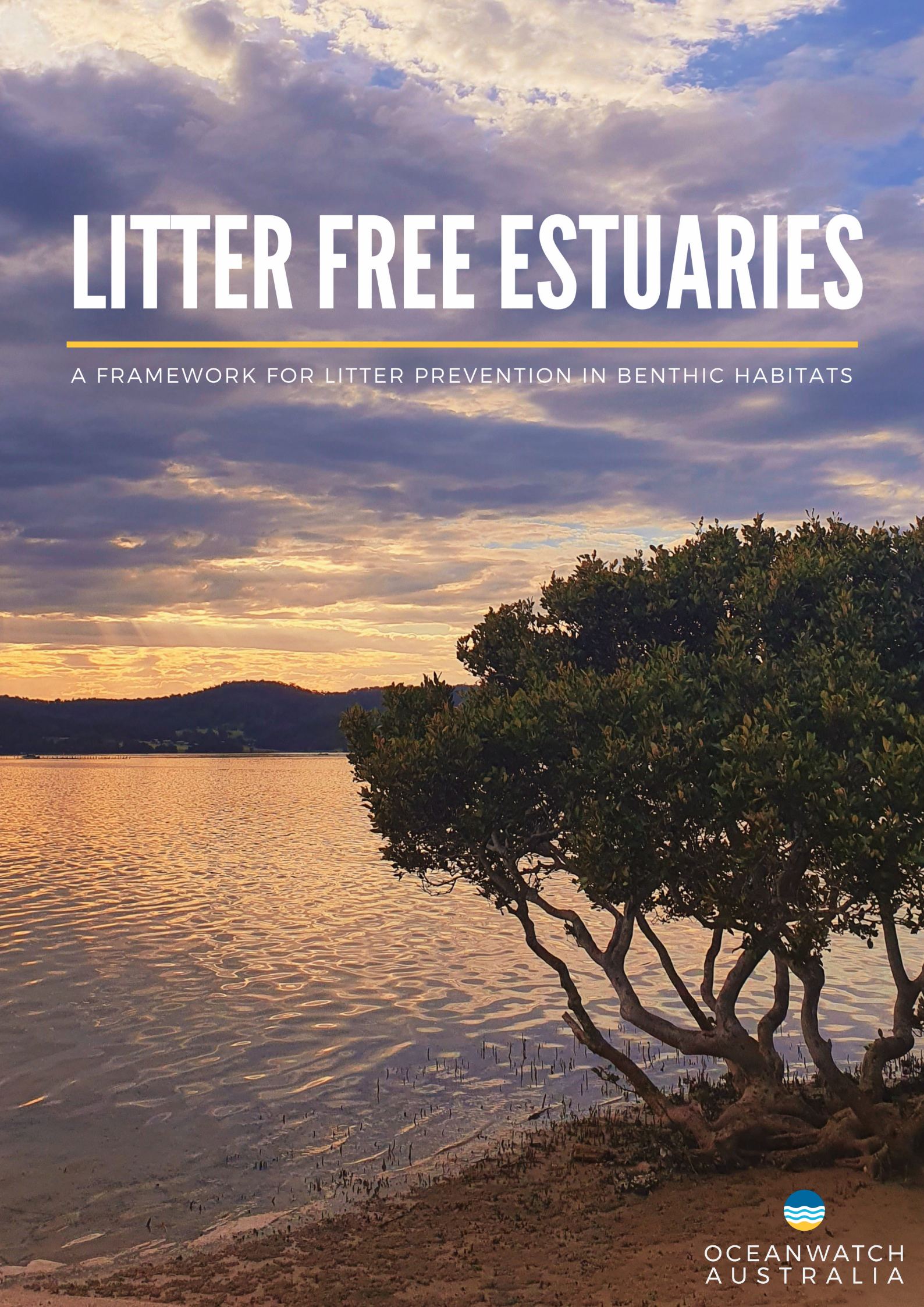
LITTER FREE ESTUARIES

A FRAMEWORK FOR LITTER PREVENTION IN BENTHIC HABITATS



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Executive Summary

The Benthic Litter Framework provides a strategy for navigating benthic litter prevention in estuaries that will be used by OceanWatch Australia and key marine stakeholders in NSW to :

"Reduce the volume of benthic litter in NSW estuaries, encourage its inclusion in NSW litter prevention efforts, and seek collaborations to achieve the NSW litter prevention target of a 60% reduction by 2030."

