wildlife.

It is predicted that flooding events will increase in frequency, emphasising the need to invest in emergency response preparedness, including plans for handling marine debris such as polystyrene. Proactive upstream mitigation measures are crucial to minimise environmental damage as is a review of the fit for purpose nature of polystyrene in marine applications as well as end of life cycle management provisions and extended producer responsibility considerations. A number of precautionary interventions are recommended in this report including subsurface integrity and tethering inspection schedules, maintenance schedules, pile height review and identification plate attachment for all remaining and future pontoons.

The disaster management response of the "White Spill" was complicated due to unclear roles and responsibilities among involved agencies, which can be attributed to the unprecedented nature of the event. This report references both Australian and international emergency marine debris regulations and policies, aiming to contribute to upstream mitigation initiatives based on the precautionary principle.

The document focuses on improving preparedness for response and recovery operations related to polystyrene debris in Queensland's waterways, coasts, and oceans following flooding events and marine debris emergencies. It also serves as a resource that can be adapted for other states and national contexts.

Drawing on the collective knowledge, expertise, and experience of Tangaroa Blue Foundation, Ten Little Pieces, Sea Shepherd Marine Debris Campaign, Ocean Crusaders Foundation, Surfrider Foundation Australia, Reef Check Australia, Take 3 for the Sea, Sunshine Coast Environmental Council, Brahminy Beach and their networks and associates, this document presents the on-ground methodologies used to recover polystyrene debris during the “White Spill” event emergency response across Mulgumpin, Noosa, and K'gari resulting from the 2022 East Coast floods. It documents the environmental impacts of polystyrene pontoon debris in detail and summarises the recommendations for improving emergency response management in future flooding events. These recommendations are summarised in Figure 1 and expanded on in the report.

Additionally, the report provides experimental data on containment and dissolution methods for virgin polystyrene that can be employed in future emergencies. It also recommends further trials to determine the most effective methods under different conditions. Through collaboration between Tangaroa Blue Foundation, Ten Little Pieces, Commonwealth Scientific and Industrial Research Organisation (CSIRO), and Royal Melbourne Institute of Technology (RMIT) University, a life cycle analysis (LCA) of polystyrene pontoons has been developed. This LCA, summarised in the report, is currently accepted in a peer-reviewed scientific journal as of June 2023.

The goal of this effort is to contribute to the state of knowledge and provide industry guidance, promoting the adoption of the precautionary principle in assessing appropriate material selection for pontoons and the management of polystyrene in marine environments.

The "White Spill" has caused a devastating and widespread impact on Southeast Queensland, including a UNESCO World Heritage site and a site listed for UNESCO World Heritage and Biosphere Reserves. It is evident that urgent actions should be taken in the manufacturing, maintenance, and lifecycle management of polystyrene pontoons. These actions should align with Australia's commitment to the United Nations Sustainable Development Goals, specifically SDG 6 (Clean Water and Sanitation), SDG 9 (Industry Innovation and Infrastructure), SDG 11 (Sustainable Cities and Communities), SDG 12 (Responsible Consumption and Production), SDG 14 (Life Below Water), and SDG 17 (Partnership for the Goals).

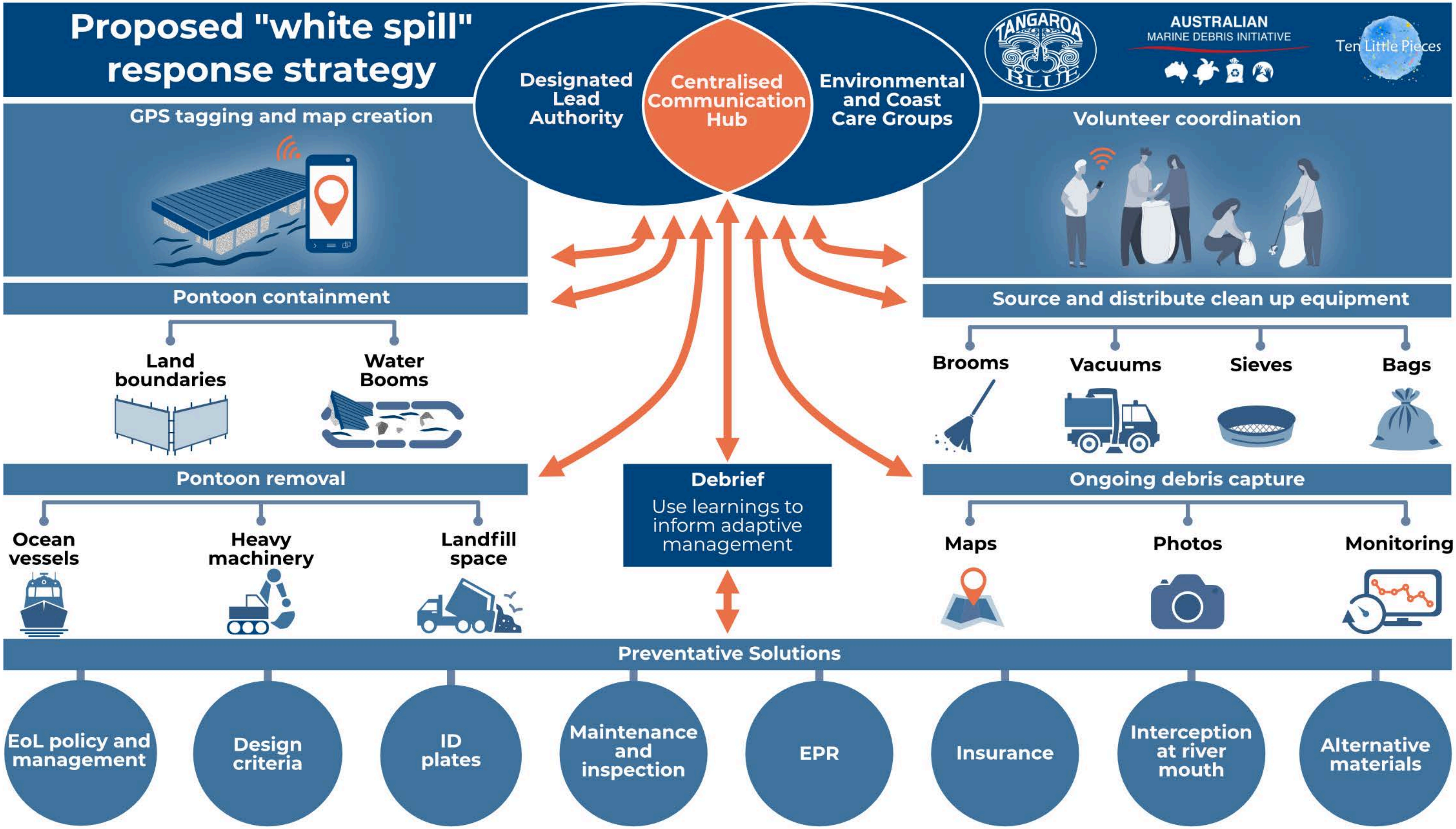

Figure 1. *Recommendations from the collective knowledge of the "White Spill" working group.*

Summary of the "White Spill" event

The Eastern Seaboard of Australia, including Southeast Queensland, experienced significant flooding due to a combination of climate drivers between 22 February and 7 March 2022. The flooding was primarily caused by highly localised thunderstorms, which resulted in intense rain and flash flooding in creeks and tributaries of major rivers (Office of the Inspector-General of Emergency Management, 2022). These floods claimed 23 lives and caused extensive damage to property and the environment (Center for Disaster Philanthropy, 2022). Devastating and record-breaking floods have occurred throughout history in these regions, and scientists predict that the potential for more devastating floods will become more likely under climate change (IPCC, 2022; Reid & King, 2022). In addition to the priceless loss of life associated with floods, the local, state, and federal governments are dealing with increasing fiscal costs associated with disaster relief and recovery. The 2022 flood insurance costs are estimated to exceed $5.72 billion making it the costliest extreme weather event in Australian history and the second costliest insured event in the world in 2022 (Insurance Council of Australia, 2022). The federal budget plans to spend an additional $6 billion on these flood recovery efforts over the next four years (Visontay, 2022). However, these numbers do not explicitly account for the environmental impacts associated with flood disasters.

Floods are associated with numerous environmental impacts and their predicted increase in frequency may result in additional impacts. These include increased erosion and transfer of sediments and nutrients, loss of habitat, dispersal of weed species or invasive species, loss of wetlands functions, loss of recreational areas and increased release of pollutants and debris (Queensland Government, 2011). In addition to reactive efforts following natural disasters exacerbated by climate change, investing in preparedness and proactive flood mitigation is important to prevent as much environmental damage as possible. Environmental recovery after floods should be part of this preparation, with developed plans for immediate responses to environmental threats and ongoing maintenance following the event to reduce overall environmental impacts. Government authorities can further prepare by including floods in the terms of reference of natural disaster event management which may expedite funding and resource allocation initiatives (Alistair Dawson, Queensland Inspector General of Emergency Management personal communication).

In Queensland, an environmental disaster dubbed the "White Spill" occurred following the 2022 floods. The "White Spill" consisted of extreme marine debris dispersal and the beaching of some 37 known pontoons, i.e., a floating platform used for various recreational and commercial activities, and the widespread dispersal of polystyrene beads covering the beaches along the Queensland coast (Figure 2). Local community citizen scientists and organisations identified the source of polystyrene pollution originating from unsecured pontoons from rivers, i.e., the Brisbane and Logan Rivers, floating north of their moorings and breaking up along 250 kilometres of coastlines, from Mulgumpin (Moreton Island) north-east of Brisbane, across Noosa Eastern Beaches and Northern Shore and K'gari (Fraser Island; Figure 3; Appendix 1).

Figure 2. Examples of various sizes of polystyrene debris found along Queensland's coasts following the 2022 floods. Visible polystyrene debris ranged in size from less than 5 mm to the entire pontoon which could be 14 m x 4 m x 1 m and weigh 15 tonnes. Photo credit: Sharyn Kerrigan

In addition to the 37 known pontoons that made landfall, Maritime Safety Queensland (MSQ) reported 300 pontoons were retrieved from open water at the outflow of the Brisbane River and Moreton Bay (Maritime Safety Queensland, 2022). Ocean Crusaders secured many untethered pontoons in the early days of the flood event, however, recorded numbers were not kept. Both the Port of Brisbane and Moreton Bay proved to be a haphazard filter for the extreme amounts of debris with excessive amounts of free-floating heavy items flowing from the Brisbane River. The Office of the Inspector-General of Emergency Management (2022) review of the floods reported that MSQ recovered more than 6,700 tonnes of debris from the Brisbane River, including 40 pontoons deemed salvageable. An unknown number of pontoons were lost to sea or sunk (Maritime Safety Queensland, 2022). In the 6 months from March to September 2022, Ocean Crusaders reported the retrieval of an average of 1.5 tonnes of debris per day from the Brisbane River, a large proportion of which was polystyrene and pontoon-related debris. Efforts to contain the untethered pontoons within the river systems and again in open water prior to making landfall are critical to reducing extreme polystyrene dispersal.

The Brisbane River was estimated to be flowing at a rate of 8 knots up to 14 knots carrying debris that caused damage to other boats and infrastructure in the river (BIA, 2022; Ocean Crusaders, 2022). Pontoons that broke free of their moorings and/or floated above their piles hit against other flood debris, river infrastructure and boats. Some pontoons translocated up to 250 km in damaged condition. On making landfall, agitation on the shore and storm surge conditions exacerbated the disintegration of the polystyrene components of the pontoons due to breached or ineffective encapsulation. Extreme distribution of polystyrene particles into the environment resulted. The event was coined the “White Spill” by environmental first responders in reference to similarities with oil spill events requiring urgent, coordinated action to mitigate the pollution.

The “White Spill” event resulted in an environmental catastrophe due to the long-lasting impacts of polystyrene on marine and coastal wildlife, the difficulty of retrieving and containing polystyrene, the sensitivity of biodiversity and ecosystems impacted, the short- and long-term impacts of microplastics on sediments, and the potential impact on tourism as a result of increased marine debris on beaches (Abt Associates et al., 2019; Krelling et al., 2017., Despotellis et al., 2021).

The Queensland Disaster Management 2016 Strategic Policy Statement identifies two strategic objectives that underpin disaster management in Queensland: 1) Strive to safeguard people, property and the environment from disaster impacts and 2) Empower and support local communities to manage disaster risks, respond to events and be more resilient (Office of the Inspector-General of Emergency Management, 2022). As outlined in their disaster management plans, multiple agencies are designated to coordinate flood recovery efforts, including the Queensland Fire and Emergency Services, State Emergency Services and local disaster management groups (Fig 4). The “White Spill” is applicable to both strategic objectives. In particular, objective one, which safeguards the environment from disaster impacts.

The management of the "White Spill" was complicated by a lack of clarity regarding the roles and responsibilities of involved agencies, which was attributed to the unprecedented nature of the event. Maritime Safety Queensland (MSQ), which is responsible for minimising vessel-sourced waste and responding to marine pollution according to the Queensland Government (2023), faced significant logistical, safety, and navigational challenges in the Brisbane River, Port of Brisbane, and Shipping Lanes during the initial stages of the crisis. These challenges included the retrieval of approximately 300 pontoons from open water, as reported by Kell Dillon, General Manager of MSQ, Noosa Council (2022).

The Wildlife Response Plan for Maritime Environmental Emergencies serves as a procedural guide for the Queensland Department for Environment and Science (DES) to ensure the prompt and effective protection of wildlife during maritime emergencies (Queensland Government, 2021). However, the plan primarily focuses on ship-sourced pollution, such as oil spills (Queensland Government, 2021). As the "White Spill" was not a ship-sourced pollution event, these guidelines and response plans were not directly applicable. Consequently, concerned citizens, environmental and conservation organisations, community groups, and tourism operators mobilised teams of volunteers and equipment to retrieve polystyrene debris, while local councils and government agencies managed the logistics of retrieving larger or inaccessible items. The need for multi-stakeholder involvement in recovery and remediation was widely recognised. Given the projected increase in flooding events in Australia, with an estimated annual cost to the government and community of $8.8 billion (CSIRO, 2022), it is crucial to establish clarity around authority, responsibilities, and an emergency command chain in anticipation of future flooding events.

As of June 2023, Ocean Crusaders is still engaged in the clean-up of polystyrene and polybergs, i.e., large floating pieces of polystyrene, in the Brisbane and Logan River systems. Other organisations, including many who contributed to this report continue to clean-up polystyrene from Mulgumpin, Noosa North Shore, Noosa Eastern Beaches and K'gari. Additionally, a recent news report by Nine News Gold Coast on May 26, 2023, highlighted the presence of an untethered marine pontoon with a concrete base floating in the waters of Currumbin (9News Gold Coast, 2023). The continuous detection of polystyrene during clean-up activities in river and marine environments suggests that these systems remain under threat. Therefore, the importance of upstream mitigation measures to reduce the impact of polystyrene, especially from marine pontoons, on the environment cannot be overstated.

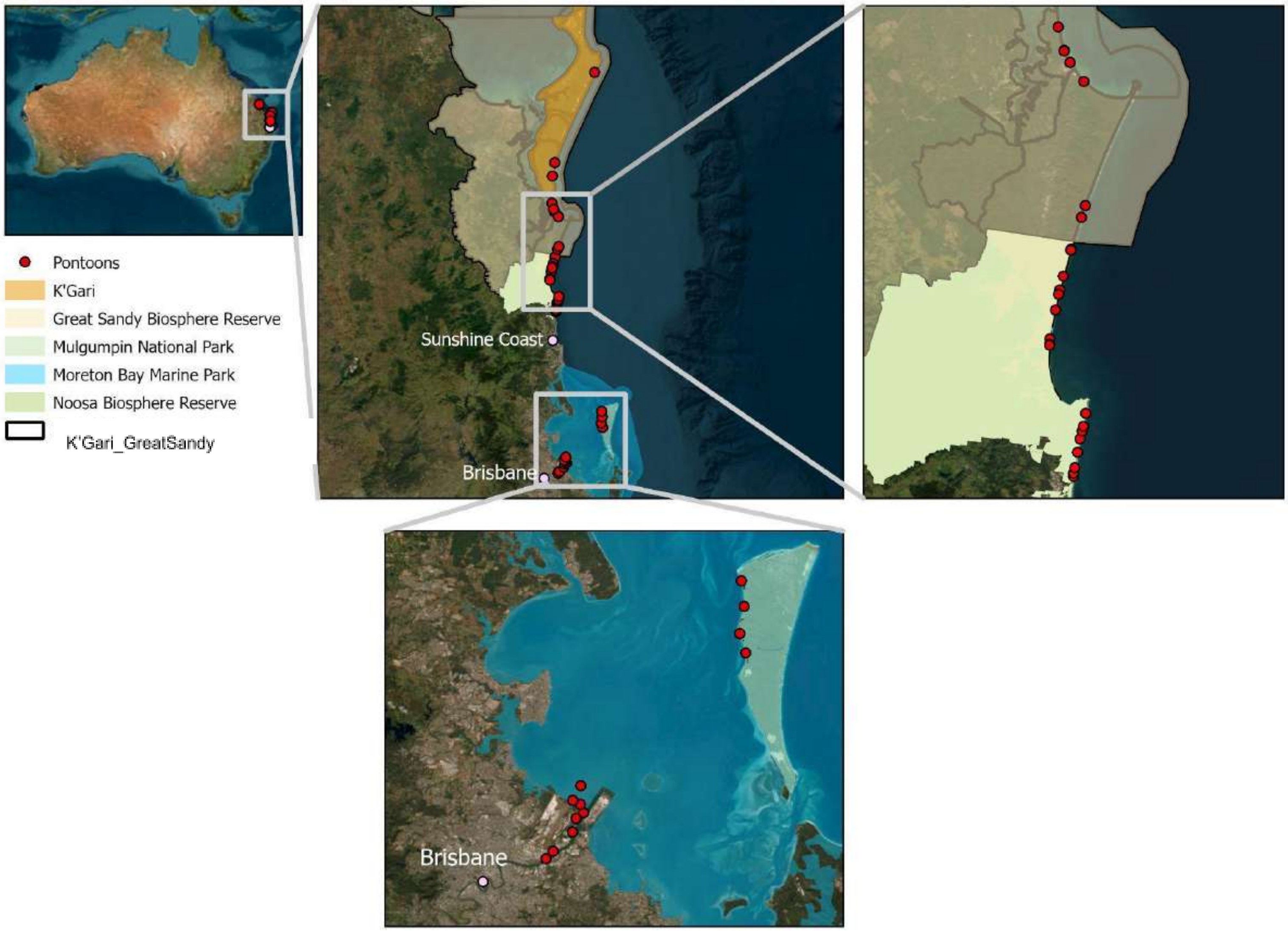

Figure 3. *Map contributed to by local stakeholders on the pontoon locations in Southeast Queensland*

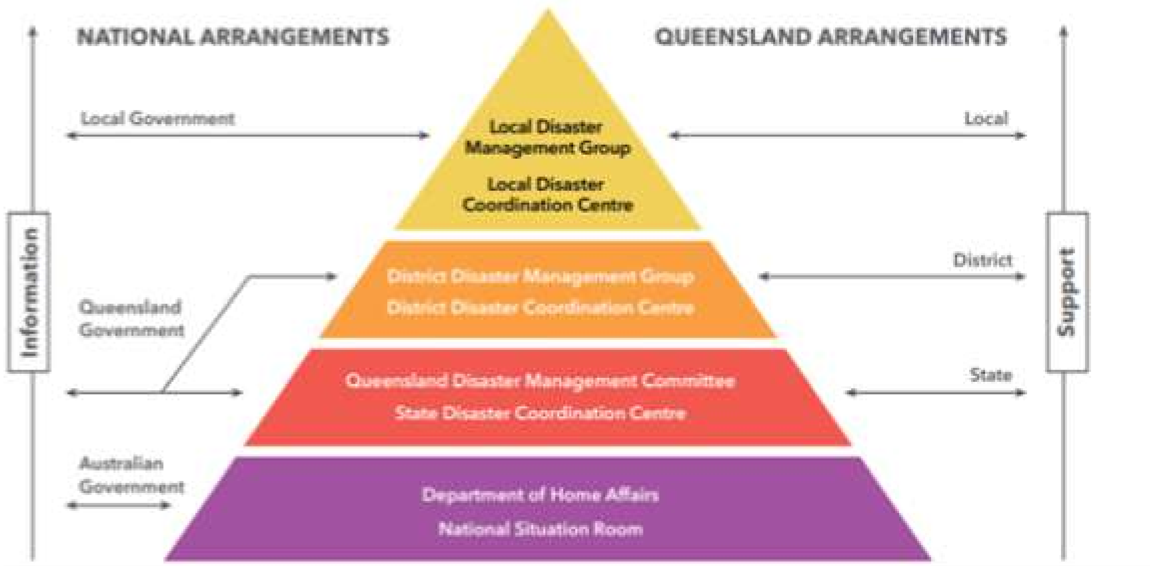

Figure 4. *Queensland's disaster management arrangements*

Developing emergency response plans for marine debris, particularly polystyrene, and implementing upstream mitigation activities are vital to prevent future marine debris disasters. These measures ensure efficient allocation of resources by federal, state, and local governments and agencies in line with relevant legislations such as the *Environment Protection and Biodiversity Conservation (EPBC) Act 1999, the Environmental Protection Act (QLD) 1994, the Integrated Planning Act (QLD) 1997, and the Transport Infrastructure Act (QLD) 1994*. By prioritising emergency response plans and mitigation activities, the risk of environmental damage, economic losses, and social impacts can be significantly reduced. Taking proactive steps to prevent future marine debris incidents is essential for safeguarding the environment, human health, and economic interests including tourism.