The framework addresses the difficulties of surveying benthic litter in estuaries, offering recommendations for monitoring these environments. It identifies key strategies to improve the monitoring of benthic litter, and reduce the volume of litter in benthic habitats. The framework builds upon extensive experience within OceanWatch Australia in the management of litter issues in the marine environment, and is aligned with our vision of Australia's marine environment being healthy, productive, valued, and used in a responsible way.

Benthic habitats are typically difficult to survey both in estuaries and the wider marine environment. As such submerged litter, that is deposited in the benthos is rarely the focus of litter prevention initiatives. This subset of litter is also not currently recognized in measures that feed into the NSW litter prevention target of a 60% reduction in litter by 2030. Without insight into benthic litter we lack a robust understanding of the issues plaguing our marine ecosystems, and can offer no targeted method to effectively improve the situation. Significant effort is required to understand litter issues in benthic habitats, initiate litter prevention activities and deliver positive outcomes for the environment and community.

Outlined in the framework are six key steps to guide litter prevention in estuaries:

1. Identify litter hotspots & high value areas

This initial step of the framework involves identifying the areas within an estuary that require intervention to mitigate and manage litter. These areas may be litter hotspots or high value areas with litter issues. This phase involves reviewing and collating available information on the estuary and litter problems that exist there. It also includes reaching out to the local community and other local stakeholders to utilise their knowledge and perspectives on litter issues and to highlight areas of concern within the estuary.

2. Select methodologies for benthic litter surveys

This step covers selecting the most effective methodology for surveying benthic habitats. The methodologies include the CHASING M2 Remotely Operated Vehicle, a trolling paravane, a benthic sled, and scuba diving. Selecting the appropriate methodology for surveying the chosen litter hotspot/high value area will relate to capacity, and the habitat of the chosen site. To assist in selecting the appropriate survey methodology, OceanWatch Australia has trialled and reviewed these methods in a variety of estuarine habitats and provided recommendations on the suitability of each. Additionally, OceanWatch Australia has provided comparisons of the survey methods based on a number of criteria including data quality, affordability, practicality, safety, and invasiveness.

3. Engage with stakeholders

This step is perhaps the most crucial part of the litter prevention process as effectively engaging stakeholders in aspects of litter prevention ensures that the initiative has a long and lasting impact on the estuary. Important stakeholders to target here are local government, NGOs and community groups, but could also include several others depending on the estuary.

Firstly it's important to understand the capacity of local government to support litter prevention initiatives in and around the estuary, and connect with NGO's to explore ideas and possible collaborations on litter prevention. Finally, engaging local communities in on-ground actions ensures the community takes ownership of litter prevention in the estuary, and can ensure the longevity of litter prevention long over funding stops. Having support of the local community on ground also increases the capacity to survey and monitor areas.

4. Conduct benthic litter surveys

This section of the framework involves conducting benthic litter surveys to identify problematic items in benthic environments. This step involves the identification of problematic items for a detailed description of what is the local litter issue. The results from the underwater surveys ultimately inform the activities of clean up and prevention.

5. Conducting litter prevention activities

The information collected in steps 1-4 offers insight into the drivers behind benthic litter within estuaries, and helps to identify the most problematic areas and items, capturing information about litter at the end point of the litter journey. This information informs step 5 of the Benthic Litter Framework. By identifying the issues that pose the greatest threat to our estuaries and marine ecosystems we can apply a risk based framework to determine the most appropriate and effective actions to prevent litter from entering estuaries and settling in benthic habitats. This allows us to effectively work back through the litter journey to implement effective actions at each stage.

This section covers the NSW Litter Prevention Strategy approaches to litter prevention, and the steps required at each part of the litter journey to prevent litter ending up in the wider environment, including the value of the Own it and Act Framework as a method to embed litter prevention into principles, policies and practices.

6. Strategic directions

This section details OceanWatch Australia's 3 key strategies to achieve our objective to reduce the volume of benthic litter in NSW estuaries, encourage its inclusion in NSW litter prevention efforts, and seek collaborations to achieve the NSW litter prevention target of 60% reduction by 2030 (Table 1).

Table 1: OceanWatch Australia's Litter Prevention Strategies

STRATEGY	ACTION	MEASURE
1. Develop methods to understand and monitor benthic litter in NSW estuaries	1.1. Investigate, trial, and validate techniques for monitoring litter in benthic habitats of estuaries. 1.2. Increase knowledge base around key litter prevention strategies applicable to benthic litter. 1.3. Publicly promote and discuss benthic litter monitoring techniques.	By 2022 recommendations for monitoring benthic litter are finalised. OceanWatch Australia discusses with stakeholders their litter prevention strategies in Brisbane Water and Sydney harbour. The awareness of monitoring techniques is amplified through publishing benthic data collection techniques.
2. Encourage long-term monitoring of benthic litter in NSW estuaries	2.1. Utilise partnerships and seek funds to identify benthic litter hotspots in NSW estuaries. 2.2. Integrate benthic litter data into a publicly available online portal for sharing and reporting information. 2.3. Develop a benthic litter monitoring plan for NSW estuaries with key partners 2.4. Encourage the integration of long-term monitoring into existing and emerging litter prevention initiatives.	Benthic litter are hotspots identified and integrated into litter prevention strategies in three NSW estuaries by 2023. Benthic data are integrated with existing databases, and are publicly available by 2023. A plan that encourages monitoring benthic litter in NSW estuaries is established by 2023. Ongoing monitoring of benthic litter is integrated into litter prevention initiatives by 2024 across NSW.
3. Collaborate with land-based stakeholders and water users to reduce inputs	3.1. Seek funding for a benthic litter prevention officer to coordinate litter prevention initiatives originating on water. 3.2. Collaborate with key partners to identify priority actions and targets required for a reduction in benthic litter. 3.3. Consolidate commitment to litter prevention among stakeholders through the integration of targets into organisational plans and policies using the Own it and Act Framework. 3.4. Collaborate on source reduction plans with stakeholders to achieve targets.	OceanWatch Australia receives funding for a marine litter prevention officer. Priority actions are identified and targets established, by 2023. The number of stakeholders that have completed Own it and Act Framework and ratified targets has increased. Three major source reduction plans developed and implemented by 2025.

Introduction

Estuaries are valuable habitats that provide crucial goods and services; however, litter can affect the health and productivity of these vital ecosystems. Estuaries serve as the main entrance of litter into the marine environment[1], and they are often plagued with litter issues. In Australia alone approximately 130,000 tonnes of plastic enter the marine environment yearly[2]. Much of this becomes trapped in estuarine habitats, and can severely degrade the environment.

Litter reduces the scenic and recreational value of the area as well as degrading habitats and harming aquatic wildlife. Mangrove habitats in particular are often hotspots for debris, as they act like rakes catching and trapping marine debris in their aerial roots (pneumatophores). The accumulation of this debris can deteriorate the health and productivity of this habitat[3]. Considerable effort has been made to remove catchment litter and other floating marine debris from these vital ecosystems, with several government organisations, NGOs and community groups implementing initiatives to tackle this issue. However, litter issues are inherently complex, particularly in marine ecosystems where litter may travel great distances before reaching one of these habitats. Marine and estuarine ecosystems themselves are dynamic environments that make surveying and understanding the issue more difficult. Indeed, there remain areas of these ecosystems such as benthic habitats, where there is little to no information on the extent of the litter issue.