Collaborative efforts between numerous stakeholders will help to develop emergency plans and mitigation initiatives. One example of this collaboration is the MSQ working group, whose aim is to address the design, anchoring and tethering systems, pile heights, identification tags, maintenance inspection schedules, extended producer responsibility, insurance considerations, end-of-life cycle management and fitness of purpose of newly manufactured pontoons containing polystyrene to mitigate environmental impacts in future flood events (Office of the Inspector-General of Emergency Management, 2022). This report references both Australian and international emergency marine debris regulations and policies with a view to contributing to upstream mitigation initiatives under the precautionary principle. The precautionary principle is defined as “when human activities may lead to a morally unacceptable harm that is scientifically plausible but uncertain, actions shall be taken to avoid or diminish that harm" (United Nations, 1992). In Australia, the precautionary principle is embedded in the *EPBC Act 1999* (Australia Government, 1999).

Australia is a nation that recognises the importance of the marine environment and is a signatory to multiple international agreements relevant to the "White Spill" event. Our obligation to the United Nations (UN) Sustainable Development Goals (SDGs), in particular, Goal 14: "*Conserve and sustainably use the oceans, seas and marine resources for sustainable development"* (United Nations, 2023), is most relevant to this event. Australia is committed to working towards achieving Goal 14's Target 14.1: "*By 2025, prevent and significantly reduce marine pollution of all kinds, in particular from land-based activities including marine debris and nutrient pollution.*" Similarly, Australia is a signatory to the *UN Convention of the Law of the Sea* (UNCLOS), which contains several articles including 192, 194, 195, and 199, which are relevant to the "White Spill event." (United Nations, 1994) Combined, these articles mandate that each member State, i.e., Australia, is obliged to protect and preserve the marine environment, including taking measures to prevent, reduce and control pollution within it and that contingency plans against pollution must be taken. The "White Spill" was an unprecedented disaster; however, it is imperative that measures are taken at all levels of government to mitigate marine debris, such as occurred during the "White Spill" event, in order to meet our obligations under UNCLOS and to help us achieve Target 14.1.

This document aims to contribute to improved preparedness for response and recovery operations of polystyrene debris in Queensland waterways, coasts and oceans following flooding events and consequent marine debris emergencies and provide a resource that can be adapted for other states and nationally. This document uses the collective knowledge, expertise and experience of Tangaroa Blue Foundation, Ten Little Pieces, Sea Shepherd Marine Debris Campaign, Ocean Crusaders Foundation, Surfrider Foundation Australia, Reef Check Australia, Take 3 for the Sea, Sunshine Coast Environmental Council, Brahminy Beach and their networks and associates to present the on-ground polystyrene recovery methodologies used in the emergency response to the reported 37 beached pontoons across Mulgumpin, Noosa and K'gari to document the environmental impacts of polystyrene pontoon debris from the 2022 East coast floods.

We also provide experimental data on containment and dissolution methods of virgin polystyrene that could be used in future emergencies and recommend future trials that could be undertaken to further determine the best methods under differing conditions. A collaboration between Tangaroa Blue Foundation, Ten Little Pieces and researchers at the Commonwealth Scientific and Industrial Research

Organisation (CSIRO) and the Royal Melbourne Institute of Technology (RMIT) University led to the development of a life cycle analysis (LCA) of polystyrene pontoons that can also be used to inform emergency response options. This LCA is summarised in the report and as of June 2023 is currently accepted in a peer-reviewed scientific journal.

Our ambition is to contribute to the state of knowledge and industry guidance to embrace the precautionary principle in assessing appropriate material selection for pontoons and end-of-life management of polystyrene in marine settings, given this event's catastrophic and widespread impact across Southeast Queensland, including a UNESCO World Heritage site and Biosphere Reserves.

What is polystyrene?

Polystyrene is a plastic polymer made of styrene monomers, specifically by-products of oil refining called benzene and ethylene (Flora & Fauna International, 2020). Expanded polystyrene (EPS) and extruded polystyrene (XPS) are two types of foamed polystyrene. These materials are cheap to produce, lightweight, impact resistant when in containment, water-resistant, and buoyant, which has historically made them useful for many marine purposes, including buoys, pontoons, and fish boxes (Flora & Fauna International, 2020). However, these same qualities that characterise them as useful are also acutely problematic in marine settings. Polystyrene causes large amounts of pollution because it can be brittle, especially under UV exposure, leading to ready fragmentation and distribution by wind and water increasing penetration by marine invertebrates (Flora & Fauna International, 2020). This fragmentation causes a wide range of sizes of polystyrene to pollute waterways, coastlines and our ocean and is reported in dense debris loads following severe weather events such as Storm Emma in the United Kingdom (Fig 5) and the 2022 floods in Australia (IUCN, 2021). Additionally, polystyrene is known to be toxic to humans and marine wildlife (Cary et al., 2023; Sun et al., 2022; Turner, 2020) and difficult if not impossible to recycle (National Plastics Plan, 2021). Combined, these qualities motivated the banning of loose packaging EPS and from consumer food and beverage containers in Australia's National Plastics Plan (DAWE, 2021). However, polystyrene in commercial applications such as construction and the marine industry was not included (Despotellis et al., 2021). This should be rectified to reduce polystyrene use in any application to mitigate polystyrene entering our marine environments.

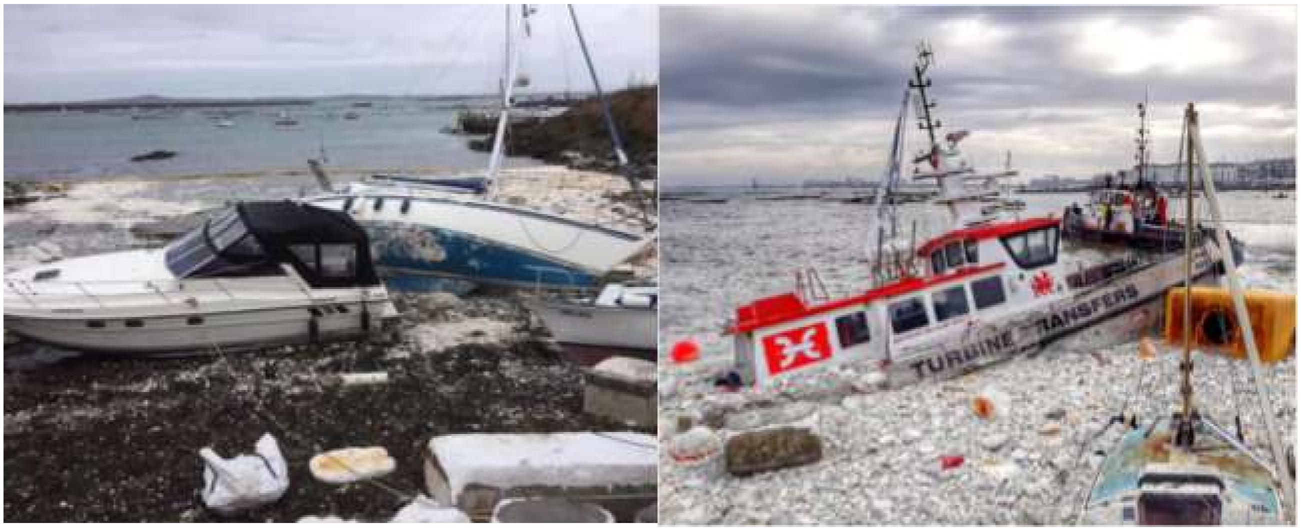

Figure 5. *Example images of polystyrene pollution from Storm Emma in the Holyhead Marina. Image on the left from (Garrod, 2019) and image on the right from Flora & Fauna International (2020).*

Environmental impacts of polystyrene

Fragility, Density & Dispersal

Polystyrene is a synthetic water-resistant plastic polymer composed of 98% air making it extremely low density, lightweight, and consequently buoyant. Expanded polystyrene (EPS) is produced from raw, pelletised beads of polystyrene that are expanded using steam and a blowing agent, e.g., pentane or butane (Turner, 2020). During the expansion process, the beads expand and fuse together, creating a closed-cell structure with a characteristic honeycomb-like appearance and help to give EPS insulating properties (Turner, 2020; Ross & Evans, 2003). The buoyancy and insulating properties of EPS make it useful in many marine applications including fish boxes, buoys, surfboards, boat stands, life jackets and pontoons (Flora & Fauna International, 2020; Turner, 2020). Concerningly, the lightness and low density of EPS results in a propensity for polystyrene to fragment and be easily transported by wind or water ensuring its wide dispersal (Flora & Fauna International, 2020; Turner, 2020). The density of EPS is significantly lower than sea water which affects the drift due to wind and it is predicted that EPS can travel three times faster in seawater than polyethylene (Turner, 2020). Polystyrene is also highly resistant to biodegradation (Mohanan et al 2020). There have been recent developments in polystyrene biodegradation by mealworms and bacteria in a controlled setting (Brandon et al., 2021; Kim et al., 2021). However, this is not currently scalable to large amounts of polystyrene as found in pontoons or seen during the “White Spill” event.

When an EPS pontoon is unencapsulated and exposed to the environment, the effects of UV light, rain, wind, and abrasion degrades the integrity of the bonded interparticle structure and rapid permanent fragmentation occurs (Turner, 2020; Yousif & Haddad, 2013). This is especially problematic in aquatic conditions and in environments where wind, waves and mechanical abrasion from contact debris and shore friction cause weathering and accelerated fragmentation. This has been demonstrated in a laboratory setting where polystyrene was exposed to UV light for up to 12 months followed by mechanical abrasion with sand for 2 months (Song et al., 2017). Song et al. (2017) found that polystyrene exposed to a combination of mechanical abrasion and UV light resulted in more than three times the number of fragmented particles of polystyrene and that 76.5% of the initial polystyrene volume was unaccounted for in the final volume of measured particles indicating that more than ¾ of the particles fragmented into submicron particles. As our understanding of the impacts of microplastics and nanoplastics on the environment increases, this is cause for concern (Goodman et al., 2022; Guimaraes et al., 2021; Hwang et al., 2020; Sun et al., 2022). In addition, there is evidence that polystyrene exposed to UV light exhibits increased toxicity upon photodegradation because of the significant amount of chemicals that it generates when exposed to UV degradation (Lee et al., 2022). UV degradation is a known challenge for polystyrene pontoons and as such, some leading Australian pontoon manufacturers provide a 10-year warranty for UV degradation (SmartBar, 2023). In the case of the "White Spill" event, polystyrene pontoons with damaged or absent encasement were exposed to wind, waves, sand and UV light for up to four months post landing and the resulting fragmentation impacted not only Queensland's coast and marine environment but wherever the resulting polystyrene is transported to via wind and currents.

Acute Aquatic Toxicity & POP adsorption

Chemicals present in polystyrene, such as styrene or oligomers, chemicals added during the creation of EPS, and any chemicals that are acquired from the environment, can cause negative environmental impacts (Turner, 2020). The creation of polystyrene results in a final product that contains chemicals that are classified as endocrine-disrupting chemicals, i.e., styrene monomers, and 8-200 times more Polycyclic Aromatic Hydrocarbons (PAH) than five of the most common plastic polymers (Rochman et al., 2013). Polystyrene is more effective at adsorbing PAHs from the environment than other common plastics due to its porous and hydrophobic surface and the volatility of styrene monomers (Agboola & Benson, 2021). The increased PAHs are problematic because they are toxic to the early development of fish, the bone and liver metabolism of fish, and impact fish reproduction (Honda & Suzuki, 2020) and are linked to cancer, liver damage and kidney damage in humans (Kim et al., 2013). Lab studies on specific species such as oysters *Crassostrea gigas* (Sussarellu et al., 2016), marine copepods *Calanus* *helgolandicus* (Cole et al., 2015) and crucian carp *Carassius carassius* (Mattsson et al., 2015) all found deleterious effects of polystyrene and thus a precautionary approach to reduce polystyrene in the environment should be taken.

Additives during the creation of polystyrene often include antimicrobials, flame retardants and ultraviolet stabilisers (Sridharan et al., 2022). In particular, the flame retardant hexabromocyclododecane (HBCD) is often added to polystyrene especially for construction materials and electrical housings (Rani et al., 2014). HBCD is easily released from polystyrene in the marine environment and is known for its environmental persistence, ability to bioaccumulate and toxicity, including endocrine disrupting effects, abnormality in foetal development and liver and kidney toxicity (Jang et al., 2017). To reduce the use of HBCD and its associated impacts, it was listed as a Persistent Organic Pollutant (POP) in Annex A of the Stockholm Convention in 2013 (UNEP, 2013) and thus signatories are legally bound to eliminate HBCD from use and production. Australia ratified this legally binding United Nations environmental treaty in 2004 when there were only twelve POPs listed (DCCEEW, 2023b). However, Australia has not formally ratified the other POPs that have since been added to this agreement, including HBCD. Whilst HBCD is not produced in Australia, it is imported and utilised as a flame retardant within the country (Department of Health and Ageing, 2012). This is particularly concerning during disaster events like the "White Spill'' since research has shown that smaller EPS particles tend to release more HBCD (Pan et al., 2023). As a result, the degradation of the pontoons and consequent fragmentation of the polystyrene particles may have potentially resulted in the release of more HBCD into the environment.

Ingestion

Over 800 species are known to be affected by marine debris through ingestion or entanglement (UNEP & CBD, 2016). Due to the inherent, adsorbed and additive toxic properties of polystyrene, which is one of the most common plastics found in beach clean-ups (Nelms et al., 2017), there are many causes for concern when marine animals ingest it. Polystyrene fragments can be small in size and their appearance can make them desirable to certain species such as sea turtles (Nelms et al., 2016; Turner, 2020) and seabirds (Robuck et al., 2022; Turner, 2020; Wang et al., 2021). As mentioned above, polystyrene contains chemical additives and can adsorb chemicals from the environment which can cause toxicity to wildlife when ingested (Rochman et al., 2013; Sridharan et al., 2022; Turner, 2020). Marine wildlife that ingests plastic, including polystyrene, can experience physical impacts on top of the potential toxic impacts from ingestion. These physical impacts can include a false feeling of fullness (Cole et al., 2011; Flora & Fauna International, 2020) and mechanical obstruction of the gut and associated responses to this inflammation (von Moos et al., 2012). The "White Spill" occurred during turtle hatching season posing an immediate risk to endangered loggerhead *Caretta caretta* and green turtles *Chelonia mydas* that are protected here in Australia under the *Environment Protection and Biodiversity Conservation Act (EPBC Act) 1999*.

Our understanding of the health implications on marine wildlife exposed to polystyrene of various sizes is still developing. There is evidence that fish exposed to nanoparticles of polystyrene have DNA damage, mutagenic and cytotoxic effects on their blood cells, and an accumulation of polystyrene nanoparticles in the liver and brain of which we don't know the implications (Guimaraes et al., 2021). As a result of our developing knowledge it is important that the precautionary principle be applied to mitigate potential impacts on marine wildlife and the environment.

Human Health Impacts

One of the building blocks of polystyrene is the molecule styrene which is known to impact human health (United States Department of Labor, n.d.). There is evidence that exposure to large amounts of styrene can result in irritation of the eyes and breathing passages and long-term exposure can result in injury to the central nervous system (United States Department of Labor, n.d.). Styrene is also considered a likely human carcinogen by the World Health Organization's International Agency for Research on Cancer (International Agency for Research on Cancer, 2019).

There is also growing evidence of the impacts of polystyrene microplastics on cells in the human body. Goodman et al. (2022) found that kidney and liver cells exposed to polystyrene microplastics resulted in morphological, metabolic, and proliferative changes to cells and cellular stress. Similarly, Hwang et al. (2020) found that polystyrene particles affected red blood cells and may induce local inflammation of tissues and organs. When studies on humans are limited, we often use experimental animals to indicate what may occur in humans. In this case, polystyrene microplastics ingested by mice resulted in severe tissue damage, dysfunction, oxidative stress and metabolic disorders (Sun et al., 2022). Concerningly, nano-plastic polystyrene particles ingested by pregnant rats passed through the intestinal barrier and then the maternal-foetal barrier of the placenta to access all foetal tissues (Cary et al., 2023). Although some of these studies are limited to experimental animals, a precautionary approach should be taken to minimise human exposure to polystyrene.

Leachate in landfill

Polystyrene is difficult to recycle unless clean resulting in more than 93% ending up in landfill here in Australia (Despotellis et al., 2021). The challenge is that polystyrene takes up a significant amount of space and can persist in a landfill for hundreds of years without degrading, instead disintegrating into microplastics (One Planet

Consulting, 2018; Rahman et al., 2023). Microplastics are then able to runoff and leak into the surrounding environment (Rahman et al., 2023) and into groundwater which can then migrate to other waterbodies (Kazour et al. 2019). As they move through the environment they can adsorb other micropollutants from within landfills such as polychlorinated biphenyls (PCBs), per- and polyfluoroalkyl substances (PFAS) and heavy metals which can then pollute other environments the microplastics enter (Rahman et al., 2023). Heavy metal adsorption by polystyrene increases with age which is a cause for concern since polystyrene can persist for hundreds of years (Mao et al. 2020).

While our knowledge of the detrimental effects of polystyrene on the environment, marine wildlife, and human health is still evolving, it is clear that urgent action to minimise environmental exposure is necessary. Emergency situations like the "White Spill" event highlight the immediate need for response and clean-up efforts. Additionally, upstream mitigation measures are crucial to prevent further harm by addressing the production, consumption, and disposal of polystyrene. By recognising the potential environmental risks of polystyrene and exploring alternative materials, pollution from this material can be minimised in the future.

Physical characteristics of new pontoons

Polystyrene pontoons can range in size and type of construction design and material usage. Industry experts in Queensland supplied basic manufacturing specifications of typical piled pontoons. Their specifications had a typical pontoon measuring 14 m x 4 m x 1 m, weighing up to 16 tonnes, including 39 m^3 of polystyrene weighing 600 kg. Pontoons are commonly encapsulated in a polyethylene liner with the remaining weight of 15,400 kg incorporating steel, aluminium and concrete (Fig 6; John Hogan, CEO Superior Jetties, personal communication). Polystyrene pontoons are not always encapsulated in another material, such as hard plastic or concrete, (Allen et al., 2021; Miller, 2021) resulting in susceptibility to flood debris impact and consequent disintegration. However, even those pontoons that are encapsulated are susceptible to damage during a flood resulting in a loss of polystyrene into the environment (Fig 6).

Figure 6. *One of the beached polystyrene pontoons on North Peregian Beach, Noosa, Queensland 4th March 2023. Image credit: Sharyn Kerrigan*

The 2011 Brisbane Floods saw a similar loss of pontoons from their piles, however, a "White Spill" event was not recorded. These floods led to the introduction of new pontoon regulations. These new regulations included specifications on the encapsulation material requirements and liner requirements (Dept. of Transport and Main Roads, 2015). Specifically, the core protection liner materials could include rotomoulded tubs, welded high-density polyethylene (HDPE) membranes or composites and the liner must include at least one layer (minimum 6 mm thick) on all sides, ends and base to protect the floatation chamber core from debris and sharp objects (Dept. of Transport and Main Roads, 2015). These regulations also introduced a specification that all pontoons must have an identification plate attached to them that identifies the lot to which the pontoon is connected (Fig 7; Dept. of Transport and Main Roads, 2015; Queensland Government, 2017). Specific encapsulation materials were not recorded by the organisations that contributed to this report following the floods but all pontoons, regardless of encapsulation, spilled polystyrene into the environment (Fig 8 & 9). Similarly, none of the recorded pontoons had an identification plate indicating a lack of compliance, monitoring and enforcement of these regulations.

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Facility ID: LLxx*

*Facility ID: LLxx to be supplied by the Principal

Figure 7. *Pontoon identification requirement. From (Dept. of Transport and Main Roads, 2015).*

***Figure 8**. Images of pontoons in the Brisbane River before the 2022 floods (top) and during the flood (bottom). Image credit: Ocean Crusaders.*

***Figure 9.** Examples of breached or absent encasement of polystyrene pontoons that were beached following the 2022 floods. Image credit: Sharyn Kerrigan*

Locations of known beached pontoons

Environmental organisations mobilised across more than 250 km of Queensland's coast from Mulgumpin (Moreton Island) and Brisbane, north to Noosa and K'gari (Fraser Island) as pontoons were documented on multiple beaches (Fig 3). The state of Queensland is home to five United Nations (UN) Educational, Scientific and Cultural Organization (UNESCO) World Heritage sites, including the Great Barrier Reef, the world's largest coral reef system (Department of Environment and Science, 2023b). The distance between the most southern part of the Great Barrier Reef (Capricorn Bunker Group) and K'gari where we found multiple pontoons is only 65.1 nautical miles (122 km). During summer, the East Australian Current (EAC) moves southward from near K'gari to the eastern shores of Tasmania (Wright, 2012). The EAC is usually stronger in summer, when it reaches further south, often bringing with it northern tropical species such as tuna (Wright, 2012). Considering pontoon debris spread across more than 250 km of coastline and an untold number of pontoons were not recovered, it is unlikely polystyrene debris ended up in the Great Barrier Reef; however, this may not be the case in future flooding events.

Designated a UNESCO World Heritage site in 1992 (UNESCO, 2023b) K'gari was impacted by 2 pontoons beached near Eurong and 2 significant portions of pontoon to the north of Wyuna and Burad Camping Zone (Fig 3). K'gari is the largest sand island in the world and home to rainforest growing on sand and half of the world's freshwater dune lakes highlighting its uniqueness and global environmental significance (UNESCO, 2023b).

Similarly, Mulgumpin is one of three proposed areas as part of the Quandamooka World Heritage Tentative List Submission (Department of Environment and Science, 2023a). The Quandamooka People have significant cultural knowledge and Quandamooka Country is recognised as outstanding natural habitat for many conservation-significant species such as dugongs and the critically endangered Eastern Australia subpopulation of grey nurse sharks (Department of Environment and Science, 2023a). The *EPBC Act 1999* mandates federal legislation for safeguarding UNESCO World Heritage sites (Commonwealth of Australia, 1999). As per the law, any activity that has the potential to significantly affect the World Heritage property must be referred to The Minister for Environment and Water, The Hon. Tanya Plibersek MP for assessment (Commonwealth of Australia, 1999; DCCEEW, 2023a). This protection highlights the need for mitigation measures and emergency response planning for marine debris originating from riverine sources, particularly polystyrene, to protect UNESCO World Heritage listed sites and wider aquatic environments.