Benthic habitats are typically difficult to survey[4] both in estuaries and the wider marine

litter prevention initiatives. This subset of litter is also not currently recognized in measures that feed into the NSW litter prevention target of a 60% reduction in litter by 2030. Without insight into benthic litter we lack a robust understanding of the issues plaguing our marine ecosystems, and can offer no targeted method to effectively improve the situation. Significant effort is required to understand litter issues in benthic habitats, initiate litter prevention activities and deliver positive outcomes for the environment and community.

There is no one size fits all methodology for surveying litter in estuaries however many initiatives and methodologies are useful in understanding and mitigating this issue. Each estuary or unique habitat has a different set of geographical features and litter issues that make a single methodology inadequate. The Benthic Litter Framework provides a strategy for navigating benthic litter prevention in estuaries that will be used by OceanWatch Australia and key marine stakeholders in NSW to :

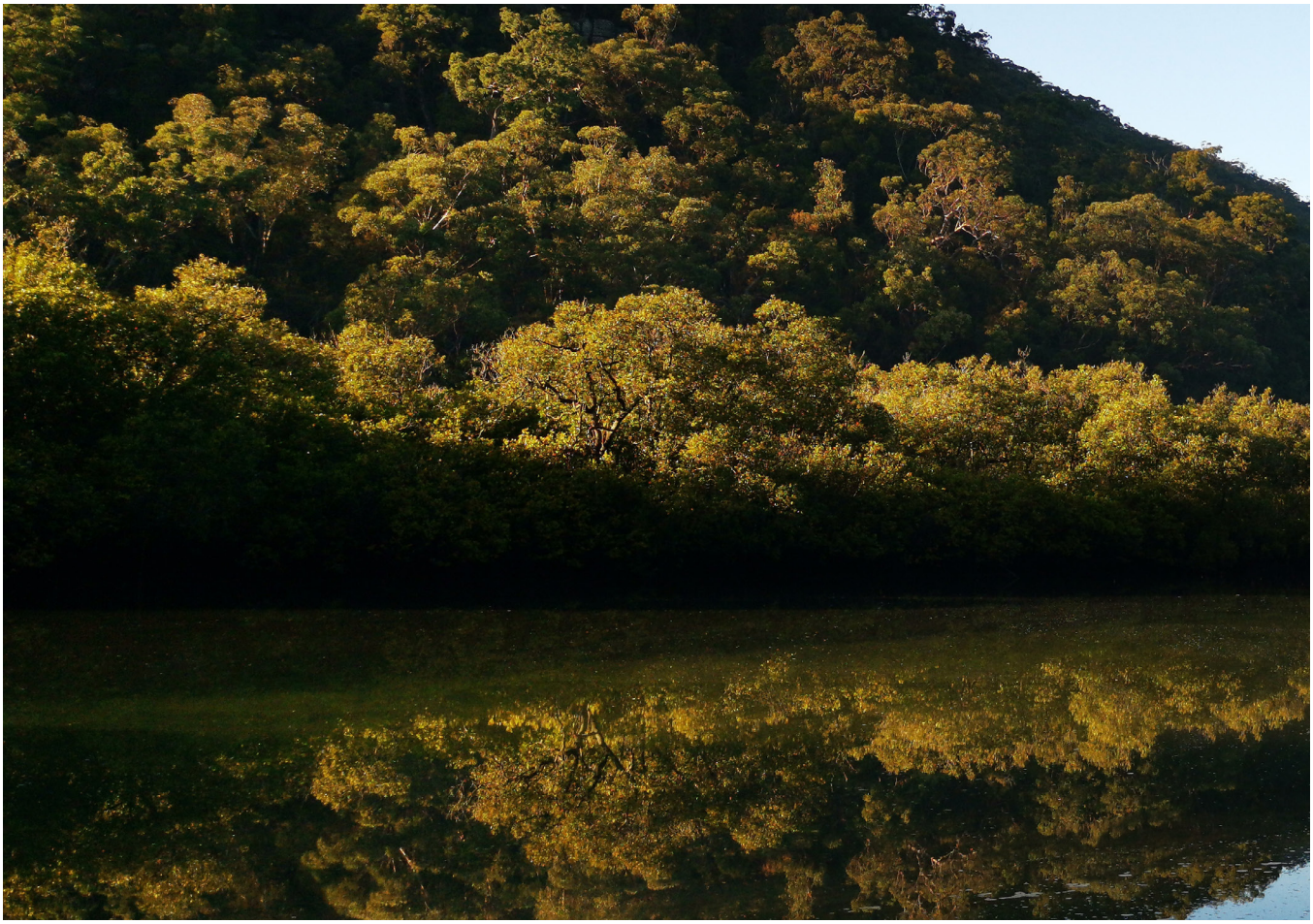
"Reduce the volume of benthic litter in NSW estuaries, encourage its inclusion in NSW litter prevention efforts, and seek collaborations to achieve the NSW litter prevention target of a 60% reduction by 2030."