The “White Spill” also impacted Noosa Eastern Beaches and Noosa North Shore, areas designated as a UNESCO Biosphere Reserve in 2007 bordering the recently declared Sunshine Coast UNESCO Biosphere (Fig 3; UNESCO, 2023a). UNESCO Biosphere Reserves are “learning places for sustainable development,” actively using science and research to trial innovative approaches to balance the needs of people and nature (Noosa Biosphere, 2019). The Noosa & the Sunshine Coast Biospheres encompass habitats used by many iconic marine species, such as endangered loggerhead turtles *Caretta caretta*, and green turtles *Chelonia mydas* (Noosa Biosphere, 2019), whose nesting season was threatened by the disaster (Fig 10). Other species include migratory shore birds, dolphins, sharks, and the humpback whales who migrate through the biosphere from Antarctic waters to their breeding grounds in the Great Sandy National Park on the Eastern Side of K'gari annually (Noosa Biosphere, 2023). Those working to contain the “White Spill '' event recognised the very serious threat to wildlife including threatened, vulnerable and endangered species within the impacted regions. They were universally motivated to stop it spreading.

***Figure 10.** Endangered loggerhead turtle hatchling on Sunshine Beach with polystyrene (left) and with microplastic (right) March 2022. Image credit: Caroline Whitehead*

Conditions of the beached pontoons

The pontoons beached in various degrees of disintegration and damage. All presented with breached or entirely shredded encapsulation membranes if, indeed, there had been any present before the flood event. Some pile loops and tethering brackets appeared to be intact but others were completely destroyed. Without exception, they were all dispersing polystyrene into the environment (Fig 11).

Dispersal of polystyrene at impacts sites

All impacted sites showed heavy polystyrene debris loads. The pontoon impact sites were smothered in large polybergs, smaller chunks and individual polystyrene particles with wave action consistently bringing wave upon wave of polystyrene flotsam (Fig 12; Appendix 2). Scientific studies have demonstrated the extreme fragility of polystyrene exposed to UV and abrasion in laboratory studies (Song et al., 2017) and this was anecdotally demonstrated in the "White Spill" event. The breached encasement covers of the pontoons combined with abrasion against the shore and exposure to both heavy wave action and high winds, accelerated the rapid and extreme fragmentation, disintegration, and dispersal of polystyrene from the pontoons. Tide lines, beaches and dune systems across the 250 km impacted range displayed streams of polystyrene. Large transects of the coastline had an appearance that resembled snow and the disaster was coined the "White Spill" by environmentalist Sharyn Kerrigan of Brahminy Beach, Noosa.

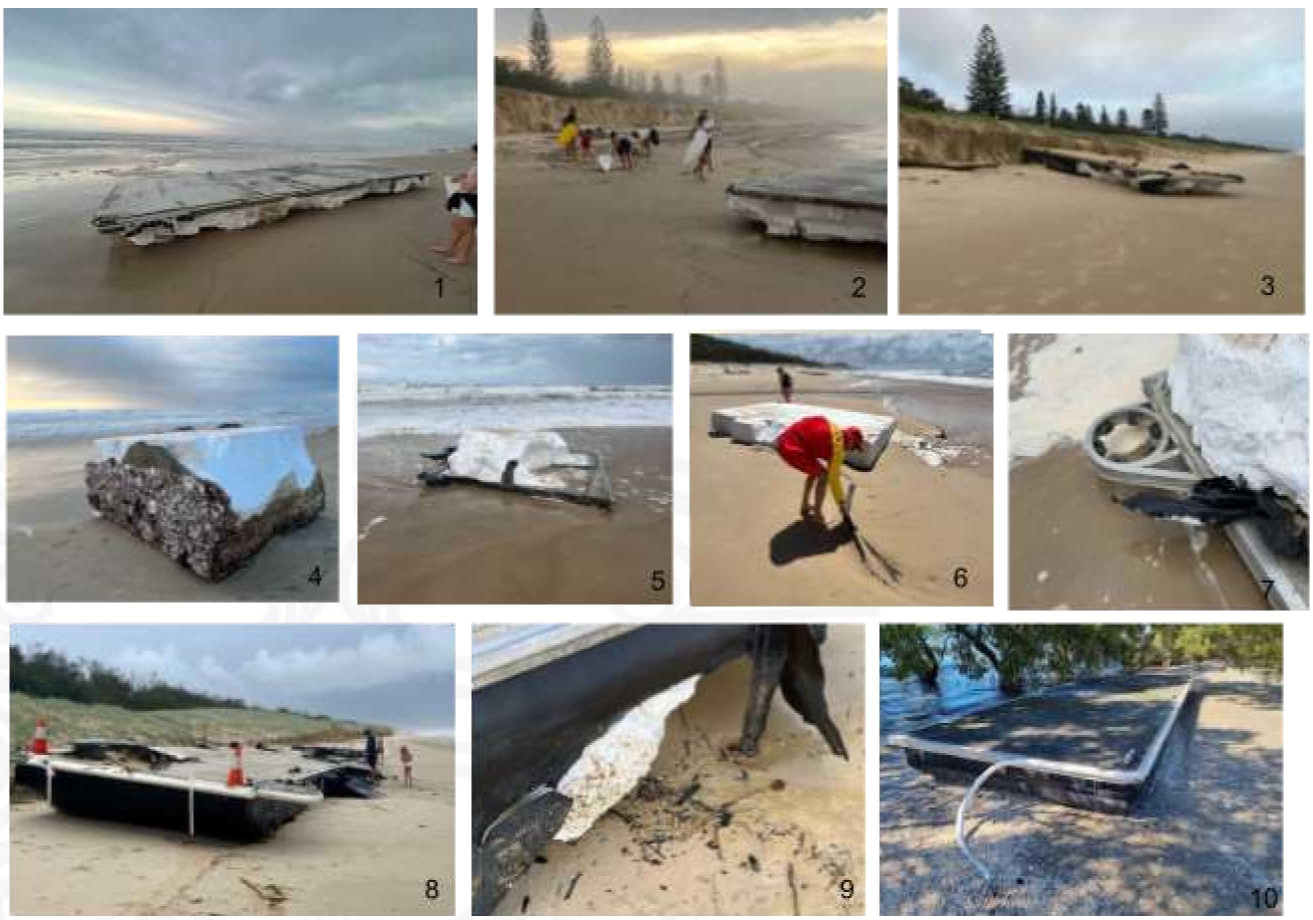

Figure 11. *Example images of pontoons dispersing polystyrene into the environment at Peregian Beach (1-6), Sunrise Beach (7) Sunshine Beach (8), Marcus Beach (9) and Pine River (10; Image credit Ocean Crusaders). Image credit: Sharyn Kerrrigan except where indicated.*

During the first days of impact (March 2 at Peregian Beach and on K'gari (Noosa Council, 2022)), marine debris retrieval efforts focused on the largest removable pieces i.e., those that could be retrieved by hand and carried off the beaches by volunteers and Local Disaster Management Group authorities. This removal did not only encompass polystyrene debris but also plastic and construction debris of all sizes. Environmental organisations, volunteers, and community groups retrieved items ranging from water tanks, domestic rubbish bins, indoor and outdoor furniture, photo albums, tyres, and industrial equipment, as well as organic debris like tree stumps. Extremely dense debris loads of domestic plastic items such as plastic bottles, shoes, food containers, personal items and microplastic confetti were reported across a coastal range much larger than the area impacted by the "White Spill" event further highlighting the need for comprehensive marine debris emergency response plans such as those produced by the United States of America's National Ocean and Atmospheric Administration (NOAA Marine Debris Program, 2021).

Figure 12. *Examples of the polystyrene pieces collected on beaches by volunteers. Image credit: Sharyn Kerrigan*

Emergency response to the "White Spill"

The remote locations and varying degrees of accessibility of the beached pontoons, in combination with the shortage of appropriately capable machinery, hampered removal logistics of the large pontoons, some weighing up to 16 tonnes. This resulted in pontoons remaining on beaches for up to four months when the final pontoons were removed from K'gari (7th July 2022).

Within days of the first pontoon impacts, volunteer teams from Tangaroa Blue Foundation, Ten Little Pieces, Brahminy Beach, Ocean Crusaders, Reef Check Australia, Sea Shepherd Australia's Marine Debris Campaign, Sunshine Coast Environmental Council, Surfrider Foundation and many community members had mobilised to begin mitigating the dispersal of polystyrene from the pontoons and to collect enormous volumes of marine debris resulting from the flood event.

These organisations, agencies and community groups developed a collaborative forum through which to share clean-up methodologies, emergency impact assessments, expertise, advice and volunteer mobilisation information. Community updates were provided through social, local and national media channels. The "White Spill" Working Group leadership and collaborative ambition led to increased uptake of mechanical technologies and physical techniques to contain polystyrene dispersal from the pontoons and retrieve distributed polystyrene from the impact sites.

Immediate clean-up efforts focussed on gathering and securely storing dispersed polystyrene chunks and fragments in a process of marine debris triage. It was immediately apparent that people power was required. Calls for volunteers were broadcast across social media, print media, radio, television, community groups, newsletters, bulletin boards, surf clubs and local businesses at impacted sites. Conservation organisations worked alongside many community groups, tourism operators, alliance and network members across the 250 km of Southeast Queensland coastline severely impacted by marine debris in the flooding event. Under the leadership of Ocean Crusaders and K'gari Fraser Island Adventures, the community on K'gari banded together with local tourism operators to recruit and transport hundreds of volunteers to begin retrieving some 50 tonnes of marine debris from the eastern coast of K'gari. This 50 tonne estimate did not include the 2 pontoons beached at Eurong which remained in situ with no containment until retrieval could be arranged on the 7th of July 2022. Ferry operators provided free transport to K'gari and Mulgumpin and distributed bags to island visitors, school groups got involved in clean-ups on their local beaches, and the environmental organisations cross-promoted debris retrieval efforts across the impacted range in an all-hands-on-deck approach.

With many of the pontoons remaining exposed in situ for many weeks and even months, the profound environmental impact of the polystyrene spread from identified “hotspots” at the impact sites to entire coastlines.

Amalgamation of learnings from the "White Spill" event

A consortium of the 10 marine and environmental conservation organisations that developed and ran the rapid disaster response to the “White Spill” event was created, named the “White Spill” Working Group, to amalgamate our learnings (Table 1). These learnings included information on the toxicity, durability, fragility, volume, and trans-locatability of polystyrene, as well as pollution containment recommendations, clean-up methodologies and techniques, and suggestions for clarifying communications between relevant agencies, Local Disaster Management Groups, and conservation organisations. The working group collated firsthand reports of the challenges impeding clean-up efforts and created a visual library of evidence (Appendix 2) in order to present upstream interventions for the design, manufacture, owner and manufacturer identification, tethering systems, and maintenance of pontoons containing polystyrene in flood susceptible waterways. A summary of these learnings was presented to the Noosa Council Polystyrene Round Table Event on 21st July 2022. Given the clearly deleterious impacts of this material in marine and coastal environments (Despotellis et al., 2021; Flora & Fauna International, 2020; Garrod, 2019), this report expands on all of the topics presented at the Round Table to inform future emergency response planning and the implementation of upstream mitigation measures.

Table 1. "White Spill" Working Group consortium organisations, their website and representatives

Organisation	Website	Representative Name
Tangaroa Blue Foundation	www.tangaroablue.org	Heidi Tait
Reef Check Australia	www.reefcheckaustralia.org	Jodi Salmond
Ocean Crusaders Foundation	www.oceancrusaders.org	Ian Thomson
Sea Shepherd Australia's Marine Debris Campaign	www.seashepherd.org.au/our-campaigns/marine-debris-campaign/	Grahame Lloyd
Coolum North Shore Coast Care	https://coolumcoastcare.org.au/	Tash Cassidy
Ten Little Pieces	www.tenlittlepieces.com	Alison Foley
Surfrider Foundation Sunshine Coast	www.surfrider.org.au	Steve James
Take 3 for the Sea	https://www.take3.org	Roberta Dixon-Valk
Clean Water Group	https://cleanwatergroup.com.au/	Aaron Horsey
Sunshine Coast Environmental Council	https://www.scec.org.au/	Narelle McCarthy

Recommended steps in future events

The learnings of the "White Spill" Working Group led to many recommendations on improving emergency response management in future flooding events. These recommendations are summarised below.

Designated Lead Authority

The lack of clarity on which organisation or agency was responsible for recovery, containment and clean-up of the polystyrene pontoons led to a delayed response. Conservation organisations and community members had to contact multiple agencies including local governments, the Local Disaster Management Authority, Maritime Safety Queensland, the Department of Environment and Science, Queensland State Emergency Service and Queensland Parks and Wildlife. Some of these agencies even discussed whether the Australian Defence Force could be involved in order to utilise helicopters to remove the pontoons. We recommend developing clear guidelines on who is responsible in each possible scenario such as:

1. a pontoon floating down the river (Fig 13),
2. a pontoon stranded on land (Fig 13)
3. a pontoon on a coastal beach being moved by the waves and surf (Fig 13) and
4. pontoon in open water (Fig 13),

and distributing this information to the general public and making this information accessible online.

Figure 13. *Example scenarios where guidelines for who is responsible should be developed including (1) pontoon floating down the Brisbane River during the 2022 floods (Image credit Ocean Crusaders); (2) pontoon on land at Kangaroo Point in April 2023 (Image credit: Tangaroa Blue Foundation); (3) a pontoon on Peregian Beach after the 2022 floods (Image credit: Sharyn Kerrigan); and (4) a pontoon in open water reported in waters off Currumbin in May 2023 (Image Credit Doug Burts Tackle World Gold Coast).*

Centralised Communication Hub

The Local Disaster Management Authority Council hosted an online hub for clean-up locations and events, logistics, debris waste fee waiver applications, beach permit applications, and photo lodgement of items of concern. A central hub could be utilised to update the community and motivate volunteer participation in areas requiring the most people power. Technologies and techniques for retrieval methodologies could be shared here as well as weather warnings, hazard updates and removal schedules. The efficiency of communications between organisations and agencies working to address marine debris as well as the wider community would be greatly improved.

GPS tracking

The pollution capacity of the stranded pontoons combined with the sensitivity of their locations within UNESCO biospheres and World Heritage Listed environments necessitates the recommendation of the application of GPS tracking devices. The potential of the pontoons to dislodge, re-float and relocate identifies them as potential hazards to both maritime safety and further environmental pollution. GPS tracking of the pontoons would have expedited the creation of a landing site map to advise logistics for heavy machinery to remove the pontoons and serve to facilitate volunteer mobilisation to retrieve debris and assist in ongoing debris monitoring for impact assessments. GPS tracking of pontoons has been used in similar scenarios such as when a large commercial pontoon that came loose in the 2011 Tōhoku earthquake and tsunami (Barnea et al., 2013). The pontoon crossed the Pacific and landed on the USA coast where multiple GPS trackers were placed on it to ensure that it could be tracked at all times until it could be safely removed (Barnea et al., 2013). This example indicates the importance of tracking pontoons for navigational safety and mitigating environmental pollution.

One option for GPS tracking is Tangaroa Blue Foundation's Project ReCon[1]. Project ReCon is a recover, repair, reuse, and recycle program for commercial fishing satellite tracking buoys. Tangaroa Blue and our partners in the Australian Marine Debris Initiative collect satellite buoys found during clean-up events and Satlink, the buoy provider, facilitates reassigning ownership of these buoys from the commercial fishing fleet to Tangaroa Blue Foundation. These buoys can be attached to pontoons and their location can be tracked by Tangaroa Blue Foundation. Similarly, in June 2021 the Australian Fisheries Management Authority, in collaboration with Parks Australia and Australian Border Force through Maritime Border Command, conducted a successful trial with GPS tracking of ghost nets in the Torres Strait until safe retrieval could be arranged (Australian Fisheries Management Authority, 2023). The GPS units employed in this trial were Collecte Localisation Satellites NAOS and MARGE-T-II devices and are another option for tracking flood debris such as pontoons (Collecte Localisation Satellites, 2023).

[1] https://www.tangaroablue.org/busting-ghost-nets-haunting-the-great-barrier-reef/

Containment of beached pontoons

It was evident in all of the beached pontoons that the encapsulation of the polystyrene had been damaged or destroyed (Fig 9). The Dept. of Transport and Main Roads (2015) Design Criteria for Pontoons, recommend a 6 mm liner thickness. However, anecdotal observations from Sharyn Kerrigan at Brahminy Beach found that the remnant coverings of pontoons on the Eastern Beaches of Noosa was a maximum of 3 mm. Some partial pontoons beached on Peregian Beach, Noosa had been originally encased in concrete. These encapsulations had also been destroyed suggesting they had been subjected to extreme levels of force resulting in the escape of the polystyrene within them (Fig 9).

Motivated to prevent further disintegration of the exposed pontoons, and in the absence of appropriate machinery to safely relocate the pontoons, immediate advice was sought from members of the UNEP Global Partnership on Plastic Pollution and Marine Litter (GPML) and efforts were made to contact international response agencies to similar disasters and polystyrene spills. The advice received was resolutely to contain the source of the material, i.e., the pontoons, at the earliest opportunity to prevent the dispersal of further polystyrene into the environment (Members of the GPML, personal communication). This advice matched the opinion of all the environmental organisations engaging in clean-up operations.

Primary Boundary

Discussions proposing methods to contain the pontoons were held and the need for a primary boundary was raised. Several suggestions for methods of primary boundary containment were put forward, including applying the physical wrapping of canvas or pallet wrap to the exposed pontoons. Also suggested was the application of a 2-part builders' foam to form a hard barrier around the pollution sources. A third suggestion was to apply appropriate heat to the exposed edges of the polystyrene to melt the individual particles together and attempt the creation of a hard barrier.

The recommendation to wrap the exposed pontoons in pallet wrap was reviewed across the environmental organisations as an emergency containment option and presented to Noosa Council in early March 2022. Given the remote, logistically challenging locations of the impact sites and weather conditions of high tides and rough surf, the pallet wrap recommendation was rejected by Noosa Council due to concerns over secondary entanglement risks to wildlife should the wrapping dislodge in the tidal zone. The collaborative response of the environmental organisations to this concern was that the employment of GPS tracking devices would minimise such risk as the pontoons could be tracked and any dislodged wrapping could be removed. Furthermore, GPS-tracking was recommended for these unsecured pollution sources to ensure they did not become a navigational or safety hazard and clean-up teams could be directed to their location immediately. In the end, no primary boundary containment was deployed on the pontoons nor were GPS trackers applied. As part of this report, we tested possible containment methods (see below). In future events, we recommend that a primary boundary is deployed as soon as is safe to reduce polystyrene entering the environment.

Secondary Boundary

Secondary containment was also suggested because of the characteristics of polystyrene and the weather. Polystyrene that dispersed from the pontoons was fragile and low density and the weather conditions were rough with heavy rain and high tides. In instances where the pontoons were above the tide line, secondary boundary containment was advised by way of physical fencing in addition to primary boundary containment. This precautionary strategy would presumably lead to a concentration of the dispersed polystyrene against the fence which would make it easier to collect and remove from the site. Similar to the primary boundary, a secondary boundary was not deployed in the "White Spill" event; however, we would encourage the use of a secondary boundary in any future events.

In both cases, the primary and secondary boundaries require surveillance for integrity and safety and regular clean-up of polystyrene within the boundaries.

Boundary clearing

Unanimously, the organisations and volunteers retrieving the polystyrene debris across all sites reported the difficulty of capturing and containing the lightweight polystyrene. Easily airborne and buoyant, wind, rain and tidal action contributed to extensive fragmentation and distribution of the material. The construction of both a primary and secondary boundary in future events will assist in containing the polystyrene. However, for any future events, it is also suggested that clearing of polystyrene that escaped from the boundary/containment of the polystyrene pontoons and caught between the primary and secondary boundaries be conducted. Handheld and over-shoulder garden vacuums were used by volunteers during the "White Spill" event and were found to be effective methods to collect this type of polystyrene debris (Fig 14), thus we recommend that these methods be used in future events to clear polystyrene from between the boundaries. Another method of polystyrene capture effectively employed during the "White Spill" event on K'gari by The Ice Man of Teewah was the use of domestic leaf blowers and temporary fence structures (see video of method here:https://fb.watch/k1JxpeDntC/). Leaf blowers were used to carefully blow the loose polystyrene across the beach and into capture fences for retrieval.

We recommend the employment of all these methods when removal of the pontoons is occurring in future events. During the "White Spill" the fragility of the polystyrene remaining within and under the pontoons became readily apparent with heavy disintegration and dispersal of the material when agitation and removal of the pontoons from their landing sites began. Temporary fences should be erected to capture windblown polystyrene at a safe distance from the machinery to be collected with leaf blowers and vacuums.

Figure 14. *Hand-held and over the shoulder vacuums used to collect polystyrene debris from beaches. (Image credit: Karen Anderson & Reef Check Australia)*

Containment booms

Other types of marine spills, such as oil, are regulated by a set of guidelines called the shipboard oil pollution emergency plan (SOPEP) (International Maritime Organization, 2023). In Australia, as part of Regulation 37 of MARPOL Annex I certain ships must carry containment booms that will stop the spread of oil (International Maritime Organization, 2023). Although the "White Spill" event was not leaking oil into the marine environment, the use of containment booms as required in the SOPEP guidelines would assist in mitigating the polystyrene entering the environment. However, the unpredictable and rough weather of the early stages of impact combined with the remote locations of some of the beached pontoons and the absence of suitable equipment prevented the deployment of SOPEP booms to protect open water dispersal of the polystyrene. Under the precautionary principle, it is strongly recommended that in future events the SOPEP booms be deployed into surrounding water on agitation, dislodgement, and transport of pontoons during removal procedures to minimise pollution distribution. Debris within the SOPEP booms could be cleared regularly with fine mesh nets to further reduce the chances of polystyrene entering the environment. Communications with Spill Station Australia said that booms could be used in future events but they must be on hand and ready to be deployed in order to be effective (Appendix 3).

On April 1st, 2022, at Beach Access 40, Castaways Beach, Noosa, Noosa Council workers aiming to separate polystyrene from sand, bulldozed large volumes of polystyrene into the open water. The lack of SOPEP boom deployment during this incident resulted in direct and deliberate pollution of the open water. Film of the incident was attached to a Pollution Incident Report filed with DES (reference N-100232403) and an immediate stop work order was urged (Appendix 4). This highlights the need for response measures to be created and distributed to all relevant stakeholders.

Clean-up methods

Clean-up of the polystyrene was challenging due to the variety in size of pieces to remove, the weather conditions, accessibility of pontoon locations, and availability of volunteers and equipment. We summarised the findings of the environmental organisations working to mitigate the polystyrene pollution here in an effort to provide information on which clean-up methods were deemed most effective during the “White Spill” event. We hope this can be used to inform emergency planning responses for future events.

1. Marine debris triage. The fragility and dispersal characteristics of polystyrene under exposed conditions requires a triage system in which the largest distributed chunks of polystyrene or pontoons are a priority (Fig 15). We believe this will limit the creation of polystyrene “snow” which is much more difficult to clean-up from the environment.

2. Vacuums
    a. Hand-held, battery-powered domestic or garden vacuums were used to collect small pieces of polystyrene from the sand and environment including some supplied by Clean Water Group (Fig 14).

b. An industrial vacuum was also operated by Ocean Crusaders. Ocean Crusaders modified a Greystone Horse Paddock Vacuum which was mounted on a surf lifesaving buggy.
c. Cleanaway's Queensland IWS was contracted by Noosa Council to remove the polystyrene from Noosa Northern Beaches and the Noosa Eastern Beaches (mid May 2022). They operated an all-terrain vacuum truck that used a vibration separator to trial removing the polystyrene from the beaches (Appendix 5 and Fig 16).

Figure 15. *Examples of large polystyrene chunks that were removed as a priority to limit dispersal. (1) Mulgumpin (Image credit: Sea Shepherd Marine Debris Australia); (2); Peregian Beach (Image credit: Sharyn Kerrigan); (3) Brisbane River (Image credit: Ocean Crusaders); (4) K'Gari (Image credit: Ocean Crusaders and K'Gari Fraser Island Adventures; (4) Castaways Beach (Image credit: Reef Check Australia); (6) Castaways Beach (Image credit: Ten Little Pieces); (7)Sunshine Beach (Image credit: Sharyn Kerrigan); (8) Peregian Beach (Image credit: Sharyn Kerrigan); and (9) Sunrise Beach (Image credit: Sharyn Kerrigan).*

d. Vacuums also collected sand and other organic material so consideration must be taken when utilising this method. Cleanaway screened the sand at a nearby quarry for polystyrene pieces and then stated they returned the sand to the beach, however, it is incredibly difficult and time-consuming to do this. Removing a small amount of collateral organic material from the environment to ensure that as much polystyrene is removed as possible may be appropriate (Dr. Paul Read, Sea Shepherd Marine Debris Campaign, personal communications). However, prevention is imperative. Due to this, we highly recommend operating the triage system to remove large pieces first and to implement boundary and containment options as soon as possible.

Figure 16. *CleanAway Queensland all terrain truck removing polystyrene from the beach (Image credit: Sharyn Kerrigan).*

3. Garden Blower

These were used in conjunction with barrier methods such as fences to gently blow the polystyrene into a larger pile or temporary fence structure to allow for easier removal of polystyrene from the beach. This was demonstrated by The Iceman of Teewah (see video here: https://fb.watch/k1JxpeDntC/). This method is useful for collecting larger amounts of small polystyrene pieces. However, it also risks blowing the polystyrene away.

4. By hand techniques
   Due to considerable dispersal of the polystyrene at the impact sites the most common clean-up method employed by the majority of volunteers were non-mechanical methods which included rakes, brooms, kitchen sieves, mesh frames, mesh bags and static electricity. These methods are effective, however they are time-consuming and require a lot of people power to clean polystyrene from even small sections of the beach.

5. Industrial equipment
   a. In addition to the Cleanaway industrial vacuum, Noosa Council also deployed a beach grader which is similar to an industrial rake. This could help to remove the large pieces of polystyrene, or at least bring them to the surface, however, it was not capable of removing small pieces of polystyrene. This method may also result in further deteriorating the polystyrene into smaller pieces.
   b. Clayton's Towing was hired to remove the pontoons. They used a variety of equipment including cranes, bulldozers, D4 diggers, and tip tray trucks. The utility of some of these large pieces of machinery on fragile polystyrene resulted in the loss of polystyrene into the environment. However, these are necessary to remove the pontoons. Thus, in future events we recommend employing boundary and containment methods to mitigate the loss of polystyrene into the environment while the pontoon is being removed.
   c. Clean Water Group also had a ute mounted vacuum that was suggested for trialling on Peregian and Sunshine Beach. However, Noosa Council did not grant permission to trial this technology.

Life Cycle Analysis (LCA) of polystyrene pontoons

Through Tangaroa Blue Foundation's collaboration with researchers at RMIT University and CSIRO's Ending Plastic Waste Mission, a life cycle assessment (LCA) approach on how to manage polystyrene from pontoons was conducted. As of June

2023, this research is currently accepted by a scientific journal. The abstract of the manuscript is included here:

> "Expanded polystyrene (EPS) pollution in the marine environment is a pressing issue in Queensland, Australia due to a recent flood that scattered hundreds of EPS-containing pontoons along the coastline, causing severe ecological damage. To assist in the clean-up effort and provide crucial data for developing management guidelines, this study investigates the environmental performance of different end-of-life (EoL) disposal/recycling methods, including (i) landfill; (ii) mechanical re-processing; and (iii) dissolution/precipitation using d-limonene. Using the life cycle assessment framework, the results showed that d-limonene was the most environmentally favourable option, especially when the polystyrene precipitate was recycled into new products. Its net impacts in climate change, acidification, and fossil fuel depletion were 414.5 kg CO_2 eq, -22.9 kg SO_2 eq, and -421.4 kg oil eq, respectively. For comparison, the impacts of landfilling EPS in these categories were found to be 700 kg CO_2 eq, 3.5 kg SO_2 eq, and 282 kg oil eq, respectively. Landfill also contributed considerably to eutrophication potential, at 3.77 kg N eq. Impacts from mechanical re-processing was moderate when compared with landfill and d-limonene. The result also showed that transportation, particularly the transportation of personnel and heavy machinery to remote beach sites, was the biggest contributor to impacts in the EoL stage. Its impacts in climate change, acidification, eutrophication potential and fossil fuel depletion were 1369.8 kg CO_2 eq, 6.5 kg SO_2 eq, 0.2189 kg N eq, and 497.7 kg oil eq, respectively. Monte Carlo analysis showed that the conclusions made from these results were stable and reliable. Limitations of this model and recommendation for future investigations were also discussed in this work."

This study highlights that at present, the standard end-of-life recommendation for pontoons, regardless of if they were flood debris, is to send them to a landfill (John Hogan, CEO Superior Jetties, personal communication). This poses a challenge as polystyrene-containing pontoons can take up large amounts of space in landfill due to their volume (Lindstrom & Hicks, 2022) and thus shorten the lifespan of the landfill. It can also break up into microplastics that can disperse from landfill and chemical leaching can occur as described above.

Alternative methods for EoL include chemical solvent application, such as d-limonene or acetone, and mechanical recycling. The LCA conducted found that chemical dissolution using d-limonene was the most environmentally favourable option, followed by mechanical recycling and then landfill. However, none of these alternative methods are commercially available at the scale required to handle pontoon debris in Australia. Mechanical recycling of **clean** polystyrene dropped off at collection depots is available, however, polystyrene collected from the "White Spill" event was not clean and thus could not be recycled. Ultimately this highlights the end-of-life disposal should not take priority over waste avoidance. Instead, alternative materials for pontoon production should be prioritised and improved maintenance and care of existing pontoons should be regulated and enforced.

Tangaroa Blue Foundation's case study on containment and clean-up options

Containment methods were recommended by conservation organisations to responsible agencies during the "White Spill" event to minimise the dispersal of polystyrene from pontoons until they could be removed. However, there were concerns that some containment methods, such as wrapping in plastic, would result in additional plastic entering the environment. The result was that pontoons were left uncovered until they were removed. Future flooding events need a coordinated and planned response for containing polystyrene debris until it can be removed.

Containment of the polystyrene can occur using barrier methods. There are numerous types of materials that can be used to wrap items to contain them. Variability in UV light and water that can enter each material exists and may impact the item contained within. During the "White Spill" event, plastic pallet wrap was proposed but there was concern around this material dislodging and entering the environment causing further damage. However, alternatives such as shade cloths and heavy-duty tarps could provide similar capabilities while reducing the potential amount of plastics in the environment.

Removal of polystyrene pontoons from beaches is a challenge due to the size and mass of these items. Polystyrene pontoons vary in size, but the typical pontoon was estimated to be 14 m x 4 m x 1 m, weighing up to 16 tonnes, including 39 m^3 of polystyrene weighing 600 kg. Removal requires large machinery and access to beaches, which is not always possible. Methods used to reduce the volume of polystyrene into a more manageable size that could be removed more quickly would reduce the amount of polystyrene entering the environment. If polystyrene is removed from the pontoon, much of the environmental damage is mitigated as the steel, aluminium, concrete, and polyethylene liner are less likely to disperse into the environment before the item can be removed.

Solvent-based material recycling is one method used to recycle polystyrene because it reduces the volume, allows the dissolved product to be reshaped and can tolerate some contamination of the polystyrene (Hattori, 2015; Hearon et al., 2014). Polystyrene has been demonstrated as soluble in numerous petroleum-based solvents and in natural solvents (Shikata et al., 2011). However, there is much debate about the suitability and safety of some of these solvents in marine applications such as beaches in the "White Spill'' event. Two of the proposed solvents are acetone, a petroleum-based solvent that is widely available in Australia, and the naturally occurring citrus fruit extract d-limonene, which is available but in reduced amounts (Graham Attwood, EPS Australia, personal communication; Hattori, 2015). Acetone is a colourless liquid with a distinct smell and taste that evaporates easily, dissolves in water and is flammable (PubChem, 2023a). Acetone is used to make many items including plastic, fibres, and other chemicals; it is also found naturally in plants, volcanic gases and forest fires (PubChem, 2023a). Acetone is considered acutely toxic for fish, aquatic invertebrates, algae and microorganisms in concentrations >1000mg/L and allowing it to enter waterways should be avoided (Diggers, 2022). D-Limonene is a clear, colourless liquid made from the oil extracted from citrus peels. It is recognised as food safe by the USA Food and Drug Administration and is often used as a flavour or fragrance but can also be used in cleaning supplies (PubChem, 2023b). Although contamination of waterways is not recommended, d-limonene is not hazardous for acute or chronic aquatic exposure indicating it may be a safer option to use in coastal environments (Gilly's, 2021).

Virgin polystyrene is a material that has not been exposed to the environment and is assumed to be in its strongest and most durable condition. Even in normal conditions, pontoons that have been deployed in the river will be exposed to wind, water, UV light, and potential debris floating down the river. Exposure to these elements may cause polystyrene to degrade and fragment into the environment (Song et al 2017; Turner et al 2020). However, a pilot trial testing polystyrene containment and dissolution methods was conducted by Tangaroa Blue Foundation (February - May 2023) using virgin polystyrene to provide a conservative estimate of the effectiveness of multiple containment methods and two solvent dissolution methods. This information could be utilised by relevant authorities to inform them of options for containment and dissolution methods in future flooding events with the understanding that older and damaged polystyrene pontoons may produce different results with these methods.

Methods

Polystyrene pontoons vary in size, but the typical pontoon was estimated to be 14 m x 4 m x 1 m, weighing up to 16 tonnes, including 39 m^3 of polystyrene weighing 600 kg. It was not possible for us to test such a large amount of polystyrene as we did not have adequate space to conduct these trials. Instead, we trialled containment and dissolution methods on three smaller-size groups of virgin polystyrene from The Foam Company (www.thefoamcompany.com.au). The trial was planned for 3 months (2 Feb - 28 Apr) because this was the length of time that the last beached pontoons were removed from the environment following the "White Spill" event (June 2022).

Experimental set-up

The three sizes of polystyrene we tested each method on were 0.1 m^3, 0.3 m^3, and 0.5 m^3. The length, width, height, weight and colour of each piece of polystyrene was recorded. There were eight testing options (six containment options and two dissolution options) that contained one of each size of polystyrene. Testing options included:

1. Control: no dissolution or containment treatment;
2. Containment: light stretch clear shrink wrap 17 um thickness;
3. Containment: heavy shrink wrap 25 um thickness;
4. Containment: biodegradable hand stretch wrap 20 um thickness;
5. Containment: shade cloth (90% UV heavy duty cloth) silver;
6. Containment: shade cloth (70% UV light duty cloth) black;
7. Containment: heavy duty tarp
8. Dissolution treatment: d-limonene
9. Dissolution treatment: acetone

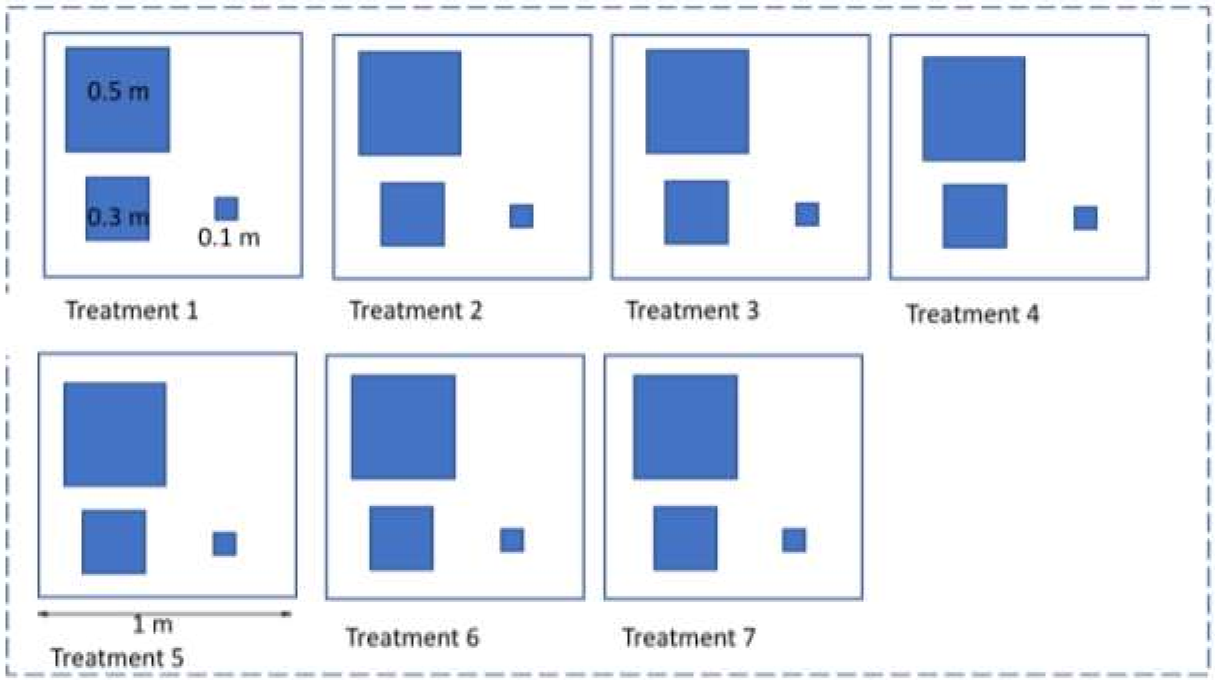

Figure 17. *Schematic of the containment method experimental set-up with seven treatment options and three size variations for each treatment option.*

Each containment method was attached to the corresponding polystyrene pieces and the length, width, height, and weight were recorded. The experiment was set up as in Figure 17 in a Tangaroa Blue Foundation employee's garden with stakes at the corner of each treatment and hessian cloths around each treatment as a primary barrier (Fig 18). All three sized pieces with the same treatment were contained within the same barrier. All pieces were staked to the ground using ratchet straps and tent pegs to ensure pieces were not carried away in any extreme weather. A secondary perimeter around all treatments was set up (Fig 18).

Figure 18. *The containment method experimental set-up.*

Abrasion and extreme weather were common in the beach environment following the "White Spill" event. To simulate abrasion to the best of our abilities in this setting, a garden hose was used to soak all containment method treatments for 1 hour each week of the experiment. Observations were recorded 2 days after the abrasion treatment was completed documenting length, width, height, weight of the treatment pieces. If any polystyrene was visible in the primary or secondary barriers the amount of polystyrene was recorded. At the end of the experiment, the containment treatment was removed from the polystyrene and the length, width, height, weight and colour of the remaining polystyrene was recorded.

Dissolution tests were conducted on all three sizes of polystyrene for both acetone and d-limonene. The initial length, width, height, weight of the treatment pieces were recorded and then each piece was placed in a plastic tub in a well-ventilated area. The volume of acetone used for dissolution were 40 mL, 660 mL, and 4000 mL for the 0.1 m3, 0.3 m3, and 0.5 m3 pieces, respectively. The volume of d-limonene used were 40 mL, 660 mL, and 3000 mL for the 0.1 m3, 0.3 m3, and 0.5 m3 pieces, respectively. The polystyrene pieces were fed into the solvent and stirred regularly. The time it took for the entire polystyrene piece to dissolve and the weight of the dissolved polystyrene were recorded.

Weather data including the minimum and maximum temperature, wind speed and direction, rainfall, and relative humidity, on each day of sampling were recorded from the Bureau of Meterology's Gympie, QLD weather station.

Results

In all three sizes, 0.1 m^3, 0.3 m^3, and 0.5 m^3, there was minimal change in the length, width and height (~1 mm) of the polystyrene pieces throughout the trial (Appendix 6 Table 1). The weight for 0.1 m^3 piece across all seven containment treatments ranged with the weight in the control treatment the lowest at the beginning (55 g) and end of the trial (85 g; Fig 19A). At the beginning of the trial, treatment 6, the shade cloth (90%, UV heavy duty) was heaviest (140 g; Fig 19A). However, by the end of the trial, treatment 7 the heavy-duty tarp, was the heaviest (165 g; Fig 19A). The weight for 0.3 m^3 piece across all seven treatments followed a similar pattern (Fig 19B). However, treatment 4 the biodegradable hand stretch wrap was lightest at the beginning of the trial (465 g). The weight for 0.5 m^3 piece across all seven treatments similarly had the control treatment the lightest across the entire trial period and treatment 7 the heavy-duty tarp the heaviest by the end of the trial (Fig 19C). However, the weight fluctuation in the heavy-duty tarp was more variable with a minimum at the beginning of the trial (2,525 g) to a peak of 3,920 g on March 31 and down to 3,760 g at the end of the trial on April 28 (Fig 19C).

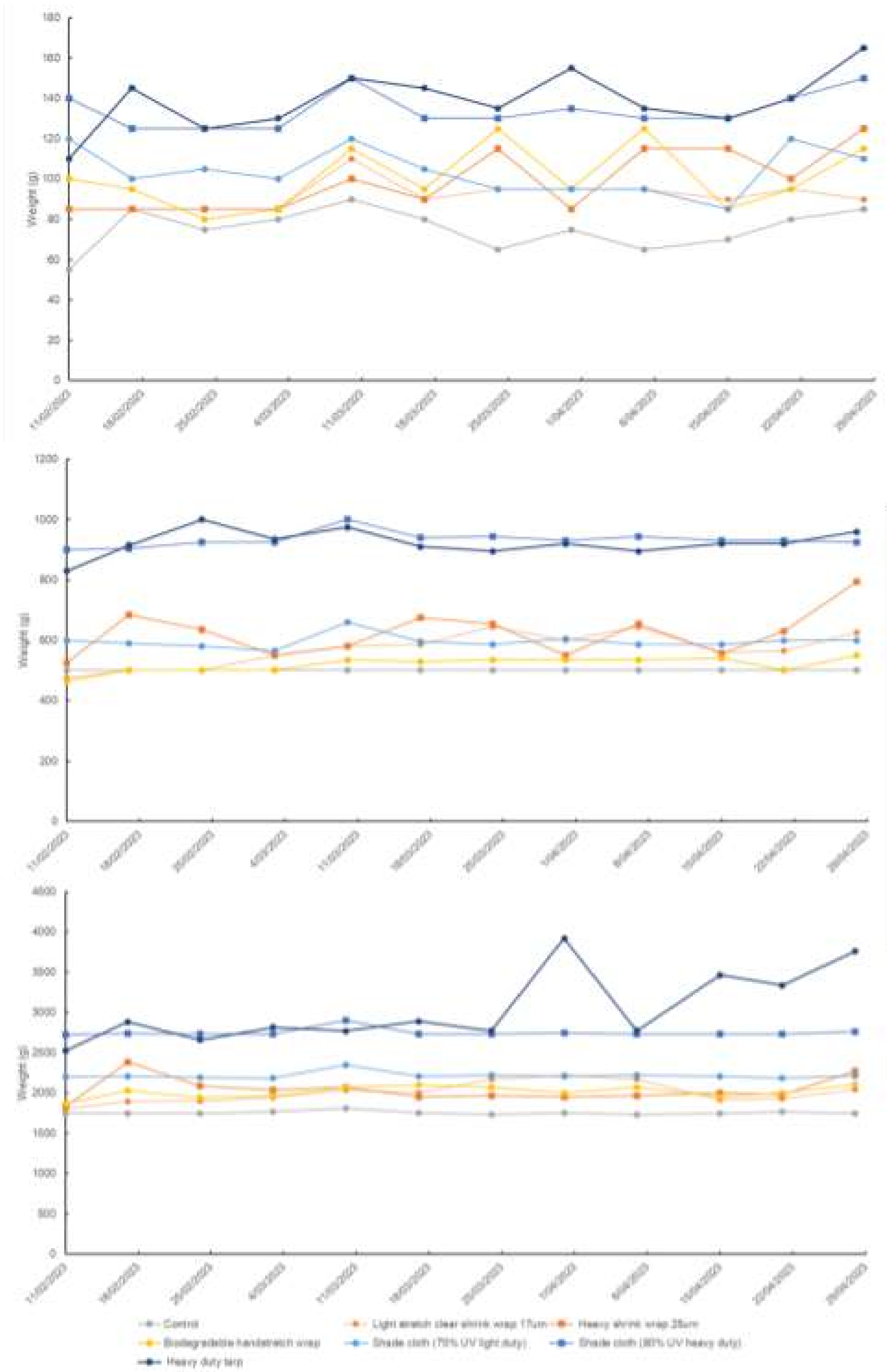

***Figure 19**. The weight of the (A) 0.1 m^3 (B) 0.3 m^3 and (C) 0.5 m^3 pieces of polystyrene and the seven treatments across the trial period (Feb 11- April 28, 2023).*

Figure 20 Control treatment with items growing out of the polystyrene (indicated in the red circles).