The Framework addresses the difficulties of surveying benthic litter in estuaries, offering recommendations for monitoring these environments. It identifies key strategies to improve the monitoring of benthic litter, and reduce the volume of litter in benthic habitats.

The Role of Estuaries

Estuaries are highly unique and complex ecosystems that encompass a wide range of habitats. The protected waters that estuaries provide are essential nursery, nesting and feeding grounds for numerous species of shore birds, fish, shellfish, marine mammals and reptiles. Estuaries are also home to critically important vegetation types including mangroves, salt marsh, and seagrass. These vegetation types are some of the most biologically productive ecosystems, providing a range of environmental services. These services include buffering shorelines from the erosive effects of storm waves and floods, trapping sediments and helping to stabilise or build up shorelines, filtering or removing pollutants and high levels of nutrients ,as well as providing a refuge and nursery grounds for fish, crustaceans, molluscs and worms. Additionally, they have the capability to filter pollutants out of the water which flows through them. These pollutants include harmful chemicals such as pesticides and herbicides and are sites that contribute to groundwater supply recharge near the coast.

Estuaries have significant commercial value, with tourism, and fishing thriving on these complex ecosystems. In New South Wales alone, commercial fishing around estuaries is worth over $80 million per year and recreational fishing an estimated $500 million per year[5]. Therefore, estuaries provide us directly or indirectly with much of the seafood produce many people rely on in their diets. The sheltered waters of estuaries also support public infrastructure, serving as harbours and ports that are essential for shipping and industry. Estuaries also provide an important buffering role and protect property and other assets from erosion the forces of the sea and during flood



events. Furthermore, chemicals extracted from estuarine species are used in pharmaceuticals, nutraceuticals and in pest control. Examples in use include anti-cancer research, agar, kelp powder and calcium powder[6].

Estuaries are easily accessed and have multiple and diverse usages that contribute to the quality of life of those around them[7]. Estuaries are some of the most intensively used areas within coastal communities with over 80% of the New South Wales population living in the coastal zone[5]. Estuaries are used as recreational areas, with activities such as boating, swimming, bird watching and fishing being common attractions to these environments. The broad range of activities surrounding estuaries explains the high rates of recreation and tourism.

Estuaries hold significant value for coastal aboriginal communities, allowing for cultural knowledge and traditions to be maintained and shared amongst the community. The use of estuaries for fishing and the harvest of other resources continues to provide sustenance and supports economic, social, and cultural values of aboriginal communities [8]. These highly productive ecosystems are a profound source of identity and spiritual wellbeing[9].