Figure 21. Polystyrene leakage in the primary barrier from the control treatment (top) and the biodegradable hand stretch wrap (bottom).

There was a noticeable change in colour of the polystyrene throughout the trial depending on the containment treatment applied (Appendix 6 Figs 1-6). By the fifth week of the trial, the control treatment, the light stretch wrap, the heavy stretch wrap, the biodegradable hand stretch wrap, and the shade cloth (90% UV) all began to show yellowing on the top face of the polystyrene that experienced more sun exposure (Appendix 6 Figs 1-5). Both shade cloth treatments had dirt enter the mesh contributing to changes in colour. The heavy-duty tarp showed no change in colour of the polystyrene across the entire trial. The control treatment also appeared to be growing something that appeared to be a mushroom out of the polystyrene by week 5 of the trial (Fig 20).

In all cases where a containment treatment was applied the treatment began to come loose from the polystyrene. However, none of the containment treatments completely came away from the polystyrene pieces. The light stretch wrap, the heavy stretch wrap, and the biodegradable hand stretch wrap noticeably collected water between the containment method and the polystyrene which likely contributed to the changes in weight recorded during the trial.

Both the primary and secondary barrier were checked for polystyrene pieces that had come loose during the trial each week when the pieces were weighed. Only the control treatment and the biodegradable hand stretch containment method recorded visible polystyrene in the barrier (Fig 21). The control treatment was degraded from the strap that was attached to the polystyrene by week 2. The friction caused the polystyrene to collapse under the strap and there were small amounts of polystyrene leakage into the barrier area (Fig 21). At the end of the trial, there were very fine particles coming off the control pieces (Appendix 6 Fig 1). The biodegradable hand stretch wrap had chunks of polystyrene come off by week 2, however they could not be found in either the containment method or the barriers. By week 3, more polystyrene was found in the primary barrier (Fig 21).

Weather during the 12-week trial varied. Wind speed varied from 4 – 17 km/h with an average wind speed of 10.3 km/h. Temperature ranged from 11.1 – 36.1 °C with an average minimum of 16.8 °C and an average maximum of 29.8 °C. Rainfall varied from 0 – 8.2 mm on the day of recording with an average of 0.9 mm across the trial. Finally, the relative humidity ranged from 25 – 96%.

All three sizes of polystyrene dissolved quickest when acetone was used as the solvent. Time for dissolution in acetone ranged from 8 minutes 27 seconds for the 0.1 m^3 piece of polystyrene to 26 minutes and 4 seconds for the 0.5 m^3 piece of polystyrene. The 0.1 m^3 piece of polystyrene dissolution rate was 0.237 grams of polystyrene dissolved per mL of acetone per minute. The dissolution rate for the 0.3 m^3, and 0.5 m^3 pieces of polystyrene were 0.0223 and 0.0226 grams of polystyrene dissolved per mL of acetone per minute, respectively. The final volume of dissolved polystyrene and acetone was 40 mL, 700 mL and 3000 mL for the 0.1 m^3, 0.3 m^3, and 0.5 m^3 of polystyrene, respectively. Similarly, the final weight of dissolved polystyrene and acetone was 20 g, 325 g and 1500 g for the 0.1 m^3, 0.3 m^3, and 0.5 m^3 of polystyrene, respectively.

All three sizes of polystyrene pieces were slower to dissolve in d-limonene than in acetone. Time for dissolution in d-limonene ranged from 20 minutes 10 seconds for the 0.1 m^3 piece of polystyrene to 6 hours 31 minutes and 12 seconds for the 0.5 m^3 piece of polystyrene. The 0.1 m^3 piece of polystyrene dissolution rate was 0.093 grams of polystyrene dissolved per mL of d-limonene per minute. The dissolution rate for the 0.3 m^3, and 0.5 m^3 pieces of polystyrene were 0.0036 and 0.0012 grams of polystyrene dissolved per mL of d-limonene per minute, respectively. The final volume of dissolved polystyrene and d-limonene was 40 mL, 800 mL and 6000 mL for the 0.1 m^3, 0.3 m^3, and 0.5 m^3 of polystyrene, respectively. Similarly, the final weight of dissolved polystyrene and d-limonene was 20 g, 795 g and 4435 g for the 0.1 m^3, 0.3 m^3, and 0.5 m^3 of polystyrene, respectively.

Discussion

In all cases except the biodegradable hand stretch wrap, the containment methods had no visible loss of polystyrene into the environment during this trial. Thus, light shrink wrap, heavy shrink wrap, two options of shade cloth and a heavy duty tarp could all be considered as containment options in future flooding events where pontoons are beached. Containment options that were more exposed to the sun including the shrink wrap and shade cloth appeared to degrade quicker as indicated by the yellowing of the polystyrene. Degradation of polystyrene when exposed to UV light and abrasion is consistent with the literature (Song et al 2017). The yellowing may indicate that it would be best to choose a containment method that reduces sun exposure to further minimise the degradation of the polystyrene.

The containment methods came loose and changed in weight throughout the trial suggesting that whichever containment method utilised in an emergency response situation should account for a loosening and collection of water. Increased water is also likely to occur in a beach environment due to waves and tides in addition to potential rainfall. During the “White Spill” event, responsible agencies were concerned that any plastic containment method could come loose and enter the environment. Throughout the trial all methods loosened somewhat, however, none came completely off suggesting that the risk of this occurring might be minimised in an emergency. The biodegradable hand stretch was the method that became least secure and also had the most polystyrene leakage into the environment other than the control which had no containment. Thus, based on this trial the biodegradable hand stretch may be the least suitable primary containment option in an emergency situation.

When there was polystyrene leakage from the control and biodegradable hand stretch the majority of visible leakage was caught in the primary barrier. A primary and secondary barrier are able to catch leakage so that it can be collected and prevented from escaping to the wider environment. However, a chunk of polystyrene from the control, which had no containment method, was lost outside of the barriers further highlighting the importance of a containment method to reduce this loss.

The dissolution methods showed that acetone was faster at dissolving all volumes of polystyrene than the d-limonene and resulted in the same or smaller final volumes of dissolved polystyrene and solvent mixture. The 0.1 m^3 dissolved more than 2-fold faster, the 0.3 m^3 dissolved more than 6-fold faster and the 0.5 m^3 18-fold faster. It is important to consider the dissolution rate because in emergency situations the crew responding may not have the capacity or time to dissolve these large volumes of polystyrene. The d-limonene took more than 6 hours to dissolve a volume of 0.5 m^3 which is significantly less than the volume of polystyrene in one pontoon. The small and medium pieces of polystyrene resulted in almost the same final volume of solvent and dissolved polystyrene. However, the largest volume, 0.5 m^3, was half the volume when acetone was used as a solvent. Acetone is also readily available here in Australia making large volumes quickly and easily accessible in emergency situations. These results indicate that acetone would be a good method for a quick way of dissolving polystyrene into a more manageable volume to remove from the environment. Anecdotally, this method is used in at-home experiments to create a resin for moldable plastic objects (killbox, 2023). However, acetone is highly flammable and considered acutely toxic for fish, aquatic invertebrates, algae and microorganisms in concentrations >1000 mg/L (Diggers, 2022). Thus, using acetone in beach or coastal environments will introduce an additional environmental contamination risk. If acetone were to be used as the dissolution solvent, the final dissolved product would also need to be contained to prevent environmental exposure to mitigate the risk from the acetone itself as well as any leached products from the dissolved polystyrene. D-limonene is a much safer option because it is not hazardous for acute or chronic aquatic exposure (Gilly's, 2021) but it took a significantly longer time to dissolve. It is important that environmental risk assessments and additional research on using these dissolution methods be conducted in order to evaluate whether these are viable options in emergency situations.

The results of this trial should be cautiously interpreted as there are numerous caveats. First, the polystyrene used in this trial was virgin polystyrene because it is assumed to be in the best condition and therefore any results from the trial would be conservative estimates of what may happen in future "White Spill" events. We did not know the age or condition of the pontoons in the "White Spill" event prior to them being beached. It is likely that the polystyrene may have been degraded prior to being beached due to wind and UV exposure (Song et al 2017; Turner et al 2020) or exposure to burrowing organisms (Jang et al. 2018). The increased age and exposure to these conditions may result in increased degradation of pontoons in flooding events. Second, the size of the polystyrene pieces is much smaller than a beached pontoon because it was not feasible due to cost, space or availability to test multiple large pontoons for this trial. Third, there was only one of each size polystyrene for each treatment. Thus, no statistical comparisons can be made between treatments. Fourth, the conditions experienced by the polystyrene in this trial are not reflective of conditions that a beached pontoon would experience. Additional abrasion from wind, waves, and tidal movements is likely to be much more intense on the pontoon than the weather experienced during this trial. However, this trial can be considered a starting point to develop further studies that test the degradation of polystyrene from pontoons and in different environments.

The results of this trial indicate that all containment methods, except biodegradable hand stretch wrap, reduced the amount of visible polystyrene leakage into the environment. Each containment method did come loose during the 12-week trial but none came completely off of the polystyrene pieces. Thus, in future events where pontoons are beached securely, attaching a containment method can reduce the polystyrene that spills into the environment. The utilisation of barriers also helped contain the minimal leakage of polystyrene that occurred during this trial indicating that it could also work in future flooding events. In both cases, the containment method and barriers should be regularly monitored for secure attachment and any leakage of polystyrene until the pontoon can be safely cleaned up.

Australian Marine Debris Initiative (AMDI) Database Recorded Polystyrene

The Australian Marine Debris Initiative is a network of communities, schools, industries, government agencies and individuals focused on reducing the amount of marine debris washing into our oceans. Citizen scientists recorded the removal of more than 5.5 tonnes of litter items from 187 clean-ups at 76 sites throughout Southeast Queensland from January 2022 to March 2023, approximately one year following the 2022 floods (Figure 22). This is a conservative estimate of the total amount of debris removed following the floods due to the excessive amounts of debris retrieved, the urgency in removal, and limited capacity to record the debris in the AMDI Database. The top item collected was hard plastic pieces (25,817 items), however, foam remnants i.e., polystyrene, were the fourth most common item collected (7,160 items; Fig 22). The majority of debris was plastic material (>70%) followed by foam materials (7%) It is not always possible to determine the origin or source of foam when it is a foam remnant, thus some of these remnants may have come from a polystyrene pontoon.

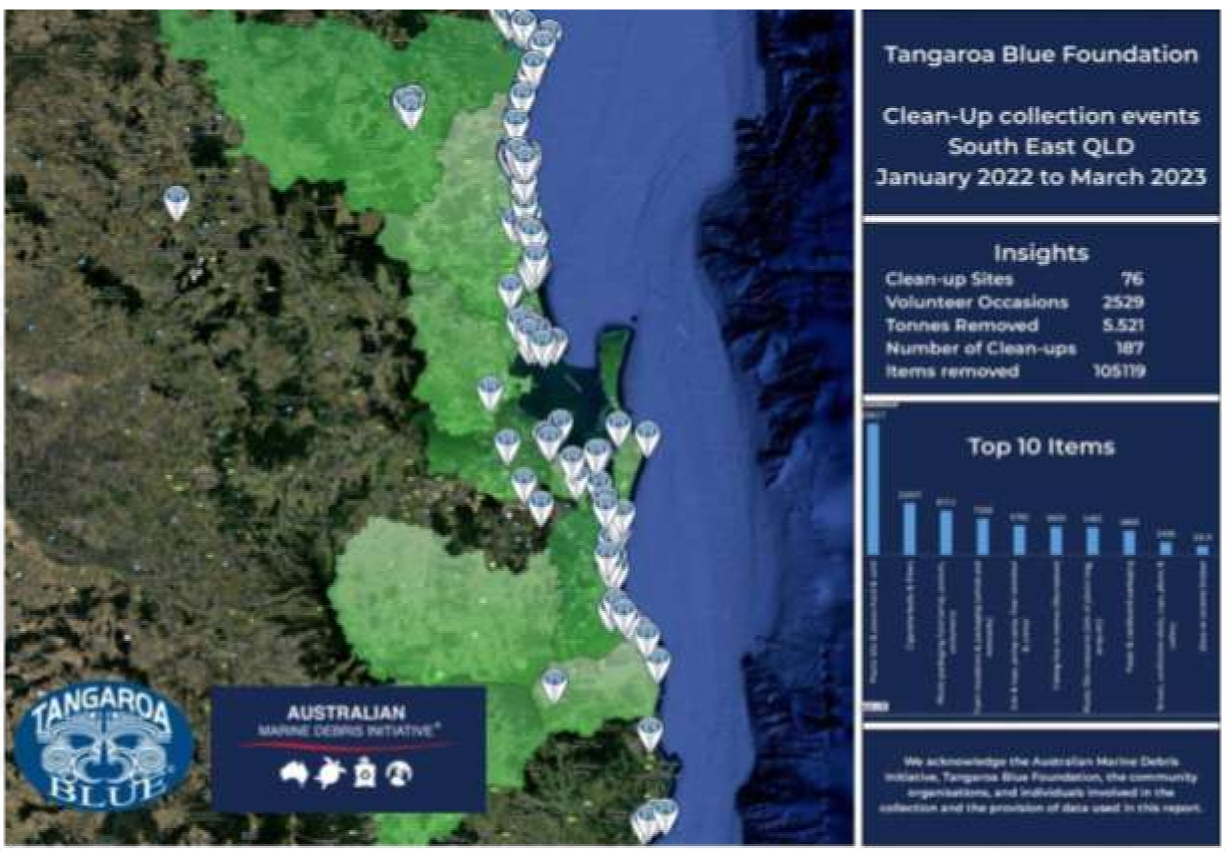

***Figure 22**. Clean-up collection events in Southeast Queensland from January 2022 to March 2023 recorded in the AMDI Database (AMDI Database, 2023).*

There is no specific item type in the AMDI Database for pontoons. However, some contributors to the AMDI Database recorded the item as a foam item and noted down that it was a pontoon. Thus, the polystyrene pontoons that were recorded in the AMDI Database were much fewer than recorded by all collaborators in this document, government agencies and local disaster management authorities (Fig 23) highlighting the need for collaboration and data sharing. Without collaboration, a comprehensive understanding of the true extent of the "White Spill'' event would not be possible. However, when we use data from the AMDI to examine foam buoys,

Figure 23. Foam material items collected during clean-up collection events in Southeast Queensland from January 2022 to March 2023 (AMDI Database, 2023).

foam sheets and foam food packaging, through time, we can see that the average number of foam items collected per clean-up ranged from 0 items to 4.7 items per clean-up (Fig 24). Foam insulation & packaging (whole and remnants) was considered separately because the average number of items collected per clean-up ranged from 5.4 in January 2023 to 140.4.in May 2022 (Fig 25). Although foam remnants, possibly from pontoons, collected during clean-ups appear to be decreasing over time, we can assume that distribution of the material into the wider environment has continued. It is possible that polystyrene may have been buried and covered up deeper in the sand than citizen scientists can collect, it may have been transported via wind, waves or tides to different habitats, or ingested by wildlife, we can not know for certain. However, in an effort to examine areas where known pontoons were beached during the "White Spill'' event, three sites in Noosa were sampled in May 2023 following the Australian Microplastic Assessment Project (AUSMAP) and AMDI Monitoring Methodologies.

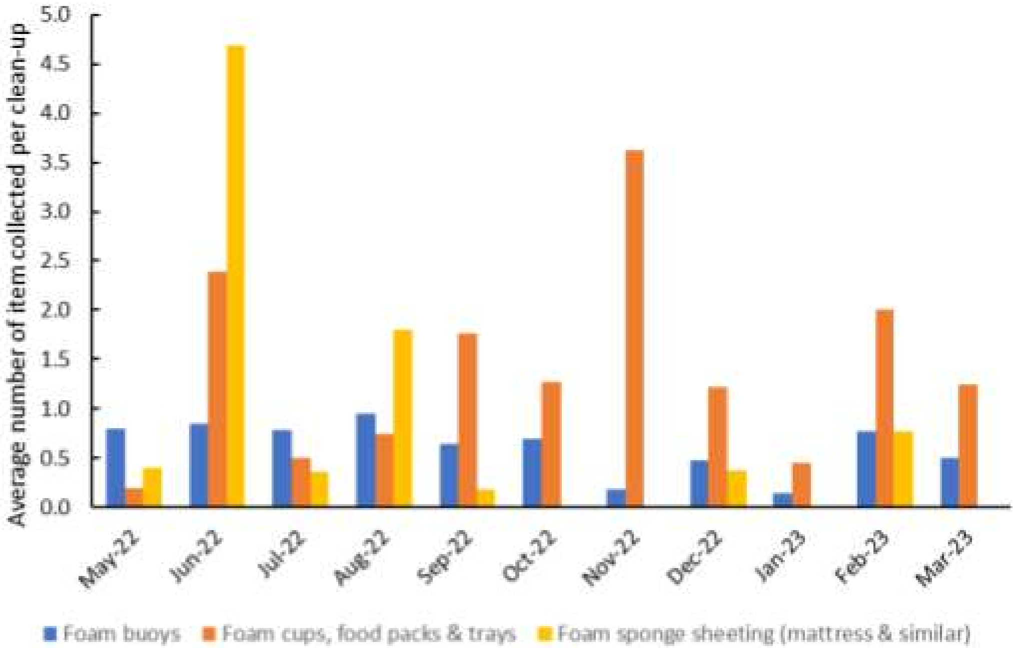

Figure 24. *The average number of foam items, by type, collected per clean-up event in Southeast Queensland from May 2022 to March 2023*

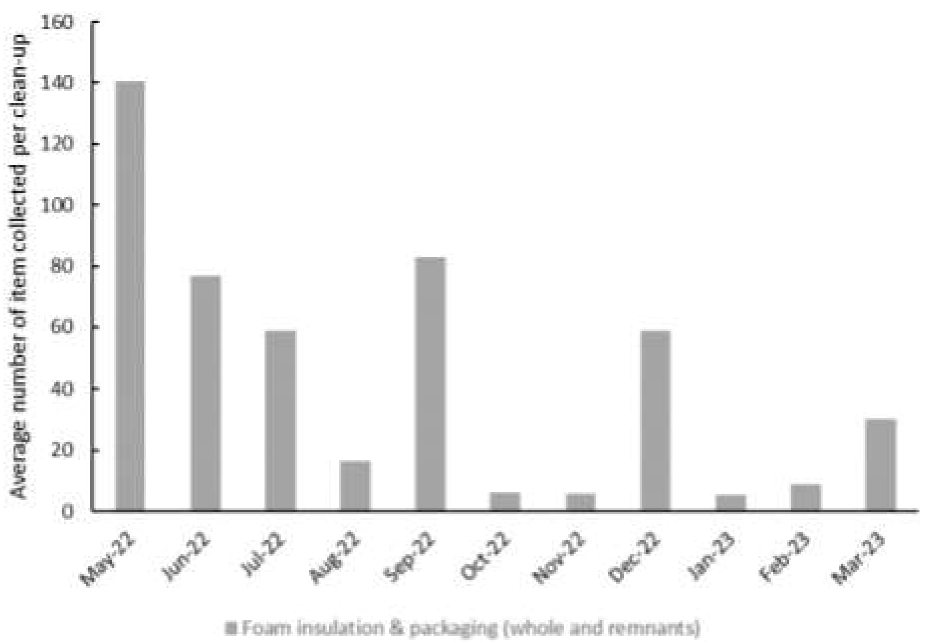

Figure 25. *The average number of foam insulation and packaging (whole and remnants) items collected per clean-up event in Southeast Queensland from May 2022 to March 2023.*

The three sites sampled were Castaways Beach, Peregian Beach and Sunshine Beach (Appendix 7). A total of 5.2 kg (701 items) was removed from all three sites The number of foam insulation & packaging (whole and remnants) collected at each site ranged from 24 items (0.06 foam items/m) at Peregian Beach to 374 items (1.1 foam items/m) at Castaways Beach. Sunshine Beach had 238 items (0.3 foam items /m). Castaways Beach was the sampled site with the most foam items. During the "White Spill" event, Castaways Beach BA 40 was used as a retrieval access point in the removal of beached pontoons. Pontoons were dragged along the beach from Sunshine and Sunrise Beaches to this Beach Access Point. On April 1st, 2022 a Pollution Incident Report was filed with DES in relation to the retrieval methodologies employed by Noosa Council (Appendix 4).

More than one year after the "White Spill" event, polystyrene is still being detected and retrieved from beaches that had known beached pontoons. We can not say for certain that these small fragments are from the pontoons. However, it is very likely considering the fragmentation and wide dispersal of polystyrene recorded by conservation organisations during the "White Spill" event. All three sampled sites are beaches used by nesting turtles and thus it is important that mitigation of polystyrene impacts occur. Anecdotally, there were no recorded turtle nests north of BA 40 in the 2023 nesting season (Coolum and North Shore Coast Care, 2023). However, reasons for this remain unclear and further research is needed.