Estuaries provide aesthetic enjoyment as they are often visually appealing, and their scenic quality is highly valued. There are proven health benefits of the natural environment by increasing human well-being and mood of those who live, work, or visit estuaries. The high human and non-human reliance on these ecosystems, and the goods and services they provide, highlights the importance of maintaining healthy, productive estuaries.

What is Litter?

Litter is defined under section 144A of the Protection of the Environment Operations Act 1997 as:

- Any solid or liquid domestic or commercial refuse, debris or rubbish including any glass, metal, cigarette butts, paper, fabric, wood, food, abandoned vehicles, abandoned vehicle parts, construction or demolition material, garden remnants and clippings, soil, sand or rocks, deposited in or on a place, whether or not it has any value when or after being deposited in or on the place.
- Any other material, substance or thing deposited in or on a place if its size, shape, nature or volume makes the place where it has been deposited disorderly or detrimentally affects the proper use of that place.

Under this framework litter is deemed any discarded item up to the size of a supermarket bag[5]. This is to differentiate littering from discarding larger items, which instead is considered 'illegal dumping'.[10] This distinction is made because there are inherent differences in the behaviour associated with littering compared to illegal dumping[10]. As such, the methods for managing and mitigating these two issues differ.

Litter may enter the environment in a number of ways (Figure 1), under section 144A of the POEO Act 'depositing litter' in or on a place includes:

- dropping or throwing litter in, on, into or onto the place, or
- leaving litter in or on the place, or
- putting litter in such a location that it falls, descends, blows, is washed, percolates or otherwise escapes or is likely to fall, descend, blow, be washed, percolate or otherwise escape into or onto the place, or
- causing, permitting or allowing litter to fall, descend, blow, be washed, percolate or otherwise escape into or onto the place.

Figure 1: Sources of litter[11]

Marine Debris

Marine debris or marine litter refers to litter that ends up in marine ecosystems, like estuaries and open waters. Marine debris comes from various sources both on land and in open water. Land based inputs can include inflows of debris from storm water, and overflowing sewage systems as well littering or carelessness near water bodies like rivers and beaches. Approximately 80% of marine debris have land-based sources[12]. Debris can also be carried on ocean currents from other locations, or can be littered directly from vessels. Plastic is one of the main sources of marine debris, accounting for 80% of debris collected from Australian beaches[13].

Benthic Litter

Benthic litter is a subset of marine debris that refers to litter that is deposited on the sea floor (Figure 2). Features of a littered items such as size, and density will affect whether it sinks to the sea floor, however bio-fouling of littered items can also cause highly buoyant litter to be deposited in the benthos[4].

Indeed, approximately 70% of all marine debris is eventually deposited in benthic habitats[14].

This subset of litter is not well understood due to the difficulty of underwater surveying[4]. Moreover, benthic litter often goes unnoticed as it is not easily observable like other subsets of litter, e.g. shoreline or floating litter.

Figure 2: An example of benthic litter

Dealing with the Problem of Litter

As litter continues to impact the social, cultural, and economic values of the environment there is demand for more stringent measures to tackle this issue. The development of various strategies as well as the implementation of relevant legislation have a crucial role in the mitigation of litter in the environment. These strategies and legislation are important considerations for on-ground litter measures, as they provide significant insight into mitigating and managing litter issues. Incoming strategies and legislation will also impact the presence of certain types of litter in the environment if their focus is to reduce the source of those littered items. As such, knowledge of these strategies would allow for increased focus on preventing litter not covered by the strategies and legislation

In NSW, the state government has taken significant measures to combat litter. In 2015 they committed to reducing NSW litter volume by 40% by 2020, from the 2013-2014 baseline. This target was exceeded in 2020, with a reduction of 43%.