Evidence-based policy and management relies on data availability. There are ongoing efforts to remove polystyrene from the environment in Southeast Queensland. We recommend investment in long-term monitoring programs to further understand polystyrene pollution levels and dispersal at beached pontoon sites and suggest utilising this monitoring data to inform future flood clean-up efforts

Upstream Mitigation Recommendations

The damage caused by the "White Spill" event underscores the importance of proactive preparation for similar incidents, emphasising the need to implement preventative measures rather than relying solely on reactive responses following an event. Upstream mitigation efforts are essential to meet SDG14, which aims to conserve and sustainably use the oceans, seas and marine resources for sustainable development. This includes reducing plastic waste that enters the ocean, promoting sustainable fishing practices, protecting and restoring coastal habitats, and improving waste management practices. Achieving SDG14 requires collaboration and coordination among multiple stakeholders, including governments, businesses, and civil society organisations.

The MSQ working group aims to address the design, anchoring and tethering systems, pile heights, identification tags, maintenance inspection schedules, extended producer responsibility, insurance considerations, end-of-life cycle management and fitness of purpose of newly manufactured pontoons containing polystyrene to mitigate environmental impacts in future flood events. However, these recommendations do not encompass existing pontoons.
There are perhaps thousands of existing pontoons in river systems across Southeast Queensland that survived the deluge and a small number of pontoons that were returned to owners following the 2022 floods.The condition and security of these pontoons is of particular concern. Satellite imagery is one tool that can assist in ascertaining the number of remaining pontoons but it can also be used to examine imagery before and after the floods to estimate the total number of pontoons lost or sunk. Conversations with the MSQ working group led us to believe that they had completed this work and thus we would encourage this data to be shared to further understand the release of pontoons during the 2022 floods.

Within the Great Barrier Reef Marine Park all anchored pontoons are subjected to inspection routines with additional inspections following significant weather events that could reasonably be considered to have an impact on their structural or operational integrity and are considered emergency inspections (S61 GBRMPA Pontoon Assessment Guidelines, 2019). For existing pontoons in flood susceptible river systems, an inspection of these pontoons for integrity of the subsurface encapsulation, if present, and the tethering systems should be mandated and repaired as a matter of urgency. It is reasonable to presume that the remaining pontoons were subject to considerable force and debris impacts during the flood event and inspection of their encapsulation could reduce the likelihood of polystyrene leakage into the river system. Likewise, the tethering systems of these pontoons could have been compromised by debris and flood water force necessitating inspection and appropriate maintenance and repair to reduce the likelihood of pontoons dislodgement under regular or flood conditions. We recommend that this is not a one off inspection but that the integrity of tethering systems and anchoring systems must be adequate to withstand predicted forces and must be routinely inspected and maintained. There should also be a trigger mechanism determined for inspections, especially in relation to flooding events. These recommendations are aligned with those of the Boating Industry Association regarding pontoons and flooding (BIA, 2022). Vessels and shipping containers are required to go through regular survey tests in order to be registered and these tests have an expiry date (The Container CSC Combined Data Plate Explained | BIC, n.d.). Similar methods could be utilised for pontoons.

Similarly, at a minimum, the identification plate requirements that currently exist (Dept. of Transport and Main Roads, 2015) must be enforced for both new and existing pontoons. Furthermore, we recommend that pontoon identification numbers be placed on a weather and corrosion resistant plate and permanently attached to the pontoon hull in a standardised location. The PIN should include the country manufacturer, serial number, date of manufacture and address of where it is installed and owners required to keep a copy of the PIN (BIA, 2022). Identification of these pontoons would allow them to be returned to their owners when possible or have the owner or insurance contribute to the clean-up costs in future flooding events.

The intact nature of many of the pile loops on the beached pontoons suggested that some pontoons floated above their piles in the event, emphasising the necessity of adequate tethering and anchoring systems. But given the failure of the piles to restrain the pontoons, reassessment of the pile height guidelines could be considered. The design criteria of new pontoons and pile heights should also be reviewed based on updated information regarding flood risks and environmental damage. New designs should consider the likelihood of floods and be built to withstand flood water forces including increased pile height and potential upstream hull dynamic redesign.Those pile loops that were not intact on the beached pontoons indicated the excessive force the pontoons had been subjected to, further motivating the need for new designs.

The Boating Industry Association issue note (Appendix 8) makes clear recommendations in relation to a pathway forward in collaboration between relevant authorities across Council, MSQ and DES in the administration and actionability of upstream interventions and we support the recommendations set forth therein (BIA, 2022). These upstream mitigation measures are reasonable, practical and actionable initiatives to support Australia's commitment to SDG 14 and given the enhanced state of knowledge we now have as to the environmental impact of these pontoons, necessary under the core principle of the Environmental Protection Act, the precautionary principle to prevent future "White Spill" events.

If these enhanced upstream mitigation measures fail and pontoons are again dislodged during a flooding event, efforts to capture the pontoons before they enter the ocean are recommended. One option suggested by Ocean Crusaders would be to deploy a Flood Debris Fence at the mouth of the river, for example at the Brisbane Port by the cruise terminal. This temporary structure flood debris fence could be towed by a tugboat to divert debris to the shore at an angle to minimise the load on the boom. This technology could be piloted in the Brisbane River and expanded to other flood prone river systems. Systems such as this can help prevent debris from dispersing when entering the ocean and in the case of pontoons becoming a navigational hazard or beaching to develop into a “White Spill” event.

Policy recommendations

Numerous places around the world are questioning the use of polystyrene in marine applications (Erdle, 2021; Flora & Fauna International, 2020). One of the objectives of Australia’s National Plastics Plan (2021) is to reduce the amount of plastic litter and pollution entering our waterways. However, the National Plastics Plan specifically excluded EPS & EXP used in building and construction despite research demonstrating the ubiquity of polystyrene within urban river systems (Despotellis et al., 2021). This report contributes directly to the state of knowledge of the perils of utilising polystyrene in marine settings by testifying to the extreme environmental impact of marine pontoons containing polystyrene dispersing fragile, buoyant, durable, lightweight, hazardous particles across 250 known kilometres of World Heritage and UNESCO listed habitats in Southeast Queensland.

Australia’s National Plastics Plan already bans polystyrene from loose packaging EPS and from consumer food and beverage containers (DAWE, 2021). A ban on the use of polystyrene in the design of future pontoons should be considered due to the damage it can cause or at a minimum require it to be adequately encapsulated. In the province of Ontario, Canada in 2021, Bill 228 was approved that prohibited un-encapsulated polystyrene in floating docks, platforms and buoys (Miller, 2021) and a federal motion to ban polystyrene in aquatic infrastructure was submitted to Canada’s House of Commons in March 2023 (Blaney, 2023). This federal motion was not passed; however, it further highlights the growing global concern surrounding the harm of polystyrene in our aquatic environments. The Australian Government could take the opportunity to incentivise the removal of existing polystyrene pontoons by subsidising the cost of more sustainable alternatives such as high density polyethylene hard plastic filled with air.

Extended Producer Responsibility (EPR) policies must be considered in the manufacture and end of life cycle management of pontoons containing polystyrene . The Organisation for Economic Cooperation and Development defines EPR as “an environmental policy approach in which a producer’s responsibility for a product is extended to the post-consumer stage of a product’s life” (OECD, 2023). In the case of pontoon manufacturers this would encourage them to have a whole of life cycle approach to their products and design pontoons which consider the environmental cost of their product. This approach would likely limit or eliminate the use of polystyrene in pontoon design due to its high environmental cost. There are alternatives to polystyrene pontoons in marine applications including high density polyethylene hard plastic filled with air, or at a minimum encapsulated polystyrene

(Erdle, 2021). Or the use of mushrooms to create buoys has already been demonstrated (https://www.mycobuoys.com/) due to the buoyancy and similar properties of polystyrene. It is possible that in the future this biomaterial could also be used for pontoons. If these alternative more sustainable materials are not utilised then pontoon manufacturers, at a minimum, should include the landfill fee for removed pontoons.

The Insurance Council of Australia in April 2023 estimated the cost of the 2022 floods at AUD$5.81 billion highlighting the importance of insurance and the potential for it to be utilised as a mechanism for pontoon debris mitigation. In North Carolina, USA, insurance premiums for homes built in flood risk areas are reduced by following building codes that result in less damage (Allen et al., 2021). Perhaps a similar scheme for pontoons could be implemented in which pontoon insurance includes environmental rehabilitation costs that can be used in the case of floods. Additionally, insurance premiums may be reduced with annual maintenance logs and inspection schedules. Implementation and enforcement of the recommendation for pontoon identification plates would assist in identifying accountability for pontoon debris mitigation, retrieval and environmental rehabilitation costs.

Conclusion

The risk and frequency of extreme weather events including floods is anticipated to increase in the future (IPCC, IGEM) and is the costliest natural disaster in Australia averaging AUD$8.8 billion annually (CSIRO, 2022). It is crucial that we learn from events such as the "White Spill" and integrate our learnings into preparedness planning for future events and preventative measures that mitigate potential environmental, human, and economic impacts.

A clear chain of command and knowledge of who is responsible for pontoon debris is required for future flood events to coordinate recovery activities. A centralised communication hub should be implemented to mobilise volunteers and organisations and transfer knowledge quickly and consistently. Beached pontoons need to be contained and cleaned-up as swiftly as possible. In instances where removal cannot occur immediately, tracking devices and containment methods should be deployed on each pontoon, and barriers around stationary pontoons should be erected. These steps will work to reduce the amount of polystyrene that can enter our coastal and marine environment when pontoons are lost during a flooding event.

Conservation organisations continue to clean-up polystyrene from Southeast Queensland. We cannot say for certain if this polystyrene is from the 2022 floods, although it is highly likely, but what it does demonstrate is the large amounts of polystyrene in our coastal and marine environments. Thus, in addition to emergency preparedness responses, we need to consider upstream mitigation measures such as design criteria, identification plates, pile height, maintenance schedules and enforcement of regulations to reduce the likelihood of pontoons being released during a flood. Australia's EPBC Act 1999 is underpinned by the precautionary principle. Both the scientific literature and the "White Spill" event highlight the negative environmental impacts of utilising polystyrene in marine applications. Thus we recommend applying a precautionary approach and implementing policies that reduce polystyrene use in aquatic environments due to its known environmental and human health impacts to promote our achievement of SDG 14.

In future instances of extreme marine debris pollution from flood events, communication with existing conservation groups to mobilise resources, expertise, volunteers and networks is of critical importance. We acknowledge the outstanding leadership and ongoing collaborative efforts of the environmental organisations dealing with marine debris across Australia and welcome the opportunity to work in partnership with authorities and agencies in the pursuit of protecting our environment and ocean.

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Appendices

Appendix 1: GPS Coordinates of beached pontoon locations
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Appendix 3: Photo and videos included as part of the Pollution Incident Report filed with DES (reference N-100232403)
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Appendix 6: Boating Industry Association Issue Note

Appendix 1: GPS Coordinates of beached pontoon locations

Table 1. Polystyrene pontoon GPS locations

Latitude	Longitude	Notes
27.43743	153.5416	Part pontoon left of dune
-23.7545	151.309	Large pieces of foam from pontoon
-25.8995	153.0919	foam bits from pontoons, various sizes
-25.8487	153.0753	small pieces of polystyrene from pontoons
-25.8822	153.0835	very small bits of polystyrene from pontoons.
-25.9262	153.1116	small polystyrene from pontoons
-25.8829	153.0838	polystyrene very small but some larger bits from pontoons etc.
-25.0778	153.3267	2 large pontoon pieces
-26.1645	153.0935	Noosa Council roundtable
-26.1661	153.0933	Noosa Council roundtable
-26.2034	153.0826	Noosa Council roundtable
-26.2226	153.0776	Noosa Council roundtable
-26.2517	153.071	Noosa Council roundtable
-26.2292	153.0759	Noosa Council roundtable
-26.2926	153.0637	Noosa Council roundtable
-26.2999	153.0628	Noosa Council roundtable
-26.3016	153.0626	Noosa Council roundtable
-26.1196	153.1083	Noosa Council roundtable
-26.103	153.114	Noosa Council roundtable
-27.4382	153.1108	1 pontoon upside down with tear in plastic
-27.4284	153.1201	3 x pontoons caught behind jetty, 2 x upright, 1 x upside down
-27.4031	153.1457	1 x pontoon upright
-27.3853	153.1504	6 x pontoons in area behind the pipeline
-27.3778	153.1598	1 x pontoon upright but broken
-27.3669	153.1559	1 pontoon upright in mangroves
-27.3615	153.146	1 small pontoon upside down deep in mangroves
-27.3428	153.1565	Also towed this pontoon to Nudgee Beach Boat Ramp where it was picked up by a truck
-25.6886	153.0776	Upside down and shredding polystyrene
-25.6083	153.092	Upside down and shredding polystyrene
-27.1684	153.3722	1 x North of Tangalooma Resort
-27.1431	153.3644	1 x South of Cowan Point
-27.1077	153.3701	1 x Bulwer swamp creek
-27.074	153.3666	2 x North of Bulwer Wrecks
-26.488	153.097	Estimated from Noosa Roundtable image
-26.4834	153.0973	Estimated from Noosa Roundtable image
-26.4754	153.0985	Estimated from Noosa Roundtable image
-26.454	153.1029	Estimated from Noosa Roundtable image
-26.4347	153.1058	Estimated from Noosa Roundtable image
-26.4235	153.1092	Estimated from Noosa Roundtable image

-26.4169	153.111	Estimated from Noosa Roundtable image
-26.3985	153.1143	Estimated from Noosa Roundtable image

Appendix 2: Visual library of evidence of polystyrene pollution

Collaborators included in this report compiled photo and video evidence of the polystyrene pollution from the "White Spill" event. Access to this shared library is available upon request from Tangaroa Blue Foundation.

Appendix 3: Spill Station Australia Compact Floating Boom

COMPACT FLOATING BOOM

Product Information

Marine containment booms are an impervious barrier designed to create marine containment barriers to deflect or contain marine spills or floating debris. These booms are sometimes also referred to as an oil containment boom, spill containment boom or floating containment boom. Containment Booms are used to reduce the possibility of polluting shorelines and other resources and to help make recovery easier.

The Spill Station Marine Boom is seen to rest on the surface of the water, however, contains 250mm 'skirt' hanging beneath the surface. The skirt is the draft or the part that is below the water surface once deployed.

Product Description

- A 200mm free-board (float)
- 250mm skirt make it suitable for most conditions.
- Six (6)mm galvanised chain ballast keeps the shirt in place during tidal movements.
- The floating containment boom is manufactured from heavy-duty oil resistant PVC
- Available in 10 metre lengths.
- Marine grade alloy joiners that easily lock together to create any length required.
- Trash and debris booms are passive booms. Water current pushes the debris up against the boom, where it can then be removed from the water.
- When not in use it packs up into a PVC carry bag measuring 600 x 350 x 450(H)mm
- Has a dry weight of 16 kilograms, per 10m lengths.

Deterioration of polystyrene pontoons in water ways

THE ISSUE: Plastic debris is currently the most abundant type of litter in the ocean, making up 80% of all marine debris found from surface waters to deep-sea sediments.

THE IMPACT: When marine organisms ingest plastic debris, these contaminants enter their digestive systems, and over time accumulate in the food web, transferring the contaminants between marine species and humans through consumption of seafood has been identified as a health hazard. Also effecting tourism, the waste damages the aesthetic value of tourist destinations, leading to decreased income from tourism. As such generating major economic costs related to the cleaning and maintenance of the sites.

WHAT CAN BE DONE: strengthen existing international legislative frameworks that address marine plastic pollution. Regional and national governments should also explore national legislative frameworks on Extended Producer Responsibility. Governments, research institutions and industries need to work collaboratively to redesign products and rethink their use and disposal.

RAPID RESPONSE: Marine containment boom for pollution marine containment booms is an impervious barrier designed to deflect or contain marine spills or floating debris. With their standard closed cell foam flotation chamber and a continuous skirt below the surface. The booms 'MUST' be on-hand, ready for deployment as soon as possible for marine containment in harbours, rivers, ponds, dams and other open waterways.

Appendix 4: Photo and videos included as part of the Pollution Incident Report filed with DES (reference N-100232403)

Videos included in the Incident Report can be found at FigShare. DOI: 10.6084/m9.figshare.23538717

Appendix 5: Cleanaway media release. “Vacuum innovation sets new standard for beach polystyrene clean-ups. Cleanaway’s Queensland IWS team sprang into action with a ground-breaking solution to combat polystyrene pollution on Noosa Beach”

Following the February flooding in South East Queensland, approximately 85km of beachfront between the North Sunshine Coast and Fraser Island was contaminated with polystyrene particles that were left behind after pontoons washed ashore.

Cleanaway's Queensland IWS team was contracted by Noosa Council to remove the polystyrene pollution from the affected areas of Noosa Beach on a trial basis. However, with no purpose-built technology for removing polystyrene pollution from beach sand, the team had to think outside the box to come up with an all-new solution for the trial.

Further complicating the problem was the terrain of Noosa Beach which featured hundreds of metres of steep sand cliffs. These cliffs had formed along the beach by rough surf and the situation made it difficult for Cleanaway all-terrain vacuum trucks to access the problem areas.

Pictured: Polystyrene particles washed up on the Noosa Beach shoreline.

“When Noosa Council approached us for a solution, I started researching beach cleaning methods and contacting people who run beach clean-up drives to check if any work had been done in the past, but I couldn’t find what we needed,” said Graduate Engineer Pir Muhammad Junejo.

“So, I approached my IWS team to see what kind of machinery and equipment we have on site. After some brainstorming sessions with the team including Branch Manager Nick Emmett, Key Account Manager Ben May, Project Manager Steve Milward and Operations Supervisor Cem Kusdemir we decided to go ahead with a vacuum unit with vibration separator as our prime method for the trial.”

Pictured: Graduate Engineer Pir Muhammad Junejo from our Queensland IWS team next to an all-terrain vacuum truck. The Noosa Beach polystyrene clean-up trial was Pir's first project with Cleanaway.

Despite the challenges, the Queensland IWS team conducted the polystyrene clean-up trial in early April 2022 – only four months into Pir's career with Cleanaway. Using his newly modified general waste vacuum unit, the team went to work sucking up layers of sand containing polystyrene, which would then be screened at a nearby quarry. Once the polystyrene particles were screened, the clean sand was returned to the beach.

Pictured: The mobile screen that was set up at a nearby quarry to screen polluted sand collected from Noosa Beach.

To facilitate the removal of polystyrene pollution from hard to reach dune areas, the Queensland IWS project team brought in extension hoses to extend the reach of the all-terrain vacuum trucks.

https://www.cleanaway.com.au/sustainable-future/beach-polystyrene-vacuum/

Pictured: The Queensland IWS team sucking up polystyrene waste from the affected areas of Noosa Beach using extension hoses.

Pictured: Some of the polystyrene debris collected during the clean-up trial.

The team's vacuum innovation cleaned up a total of 160L of polystyrene along 5.5km of beachfront in just five days. Any remaining polystyrene particles were collected by hand by Noosa Council crews who were brought in to follow behind Cleanaway vacuum operators.

This successful trial eliminated the risk of microplastics entering the water table and impacting the marine life off the Noosa Beach coast.

"Seeing our methodology work and our team effort pay off gave me immense contentment," said Pir.

"During this trial, we also gained valuable learnings on how we can improve it for implementation in similar projects in the future."

Appendix 6: Supplementary Information for Tangaroa Blue Foundation's containment and dissolution trial

Table 1. Polystyrene containment methods measured during the trial (Feb 11-April 28, 2023)

Date	Time	Treatment	Treatment	Polystyrene size (m^3)	Length (cm)	Width (cm)	Height (cm)	Weight (g)
11/02/23	15:18	1	Control	100	10	9.95	9.95	55
11/02/23	15:28	1	Control	300	29.9	30.05	30	500
11/02/23	15:36	1	Control	500	49.7	50	50	1745
17/02/23	15:35	1	Control	100	10	10	9.9	85
17/02/23	15:47	1	Control	300	29.9	30	30	500
17/02/23	15:50	1	Control	500	49.7	49.9	49.9	1745
24/02/23	16:28	1	Control	100	10	10	9.9	75
24/02/23	16:32	1	Control	300	30	30.1	30	500
24/02/23	16:34	1	Control	500	49.7	49.9	49.8	1745
3/3/23	15:43	1	Control	100	10	10	9.9	80
3/3/23	15:45	1	Control	300	29.9	30.1	30	500
3/3/23	15:47	1	Control	500	49.7	49.9	49.9	1765
10/3/23	16:43	1	Control	100	10	9.9	10	90
10/3/23	16:44	1	Control	300	29.9	30	29.9	500
10/3/23	16:45	1	Control	500	49.7	50	49.8	1810
17/03/23	14:00	1	Control	100	10	10	9.9	80
17/03/23	14:02	1	Control	300	30	30	29.9	500
17/03/23	14:04	1	Control	500	49.6	49.9	49.8	1755
24/03/23	16:17	1	Control	100	10	10	9.9	65
24/03/23	16:19	1	Control	300	29.9	30.1	30	500
24/03/23	16:21	1	Control	500	49.7	49.9	50	1730
31/03/23	16:00	1	Control	100	10	9.9	9.9	75
31/03/23	16:03	1	Control	300	30	30	29.9	500
31/03/23	16:06	1	Control	500	49.7	49.9	49.9	1755
7/4/23	15:05	1	Control	100	10	10	9.9	65
7/4/23	15:10	1	Control	300	29.9	30.1	30	500
7/4/23	15:12	1	Control	500	49.7	49.9	50	1730
15/4/23	17:12	1	Control	100	9.9	10	10	70
15/4/23	17:15	1	Control	300	30	30	30	500
15/4/23	17:20	1	Control	500	49.9	49.7	49.8	1745
21/04/23	16:13	1	Control	100	10	9.9	9.9	80
21/04/23	16:16	1	Control	300	30	29.9	29.9	500
21/04/23	16:18	1	Control	500	49.9	49.7	49.7	1765
28/04/23	12:47	1	Control	100	9.9	10	9.9	85
28/04/23	12:54	1	Control	300	30	29.9	30	500
28/04/23	12:57	1	Control	500	49.9	49.8	49.6	1745
11/02/23	15:45	2	Light stretch clear shrink wrap 17um	100	11	10	10	85

Table 1. Polystyrene containment methods measured during the trial (Feb 11-April 28, 2023)

Date	Time	Treatment	Treatment	Polystyrene size (m^3)	Length (cm)	Width (cm)	Height (cm)	Weight (g)
11/02/23	15:55	2	Light stretch clear shrink wrap 17um	300	30	30.1	30.09	475
11/02/23	16:10	2	Light stretch clear shrink wrap 17um	500	50.1	50.1	50	1805
17/02/23	15:52	2	Light stretch clear shrink wrap 17um	100	11.3	10.1	10.8	85
17/02/23	15:54	2	Light stretch clear shrink wrap 17um	300	30	30.1	30.8	500
17/02/23	15:57	2	Light stretch clear shrink wrap 17um	500	50	50.1	50.2	1895
24/02/23	16:36	2	Light stretch clear shrink wrap 17um	100	11.8	10.6	13.5	85
24/02/23	16:38	2	Light stretch clear shrink wrap 17um	300	32.5	30.2	30.7	500
24/02/23	16:40	2	Light stretch clear shrink wrap 17um	500	51.4	50.2	50.4	1905
3/3/23	15:48	2	Light stretch clear shrink wrap 17um	100	10.8	11.1	13.7	85
3/3/23	15:50	2	Light stretch clear shrink wrap 17um	300	31.8	31.2	31	550
3/3/23	15:51	2	Light stretch clear shrink wrap 17um	500	51.3	51	50.7	1945
10/3/23	16:46	2	Light stretch clear shrink wrap 17um	100	11	12.3	12.7	110
10/3/23	16:48	2	Light stretch clear shrink wrap 17um	300	31.2	31	31.6	580
10/3/23	16:49	2	Light stretch clear shrink wrap 17um	500	50	52.5	50	2040
17/03/23	14:06	2	Light stretch clear shrink wrap 17um	100	10.8	12.6	12.8	90
17/03/23	14:08	2	Light stretch clear shrink wrap 17um	300	30	31	31	585
17/03/23	14:10	2	Light stretch clear shrink wrap 17um	500	50.1	50	49.9	2000
24/03/23	16:23	2	Light stretch clear shrink wrap 17um	100	11	12.2	12.5	95
24/03/23	16:25	2	Light stretch clear shrink wrap 17um	300	30.6	30.3	30.7	645
24/03/23	16:27	2	Light stretch clear shrink wrap 17um	500	50.1	52.6	55	2170
31/03/23	16:09	2	Light stretch clear shrink wrap 17um	100	11	12.2	13.2	95
31/03/23	16:12	2	Light stretch clear shrink wrap 17um	300	30	30.8	31.7	600
31/03/23	16:15	2	Light stretch clear shrink wrap 17um	500	50	50	49.9	2225
7/4/23	15:15	2	Light stretch clear shrink wrap 17um	100	11	12.2	12.5	95
7/4/23	15:18	2	Light stretch clear shrink wrap 17um	300	30.6	30.3	30.7	645
7/4/23	15:20	2	Light stretch clear shrink wrap 17um	500	50.1	52.6	55	2170

Table 1. Polystyrene containment methods measured during the trial (Feb 11-April 28, 2023)

Date	Time	Treatment	Treatment	Polystyrene size (m^3)	Length (cm)	Width (cm)	Height (cm)	Weight (g)
15/4/23	17:23	2	Light stretch clear shrink wrap 17um	100	12	11	12.8	90
15/4/23	17:25	2	Light stretch clear shrink wrap 17um	300	30.2	32	30.4	560
15/4/23	17:28	2	Light stretch clear shrink wrap 17um	500	52.5	50	52.8	1920
21/04/23	16:21	2	Light stretch clear shrink wrap 17um	100	12.2	12.2	10.7	95
21/04/23	16:22	2	Light stretch clear shrink wrap 17um	300	30.3	31.6	31.2	565
21/04/23	16:23	2	Light stretch clear shrink wrap 17um	500	52.6	50.2	50.1	1935
28/04/23	12:59	2	Light stretch clear shrink wrap 17um	100	12.1	13	11.1	90
28/04/23	13:04	2	Light stretch clear shrink wrap 17um	300	30.6	31.5	30.7	625
28/04/23	13:09	2	Light stretch clear shrink wrap 17um	500	50	49.9	49.9	2045
11/02/23	16:20	3	Heavy shrink wrap 25um	100	10.1	11	10.1	85
11/02/23	16:28	3	Heavy shrink wrap 25um	300	30.2	31	30.5	525
11/02/23	16:35	3	Heavy shrink wrap 25um	500	50.5	50.5	50.1	1835
17/02/23	16:01	3	Heavy shrink wrap 25um	100	10.5	13.2	10.1	85
17/02/23	16:03	3	Heavy shrink wrap 25um	300	30.1	30.3	30.1	685
17/02/23	16:06	3	Heavy shrink wrap 25um	500	51	51	49.8	2385
24/02/23	16:43	3	Heavy shrink wrap 25um	100	10.4	14.2	10.3	85
24/02/23	16:44	3	Heavy shrink wrap 25um	300	30.1	35.5	30.5	635
24/02/23	16:46	3	Heavy shrink wrap 25um	500	54	53	50.3	2085
3/3/23	15:53	3	Heavy shrink wrap 25um	100	10.4	14	13	85
3/3/23	15:55	3	Heavy shrink wrap 25um	300	30.2	36	31	550
3/3/23	15:57	3	Heavy shrink wrap 25um	500	60	53	50.2	2035
10/3/23	16:52	3	Heavy shrink wrap 25um	100	10.6	14	12.5	100
10/3/23	16:53	3	Heavy shrink wrap 25um	300	30.4	32	30.8	580
10/3/23	16:54	3	Heavy shrink wrap 25um	500	55	57	52	2070
17/03/23	14:12	3	Heavy shrink wrap 25um	100	10.6	13.8	12.7	90
17/03/23	14:14	3	Heavy shrink wrap 25um	300	30.2	33.5	30.5	675

Table 1. Polystyrene containment methods measured during the trial (Feb 11-April 28, 2023)

Date	Time	Treatment	Treatment	Polystyrene size (m^3)	Length (cm)	Width (cm)	Height (cm)	Weight (g)
17/03/23	14:16	3	Heavy shrink wrap 25um	500	55	53.2	51.2	1950
24/03/23	16:29	3	Heavy shrink wrap 25um	100	10.6	12.6	14.3	115
24/03/23	16:31	3	Heavy shrink wrap 25um	300	30.3	36	31.4	655
24/03/23	16:33	3	Heavy shrink wrap 25um	500	59	53.5	52	1970
31/03/23	16:18	3	Heavy shrink wrap 25um	100	10.5	14	12.7	85
31/03/23	16:20	3	Heavy shrink wrap 25um	300	30.5	35	31	550
31/03/23	16:23	3	Heavy shrink wrap 25um	500	52.5	53.2	52	1950
7/4/23	15:23	3	Heavy shrink wrap 25um	100	10.6	12.6	14.3	115
7/4/23	15:26	3	Heavy shrink wrap 25um	300	30.3	36	31.4	655
7/4/23	15:29	3	Heavy shrink wrap 25um	500	59	53.5	52	1970
15/4/23	17:32	3	Heavy shrink wrap 25um	100	14	10.6	12.7	115
15/4/23	17:35	3	Heavy shrink wrap 25um	300	34	31	30.1	555
15/4/23	17:38	3	Heavy shrink wrap 25um	500	53	58	53	2000
21/04/23	16:25	3	Heavy shrink wrap 25um	100	13	12.5	12.2	100
21/04/23	16:27	3	Heavy shrink wrap 25um	300	35	31	31	630
21/04/23	16:28	3	Heavy shrink wrap 25um	500	53	51	59	1980
28/04/23	13:14	3	Heavy shrink wrap 25um	100	13.9	12.2	12.7	125
28/04/23	13:19	3	Heavy shrink wrap 25um	300	34.8	31.3	30.7	795
28/04/23	13:21	3	Heavy shrink wrap 25um	500	52	60	54	2275
11/02/23	16:45	4	Biodegradable hand stretch wrap (20um)	100	10.5	11	10.2	100
11/02/23	16:55	4	Biodegradable hand stretch wrap (20um)	300	31.5	30.5	30.1	465
11/02/23	17:05	4	Biodegradable hand stretch wrap (20um)	500	50.3	50.5	50.5	1865
17/02/23	16:09	4	Biodegradable hand stretch wrap (20um)	100	10.8	10.3	10.8	95
17/02/23	16:11	4	Biodegradable hand stretch wrap (20um)	300	31	30.5	30.2	500

Table 1. Polystyrene containment methods measured during the trial (Feb 11-April 28, 2023)

Date	Time	Treatment	Treatment	Polystyrene size (m^3)	Length (cm)	Width (cm)	Height (cm)	Weight (g)
17/02/23	16:13	4	Biodegradable hand stretch wrap (20um)	500	50.1	50.2	50.4	2030
24/02/23	16:49	4	Biodegradable hand stretch wrap (20um)	100	17	11	14.3	80
24/02/23	16:53	4	Biodegradable hand stretch wrap (20um)	300	31	31.2	30.5	500
24/02/23	16:56	4	Biodegradable hand stretch wrap (20um)	500	50.5	51	50.2	1945
3/3/23	16:00	4	Biodegradable hand stretch wrap (20um)	100	18	17	15	85
3/3/23	16:01	4	Biodegradable hand stretch wrap (20um)	300	32	31.7	30.7	500
3/3/23	16:02	4	Biodegradable hand stretch wrap (20um)	500	50.2	53	50.5	1965
10/3/23	16:57	4	Biodegradable hand stretch wrap (20um)	100	24	17	20	115
10/3/23	16:59	4	Biodegradable hand stretch wrap (20um)	300	32	31.5	30.8	535
10/3/23	17:00	4	Biodegradable hand stretch wrap (20um)	500	50.6	54	50.8	2075
17/03/23	14:18	4	Biodegradable hand stretch wrap (20um)	100	18	14	17	95
17/03/23	14:20	4	Biodegradable hand stretch wrap (20um)	300	31.5	30.3	30.4	530
17/03/23	14:22	4	Biodegradable hand stretch wrap (20um)	500	50	55	50	2105
24/03/23	16:35	4	Biodegradable hand stretch wrap (20um)	100	18	16.5	16	125
24/03/23	16:37	4	Biodegradable hand stretch wrap (20um)	300	31.5	31	30.5	535
24/03/23	16:39	4	Biodegradable hand stretch wrap (20um)	500	50.4	50.8	50.1	2070
31/03/2023	16:26	4	Biodegradable hand stretch wrap (20um)	100	18	17	10.5	95

Table 1. Polystyrene containment methods measured during the trial (Feb 11-April 28, 2023)

Date	Time	Treatment	Treatment	Polystyrene size (m^3)	Length (cm)	Width (cm)	Height (cm)	Weight (g)
31/03/23	16:29	4	Biodegradable hand stretch wrap (20um)	300	31	31.2	30.5	535
31/03/23	16:31	4	Biodegradable hand stretch wrap (20um)	500	50.5	50.5	50.1	2000
7/4/23	15:32	4	Biodegradable hand stretch wrap (20um)	100	18	16.5	16	125
7/4/23	15:36	4	Biodegradable hand stretch wrap (20um)	300	31.5	31	30.5	535
7/4/23	15:40	4	Biodegradable hand stretch wrap (20um)	500	50.4	50.8	50.1	2070
15/4/23	17:41	4	Biodegradable hand stretch wrap (20um)	100	22	20	11.5	85
15/4/23	17:45	4	Biodegradable hand stretch wrap (20um)	300	31.5	32	50.5	540
15/4/23	17:48	4	Biodegradable hand stretch wrap (20um)	500	50.5	55	50.4	1955
21/04/23	16:30	4	Biodegradable hand stretch wrap (20um)	100	19	20	17	95
21/04/23	16:32	4	Biodegradable hand stretch wrap (20um)	300	30.5	31.5	31.3	500
21/04/23	16:33	4	Biodegradable hand stretch wrap (20um)	500	50.7	50.2	50.4	2000
28/04/23	13:29	4	Biodegradable hand stretch wrap (20um)	100	20	21	16	115
28/04/23	13:34	4	Biodegradable hand stretch wrap (20um)	300	32	31.5	30.8	550
28/04/23	13:40	4	Biodegradable hand stretch wrap (20um)	500	52	49.9	56	2110
11/02/23	17:15	5	Shade cloth (90% UV heavy duty)	100	12	20	13	140
11/02/23	17:22	5	Shade cloth (90% UV heavy duty)	300	34	58	44	900
11/02/23	17:32	5	Shade cloth (90% UV heavy duty)	500	53	65	50.3	2725
17/02/23	16:19	5	Shade cloth (90% UV heavy duty)	100	12	20	13	125
17/02/23	16:21	5	Shade cloth (90% UV heavy duty)	300	34	50	42	905

Table 1. Polystyrene containment methods measured during the trial (Feb 11-April 28, 2023)

Date	Time	Treatment	Treatment	Polystyrene size (m^3)	Length (cm)	Width (cm)	Height (cm)	Weight (g)
17/02/23	16:23	5	Shade cloth (90% UV heavy duty)	500	60	93	66	2740
24/02/23	17:00	5	Shade cloth (90% UV heavy duty)	100	12	20	14.5	125
24/02/23	17:02	5	Shade cloth (90% UV heavy duty)	300	31	54	44	925
24/02/23	17:06	5	Shade cloth (90% UV heavy duty)	500	58	96	69	2730
3/3/23	16:06	5	Shade cloth (90% UV heavy duty)	100	13	19.6	14.8	125
3/3/23	16:08	5	Shade cloth (90% UV heavy duty)	300	32.5	55.5	54	925
3/3/23	16:09	5	Shade cloth (90% UV heavy duty)	500	54	92	83	2735
10/3/23	17:01	5	Shade cloth (90% UV heavy duty)	100	12	20.4	15.5	150
10/3/23	17:02	5	Shade cloth (90% UV heavy duty)	300	36	47.5	45.5	1000
10/3/23	17:04	5	Shade cloth (90% UV heavy duty)	500	54	93	75	2905
17/03/23	14:25	5	Shade cloth (90% UV heavy duty)	100	14	20	15	130
17/03/23	14:27	5	Shade cloth (90% UV heavy duty)	300	39	58	45	940
17/03/23	14:29	5	Shade cloth (90% UV heavy duty)	500	57	93	59	2730
24/03/23	16:41	5	Shade cloth (90% UV heavy duty)	100	14.5	21.7	14.5	130
24/03/23	16:53	5	Shade cloth (90% UV heavy duty)	300	35	53	41	945
24/03/23	16:45	5	Shade cloth (90% UV heavy duty)	500	54.5	92	74.5	2730
31/03/23	16:33	5	Shade cloth (90% UV heavy duty)	100	13.3	20	14.7	135
31/03/23	16:36	5	Shade cloth (90% UV heavy duty)	300	38.5	54.5	43.7	930
31/03/23	16:39	5	Shade cloth (90% UV heavy duty)	500	53	88	79.8	2745
7/4/23	15:45	5	Shade cloth (90% UV heavy duty)	100	14.5	21.7	14.5	130
7/4/23	15:48	5	Shade cloth (90% UV heavy duty)	300	35	53	41	945
7/4/23	15:52	5	Shade cloth (90% UV heavy duty)	500	54.5	92	74.5	2730
15/4/23	17:51	5	Shade cloth (90% UV heavy duty)	100	20	14.5	11.1	130
15/4/23	17:54	5	Shade cloth (90% UV heavy duty)	300	33.8	40.5	56	930
15/4/23	17:56	5	Shade cloth (90% UV heavy duty)	500	56.6	79	91	2730
21/04/23	16:36	5	Shade cloth (90% UV heavy duty)	100	19.4	14.2	10.6	140

Table 1. Polystyrene containment methods measured during the trial (Feb 11-April 28, 2023)

Date	Time	Treatment	Treatment	Polystyrene size (m^3)	Length (cm)	Width (cm)	Height (cm)	Weight (g)
21/04/23	16:38	5	Shade cloth (90% UV heavy duty)	300	55	34.5	40	930
21/04/23	16:40	5	Shade cloth (90% UV heavy duty)	500	93	89	57	2730
28/04/23	13:48	5	Shade cloth (90% UV heavy duty)	100	20	14.5	11	150
28/04/23	13:50	5	Shade cloth (90% UV heavy duty)	300	49	41	34	925
28/04/23	13:55	5	Shade cloth (90% UV heavy duty)	500	92	71	53	2760
11/02/23	17:41	6	Shade cloth (70% UV light duty)	100	14	14	16	120
11/02/23	17:50	6	Shade cloth (70% UV light duty)	300	33	40	36	600
11/02/23	17:59	6	Shade cloth (70% UV light duty)	500	61	70	60	2200
17/02/23	16:27	6	Shade cloth (70% UV light duty)	100	13	13	11	100
17/02/23	16:29	6	Shade cloth (70% UV light duty)	300	31.2	31.2	41.2	590
17/02/23	16:33	6	Shade cloth (70% UV light duty)	500	62	75	57	2205
24/02/23	17:08	6	Shade cloth (70% UV light duty)	100	13.2	14.5	13	105
24/02/23	17:10	6	Shade cloth (70% UV light duty)	300	32.5	33	39.5	580
24/02/23	17:12	6	Shade cloth (70% UV light duty)	500	59	75	63	2195
3/3/23	16:13	6	Shade cloth (70% UV light duty)	100	13.5	17	13	100
3/3/23	16:15	6	Shade cloth (70% UV light duty)	300	34	37	44	565
3/3/23	16:16	6	Shade cloth (70% UV light duty)	500	59	57	78	2185
10/3/23	17:08	6	Shade cloth (70% UV light duty)	100	15	14.5	13	120
10/3/23	17:09	6	Shade cloth (70% UV light duty)	300	35	37	42	660
10/3/23	17:11	6	Shade cloth (70% UV light duty)	500	59	57	74	2350
17/03/23	14:32	6	Shade cloth (70% UV light duty)	100	13	16	12	105
17/03/23	14:34	6	Shade cloth (70% UV light duty)	300	41.2	37	34	595
17/03/23	14:36	6	Shade cloth (70% UV light duty)	500	58	55	61.5	2205
24/03/23	16:47	6	Shade cloth (70% UV light duty)	100	13.5	15	15	95
24/03/23	16:49	6	Shade cloth (70% UV light duty)	300	31	42	35.5	585
24/03/23	16:51	6	Shade cloth (70% UV light duty)	500	57.2	58.7	91	2220

Table 1. Polystyrene containment methods measured during the trial (Feb 11-April 28, 2023)

Date	Time	Treatment	Treatment	Polystyrene size (m^3)	Length (cm)	Width (cm)	Height (cm)	Weight (g)
31/03/23	16:42	6	Shade cloth (70% UV light duty)	100	14.5	16	12	95
31/03/23	16:45	6	Shade cloth (70% UV light duty)	300	31.5	33.9	44.4	605
31/03/23	16:48	6	Shade cloth (70% UV light duty)	500	75.6	58	73	2205
7/4/23	15:55	6	Shade cloth (70% UV light duty)	100	13.5	15	15	95
7/4/23	15:58	6	Shade cloth (70% UV light duty)	300	31	42	35.5	585
7/4/23	16:03	6	Shade cloth (70% UV light duty)	500	57.2	58.7	91	2220
15/4/23	17:59	6	Shade cloth (70% UV light duty)	100	13	16	11.5	85
15/4/23	18:03	6	Shade cloth (70% UV light duty)	300	32	48	34	585
15/4/23	18:05	6	Shade cloth (70% UV light duty)	500	62.5	68	58	2210
21/04/23	16:41	6	Shade cloth (70% UV light duty)	100	17	13	12.6	120
21/04/23	16:42	6	Shade cloth (70% UV light duty)	300	33.5	31.3	37.9	600
21/04/23	16:43	6	Shade cloth (70% UV light duty)	500	50.5	73	58	2190
28/04/23	13:59	6	Shade cloth (70% UV light duty)	100	18	13	14	110
28/04/23	14:04	6	Shade cloth (70% UV light duty)	300	35	53	31.7	600
28/04/23	14:08	6	Shade cloth (70% UV light duty)	500	57	59.5	77	2215
11/02/23	18:10	7	Heavy duty tarp	100	15	18	21	110
11/02/23	18:21	7	Heavy duty tarp	300	38	52	52	830
11/02/23	18:29	7	Heavy duty tarp	500	62	67	73	2525
17/02/23	16:34	7	Heavy duty tarp	100	14	19	17	145
17/02/23	16:36	7	Heavy duty tarp	300	36	45	47	915
17/02/23	16:37	7	Heavy duty tarp	500	56	73	69	2885
24/02/23	17:14	7	Heavy duty tarp	100	15	17	19	125
24/02/23	17:15	7	Heavy duty tarp	300	37	53	47	1000
24/02/23	17:17	7	Heavy duty tarp	500	54	69	71.5	2660
3/3/23	16:18	7	Heavy duty tarp	100	15	19	16	130
3/3/23	16:20	7	Heavy duty tarp	300	33	49	54	935
3/3/23	16:21	7	Heavy duty tarp	500	57	80	69	2815
10/3/23	17:12	7	Heavy duty tarp	100	14	20	17.5	150
10/3/23	17:13	7	Heavy duty tarp	300	47	47.6	52	975
10/3/23	17:15	7	Heavy duty tarp	500	55	72	71	2770
17/03/23	14:38	7	Heavy duty tarp	100	15.9	20.1	18	145
17/03/23	14:40	7	Heavy duty tarp	300	34	47	47	910
17/03/23	14:45	7	Heavy duty tarp	500	59	75	69	2890

Table 1. Polystyrene containment methods measured during the trial (Feb 11-April 28, 2023)

Date	Time	Treatment	Treatment	Polystyrene size (m^3)	Length (cm)	Width (cm)	Height (cm)	Weight (g)
24/03/23	16:52	7	Heavy duty tarp	100	12.3	19.7	16	135
24/03/23	16:54	7	Heavy duty tarp	300	36	54	44.5	895
24/03/23	16:56	7	Heavy duty tarp	500	57	75	68	2775
31/03/23	16:51	7	Heavy duty tarp	100	11.4	19	15	155
31/03/23	16:53	7	Heavy duty tarp	300	35	46	45	920
31/03/23	16:56	7	Heavy duty tarp	500	54.5	75	67.3	3920
7/4/23	16:06	7	Heavy duty tarp	100	12.3	19.7	16	135
7/4/23	16:10	7	Heavy duty tarp	300	36	54	44.5	895
7/4/23	16:13	7	Heavy duty tarp	500	57	75	68	2775
15/4/23	18:08	7	Heavy duty tarp	100	11.5	16	19	130
15/4/23	18:13	7	Heavy duty tarp	300	33	45	53	920
15/4/23	18:16	7	Heavy duty tarp	500	54	71	68	3465
21/04/23	16:45	7	Heavy duty tarp	100	10.8	19.3	15	140
21/04/23	16:46	7	Heavy duty tarp	300	50	45	49	920
21/04/23	16:48	7	Heavy duty tarp	500	52	70	51	3339
28/04/23	14:12	7	Heavy duty tarp	100	15	18	19.5	165
28/04/23	14:14	7	Heavy duty tarp	300	50	48	34	960
28/04/23	14:18	7	Heavy duty tarp	500	71	67	50.6	3760

Supp Fig 1. Control treatment at the beginning of the experiment (A); the 0.3 m^3 piece at the end (B-D) and the 0.5 m^3 piece at the end (E-H).

Supp Fig 2. Treatment 2: light stretch clear shrink wrap (17 um thickness) at the beginning of experiment (A); the 0.1 m^3 piece at the end (B-C); the 0.3 m^3 piece at the end (D-F); and the 0.5 m^3 piece at the end (G-H).

Supp Fig 3. Treatment 3: heavy shrink wrap (25 um thickness) at the beginning of experiment (A); the 0.1 m^3 piece at the end (B-C); the 0.3 m^3 piece at the end (D-E); and the 0.5 m^3 piece at the end (F-H).

Supp Fig 4. Treatment 4: biodegradable hand stretch wrap (25 um thickness) at the beginning of experiment (A); the 0.1 m^3 piece at the end (B-D); the 0.3 m^3 piece at the end (E); polystyrene caught within the primary barrier (F); and the 0.5 m^3 piece at the end (G-H).

Supp Fig 5. Treatment 5: shade cloth silver (90% UV heavy duty cloth) at the beginning of experiment (A); the 0.1 m^3 piece at the end (B-C); the 0.3 m^3 piece at the end (D-E); and the 0.5 m^3 piece at the end (F-G).

Supp Fig 6. Treatment 6: shade cloth black (70% UV light duty cloth) at the beginning of experiment (A); the 0.1 m^3 piece at the end (B-C); the 0.3 m^3 piece at the end (D-E); and the 0.5 m^3 piece at the end (F-G).

Supp Fig 7. Treatment 7: heavy duty tarp at the beginning of experiment (A); the 0.1 m^3 piece at the end (B-C); the 0.3 m^3 piece at the end (D-E); and the 0.5 m^3 piece at the end (F-H).

Appendix 7: AMDI and AUSMAP survey report

AMDI/AUSMAP Coastal Shoreline Monitoring

Site 1: Sunshine Beach
Date of Survey: 20st May 2023
Conducted by: Alison Foley
Low tide: 2.07pm
Time on site: 11.00am – 4.00pm

Site Selection:
Sunshine Beach was impacted by 2 beached pontoons in the East Coast Flood Event of February/March 2022. The pontoon locations were recorded by Maritime Safety Queensland as landing at:

1. -26.4069699, 153.1128868,
2. -26.4083082, 153.1127057

Pre-Survey Site Check:

- Coastal Shoreline with no factors influencing debris.
- Open water facing sandy beach.
- Gentle surf <2m.
- Sunny conditions with light breeze.
- Very northern segment of the beach is an off-leash dog exercise area.

Transect Range Start Point: BA 31 **GPS Coordinates: -26.404698 153.113492** **Survey Distance: 300m** heading North				
	Random number	**GPS Coordinates**	**AUSMAP quadrat high tide line random number**	**Photos taken**
Transect 1	**14 - 39m**	**-26.404424 153.113514**	**21m**	**Yes**
Transect 2	**75 - 100m**	**-26.403977 153.113530**	**91m**	**Yes**
Transect 3	**128 - 153m**	**-26.403434 153.113605**	**138m**	**Yes**
Transect 4	**246 - 271m**	**-26.402372 153.113831**	**259m**	**Yes**

Map 1: Sunshine Beach, Qld. AMDI/AUSMAP Survey 20th May 2023.

Figure 1: Debris sort AMDI/AUSMAP Survey Sunshine Beach, Qld. May 20th 2023.

Images from Sunshine Beach, Qld Survey
20th May 2023

Top L-R:

1. Sunshine Beach Survey Northerly aspect
2. Single polystyrene bead AMDI Transect 1 main beach
3. Single polystyrene bead AMDI Transect 1 dunes
4. AUSMAP quadrat 2 within AMDI Transect 2
5. Single polystyrene bead AMDI Transect 2 main beach

Middle L-R:

6. Single polystyrene bead AMDI Transect 2 dunes
7. Southern boundary of AMDI Transect 3
8. Marine debris AMDI Transect 3: cigarette butt, polystyrene remnant >5mm andcyalume stick
9. AUSMAP Quadrat 3 within AMDI Transect 3 polystyrene remnant >5mm
10. AUSMAP Quadrat 3 within AMDI Transect 3 polystyrene remnant <5mm with microplastics

Bottom L-R:

11. AMDI Transect 4 polystyrene remnant >15mm
12. AMDI Transect 4 polystyrene remnant >20mm
13. AMDI Transect 3 polystyrene remnant >20mm
14. AMDI Transect 4 polystyrene remnant >20mm
15. AMDI Transect 4 from dunes to waterline Easterly aspect

Site 2: Castaways Beach
Date of Survey: 21st May 2023
Conducted by: Alison Foley
Low tide: 2.43pm
Time on site: 11.30am – 4.30pm

Site Selection:
Castaways Beach BA 40 was used as a retrieval access point in the removal of beached pontoons during the "White Spill" disaster. Pontoons were dragged along the beach from Sunshine and Sunrise Beaches to this Beach Access Point. On April 1st 2022 a Pollution Incident Report was filed with DES in relation to the retrieval methodologies employed by Noosa Council.
Pre-Survey Site Check:
- Coastal Shoreline with no factors influencing debris.
- Open water facing sandy beach.
- Gentle surf <1m.
- Sunny conditions with light breeze.
- Significant polystyrene snow recorded along the BA 40 from carpark to beach.

Transect Range Start Point: BA 40 **GPS Coordinates: -26.434672, 153.106856** **Survey Distance: 400m heading North**				
	Random number	**GPS Coordinates**	**AUSMAP quadrat high tide line random number**	**Photos taken**
Transect 1	**26-51m**	**-26.43447, 153.10700**	**14m**	**Yes**
Transect 2	**58-83m**	**-26.43418, 153.10707**	**64m**	**Yes**
Transect 3	**175-200m**	**-26.43295 153.10733**	**197m**	**Yes**
Transect 4	**336-361m**	**-26.43149 153.10763**	**348m**	**Yes**

Map 2: Castaways Beach, Qld. AMDI/AUSMAP Survey 21st May 2023

Figure 2: Debris sort AMDI/AUSMAP survey Castaways Beach, Qld. May 21st 2023.

Images from Castaways Beach, Qld Survey
21st May 2023

Top L-R:

1. BA 40 entrance, Castaways Beach QLD.
2. AUSMAP quadrant 1, AMDI Transect 1, polystyrene bead
3. AMDI Transect 1 dunes polystyrene remnant debris
4. AMDI Transect 1 dunes individual polystyrene bead
5. AMDI Transect 2 Northerly aspect

Middle L-R:

6. AMDI Transect 3 polystyrene debris
7. AMDI Transect 4 polystyrene embedded in eroded dunes
8. AMDI Transect 4 polystyrene embedded in eroded dunes
9. AMDI Transect 4 fragile polystyrene removal from eroded dunes
10. AMDI Transect 4 polystyrene with dune grass roots growing through debris

Bottom: L-R:

11. AMDI Transect 4 Southerly Aspect across survey range
12. AMDI Transect 4 main beach polystyrene fragment recovery
13. AUSMAP Quadrant 4 within AMDI Transect 4 microplastic and polystyrene debris <5mm
14. AMDI Transect 4 dunes polystyrene remnant debris
15. AMDI Transect 4 dunes polystyrene remnant debris

Site 3: Peregian Beach, Queensland
Date of Survey: 27th May 2023
Conducted by: Alison Foley
Low tide: 8.30am
Time on site: 7.30am- 11.00am

Site Selection:

Peregian Beach was impacted by 4 beached pontoons in the East Coast Flood Event of February/March 2022. The pontoon locations were recorded by Maritime Safety Queensland as landing at:

1. -26.47543506, 153.0992281
2. -26.47558168, 153.0991201
3. -26.48243239, 153.0981438
4. -26.48117849, 153.0982639

Additionally, several large partial pontoons impacted the shoreline during the "White Spill" Event.

Pre-Survey Site Check:

- Coastal Shoreline with no factors influencing debris.
- Open water facing sandy beach.
- Gusty winds
- Moderate surf <2.5m

Transect Range Start Point: between BA 59 & BA 60 GPS Coordinates: -26.48426, 153.09790 Survey Distance: 400m heading North				
	Random number	**GPS Coordinates**	**AUSMAP quadrat high tide line random number**	**Photos taken**
Transect 1	**170-195m**	**-26.48268 153.09813**	**188m**	**Yes**
Transect 2	**212-237m**	**-26.48243 153.09825**	**216m**	**Yes**
Transect 3	**286-311m**	**-26.48177 153.09834**	**297m**	**Yes**
Transect 4	**356-381m**	**-26.48114 153.09840**	**376m**	**Yes**

Map 3: Peregian Beach, QLD. AMDI/AUSMAP Survey 27th May 2023.

Figure 3: Debris sort AMDI/AUSMAP survey Peregian Beach, Qld. May 27st 2023.

Images from Peregian Beach, QLD Survey
27th May 2023

Top L-R:
1. AMDI Transect 1
2. AUSMAP Quadrat 2 within AMDI Transect 2
3. Rope remnant AMDI Transect 1
4. Polystyrene bead AMDI Transect 3
5. Polystyrene remnant AMDI Transect 4

Bottom L-R:
6. Plastic Debris AMDI Transect 1 dunes
7. Polystyrene found outside AMDI transects but within survey range
8. AUSMAP fine sieve microplastic yield AMDI Transect 1.
9. AUSMAP sieve microplastic yield AMDI Transect 3
10. Plastic Debris AMDI Transect 4 main beach

All debris data has been entered into the Australian Marine Debris Initiative Database including AUSMAP debris summaries. All three sites were sampled following the Australian Microplastic Assessment Project (AUSMAP) and AMDI Monitoring Methodologies. Microplastic samples from each quadrat within each of the 12 transects have been sent to AUSMAP for further analysis.

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We acknowledge the traditional owners of the land on which we live, work and play, and pay our respects to Elders past, present and emerging.

Appendix 8: Boating Industry Association Issue Note

Boating Industry Association

ISSUE NOTE:
Flooding and pontoons, mooring and anchoring

Purpose

To provide a guide to improved outcomes regarding the resilience of boating infrastructure impacted by high-flow rates due to extreme weather/ flooding on the Brisbane River in February 2022.

Background

1. The 2022 Eastern Australia floods were one of the nation's worst recorded flood disasters with a series of floods that occurred in South East Queensland, the Wide Bay–Burnett and parts of coastal New South Wales.
2. On 28 February the Brisbane River's height reached 3.8 metres (12 ft), higher than the 2.3-metre (7 ft 7 in) peak height of flooding in 2013 and below the 3.9 metres recorded during the 2010–2011 Queensland floods but less than the peak height of 4.46m in 2011.
3. The flooded Brisbane River was said to have been flowing in the region of 12-14 knots and the deluge across the catchment led to significant amounts of flood debris comprised of organic and inorganic materials. The latter included a variety of vessels and pontoons, mostly residential, which broke free in the strong currents caused safety and environmental issues.
4. The State Government emergency response included assets from multiple departments, supported by volunteers, to minimise threats to safety and environmental pollution.
5. Maritime Safety Queensland (MSQ) is the marine safety and navigation authority in the State. MSQ reported 7000 tonnes of debris was collected from the river as part of the response.
6. Council requires a person who seeks to build a pontoon or jetty in Brisbane's local government tidal area to submit a development application to Brisbane City Council and receive consent from the Queensland Government, as the owner of the tidal area. The Qld Department of Environment and Science (DES) has a key role here as an assessment agency for tidal works in 'natural' waterways and has developed the prescribed tidal works code under the Coastal Protection and Management Act 1995 and Regulations. The PTW Code sets the standards for these works (in addition to Australian Standards).

Current Situation

7. The State Government is keen to establish a solution to the environmental and safety risk posed by flood impacts on marine infrastructure.
8. The BIA recognises the risks and challenges of Climate Change and will actively pursue a sustainable future for the marine industries by supporting its members interests in addressing this challenge.

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Boating Industry Association

ISSUE NOTE: Flooding and pontoons, mooring and anchoring

Justification for position

BIA believes the opportunity is to enhance partnerships and collaboration with key stakeholders to minimise the risk of similar pollution and safety outcomes in future flooding events on such rivers.

Summary

To collaborate and focus on flexible and adaptive infrastructure, systems and operations to allow for future modification and to avoid 'locking in' to solutions that prove inappropriate as conditions change and risk profiles vary by location.

Recommendation

BIA suggests countermeasures need to be considered to minimise safety and pollution risks from extreme weather event floodings.

11. **Residential and commercial installation** of pontoons should include the following:
    a. Council require adherence to the Australian standard for marina design for pontoon construction.
        i. Some of these structures which failed would be unapproved – others would be built not in accordance with approved design. So an initial step may be to work on a program to identify these and providing some incentives and/ or regulation to bring them into compliance;
    b. Council administer this along the lines of pool fence certification with visual inspection by an experienced and competent person applying an appropriate assessment of compliance of standards, engineering and installation. This person could be a Registered Professional Engineer of Queensland (RPEQ) registered inspector with some experience with the appropriate Australian Standard as well as the Prescribed Tidal Works Code under Coastal Regulations
        i. and sourced from a preferred panel of appropriate engineers the Government identifies for provision of such services;
        ii. costs must be fair and reasonable
    c. DES should have a key role in the solution – along with Council and MSQ.
12. MSQ, with DES and Council, review the tethering system and safety load limits required to ensure it is appropriate for the likely future risk of significant flooding impact. This is important noting that the current standards themselves likely need to be reviewed to provide for a more conservative design to account for future (large) flood events

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13. MSQ, with DES and Council, to consider additional engineering and load limits to be applied to the upstream tethering system and for the upstream pile(s) as these take impact loads of debris in the river. Owners and regulators should be aware of the increased risk of loadings from hydrodynamic currents and debris on the upstream face of any pontoon – this must be recognised in the structural strength of piles or mooring lines.
    a. A sensible approach (similar to that adopted in design/construction of stormwater trashracks) is to have upstream current/debris deflectors and a breakaway mechanism that releases the pontoon from all but a single very strong mooring and cable – allowing the pontoon to float downstream but be restrained
14. MSQ with Council should consider a pontoon identification number (PIN) similar to a vessel Hull Identification Number which should include country (in case of imported product), manufacturer, serial number, date of manufacture and address of where it is installed. This should be permanently attached to the pontoon hull on a weather and corrosion resistant plate, and in a standard location to eliminate guesswork of where to find it. The owner should be required to keep a copy of the PIN;
15. Council ensure a proper process of identification system for the pontoon and this could/ should make use of a QR code.
16. The RPEQ certifier conduct an in-person inspection ie every 5 years to ensure the pontoon, piles, tethering and PIN is as described, and in a fair and reasonable condition. The cost of the inspection is borne by the pontoon owner If the inspection shows that the structure is not up to scratch will need to provide for next steps – tidal works notice issued under the Coastal Protection and Management Act 1995 could be one remedy but would again need some engagement from DES on this;
17. Council to provide a clear and plain English guide available online of the approval process and requirements of installing a pontoon;
18. Where appropriate and structurally appropriate to the intended end use, the industry - including associated manufacturers and suppliers - investigates alternatives to non-biodegradable polystyrene as the void form/ positive buoyancy solution including solutions that are being successfully trialled or used in other jurisdictions.
19. As an interim measure, MSQ to work with industry to consider making a requirement to wrap polystyrene in sheeting to effectively 'bag' it in case of structural failure or break up of the pontoon.
20. Consideration could be given to the development, by the owner of the bed of the Brisbane River and/or the consent authority, of minimum specifications for pontoon restraint systems, which are then provided to Applicants. These specifications may differ for different sections of the river depending on current speeds and other factors. This provides a consistency of approach and a clear message of what is acceptable.

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21. In addition to regular compliance inspections, a trigger mechanism for inspections should be included related to particular magnitude flooding events or similar by risk according to location.
22. MSQ to consider what steps can be introduced as quick wins and interim measures whist standards are brought up to an appropriate level where necessary re.,: manufacture, installation, inspections and de-commissioning.
    a. The aim must be to aim for flexible and adaptive measures and standards that avoid 'locking in' a solution which is proven through time to be inadequate, particularly against the background of the dynamic nature of Climate Change and variabilities in the marine environment by location and waterway characteristics.
    b. An approach which responds to counter measures in zones by risk level would help restrain red tape and cost implications impacting all such infrastructure which may be in extremely low risk installations and locations especially if applied across other areas in Qld. For eg., establish a map of known or agreed boundaries of the areas affected by river flooding & those not affected, throughout QLD. (Reduced risk of incurring potential unnecessary long term compliance or expense on unaffected marina operators).
    c. Furthermore, it would be recommended that any high-risk zone areas are clearly identified in the policy/ strategy/ program description online or in legislation to help avoid any increased or additional insurance costs imposed by the insurance industry on unaffected operators.

23. **Mooring/ anchoring of vessels** should be reviewed as follows:

i. Phase One:
   a. MSQ/DES to review the mooring apparatus specifications/ standards applied for use in the river to ensure the standards, engineering and installation are appropriate for the likely risk of future flooding impact;
   b. MSQ/Council to review its requirements upon owners of moored/ anchored vessels to ensure the mooring/ anchored apparatus is routinely serviced and maintained as sufficient, fit for purpose and such conditions are spelt out in the mooring permit/ licence/ anchoring permissions; and
   c. MSQ/Council to review its education, compliance and enforcement programs relating to owners of vessels moored/ anchored vessel in the river.

ii. Phase Two:
   a. MSQ should review, in collaboration with stakeholders including the Queensland Maritime Committee, the following:
      i. the appropriateness of private moorings, by location, in the Brisbane River. Consideration should be given to all moorings on the river to be managed by an appropriate commercial provider experienced in managing moorings. The notes above should be incorporated into the

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commercial management of such moorings. Should this be considered difficult to deliver, as there are many private moorings in the river and tributaries, an easier first step may be an inspection and certification process to a stated standard)

b. MSQ to work with stakeholders including the Queensland Maritime Committee to consider making it a condition of using a mooring/ anchoring on the river that the vessel is 'seaworthy' and insured, and that it is the mooring owners' responsibility for the adherence to this.
   i. Should this be considered problematic for moorings, as the tidal works approval traditionally attaches to the coastal land and is designed to define and accommodate an adjacent water allocation area. The holder of the development approval needs to ensure the moored vessel does not extend outside of the defined water allocation area; but the works approval does not extend to the condition or operation of the vessel. Creating a nexus between the approval and the vessel condition may only be able to be applied to new development as opposed to myriad of existing development approvals); and
   ii. MSQ to adopt a Hull Identification Number system (as recommended in the War on Wrecks Recommendations) and the Australian Builders Plate as means to identify new and used vessels, ensure compliance with vessel capacity and safety standards, and resolve issues relating to abandoned, wrecked and/ or adrift vessels.
   iii. There should be minimum specifications/standards available for mooring apparatus (swing moorings). The minimum specifications/standards could differ depending on the degree of shelter from current and wind. Inevitably, in the absence of clear minimum specifications/standards the matter can end up a struggle between the vessel owner, the swing mooring installation contractor, the commercial marina operator (for commercial swing moorings), and the maritime authority.

24. Flood communications to boat owners

iii. MSQ to review existing or emerging communication opportunities to improve advisory, early warning and emergency advice to recreational and commercial vessel owners on the river via technology such as sms messaging. For example this could include advice to consider alternative safe havens but only if it is safe to do so.

iv. Work should be done to identify where these safe harbour areas are and there may need to be additional moorings approved/established to provide capacity; and

v. MSQ to consider that upon knowledge of the likelihood of flooding, the Harbourmaster should issue a "Notice to Mariners" that all vessels on moorings or anchor are to evacuate the Brisbane River to a safe harbour or anchorage outside of the Brisbane River boundary. This procedure should be

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agreed by all vessels and persons managing a mooring prior to use. The commercial operator should also provide evidence of an emergency plan that details the evacuation procedure.

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