The **NSW Litter Prevention Strategy 2019-2022**[10] has been critical in achieving this commitment. The strategy provides the framework used to prioritise funding and action to reduce litter and achieve this objective. The strategy has five key pillars (Figure 3):

1. *Rewarding responsible behaviour*
2. *Education and awareness*
3. *Infrastructure and clean-up*
4. *Regulation and enforcement*
5. *Evaluation and monitoring*

This strategy has been renewed within the release of the new **NSW Waste and Sustainable Materials Strategy 2041**[15] which comes with additional targets:

- A new overall litter reduction target of 60% by 2030
- A plastic litter reduction target of 30% by

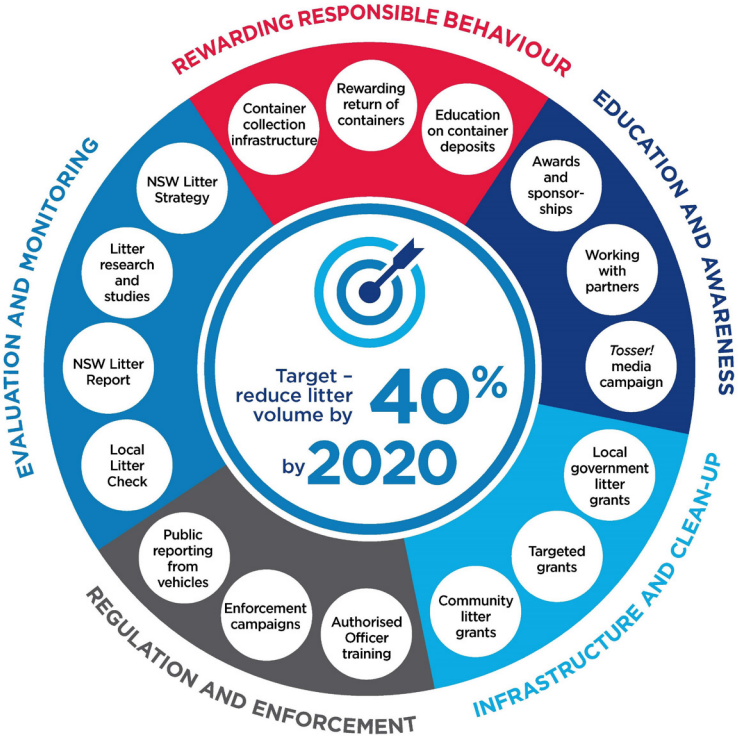


Figure 3: EPA's litter prevention framework[10]

In June 2021, the **NSW Government released the NSW Plastics Action Plan**[16]. The plan outlines a comprehensive suite of actions to address plastic at all points of its life cycle, from production and consumption to disposal and recycling. Outcome 1 of the plan, labeled 'reduced plastic waste generation', is highly relevant for litter prevention initiatives. Through Outcome 1, NSW has introduced legislation to phase out some of the most littered plastic items (Table 1). This legislation is predicted to stop 2.7 billion items of plastic litter from entering our natural ecosystems over 20 years. Whilst the plan has set out clear intentions for the phase out of problematic plastics, some items where suitable alternatives are not widely available have been set for review in 3 years (Table 2).

More specific to estuaries the **NSW Marine Estate Management Strategy**[17] recognises litter and marine debris as one of the three highest priority threats facing the marine estate. The strategy outlines nine management initiatives and actions to manage the identified threats including, improving water quality, and reducing litter.

At the federal level, the National Plastics Plan has been developed. This plan outlines actions and key milestones to reduce Australia's plastics problem. The reduction of plastic will help to limit the amount of plastics entering our marine ecosystems. The goals of the plan include:

- Reducing plastic waste and increasing recycling rates
- Finding alternatives to the plastics we don't need
- Reducing the amount of plastics impacting our environment.

The plan includes the phasing out of materials such as expanded polystyrene in consumer packaging (July 2022), and consumer food and beverage (December 2022). As well as the phasing out of PVC packaging labels (December 2022) and plastic packaging products with fragmentable technology which do not meet compostable standards (July 2022).

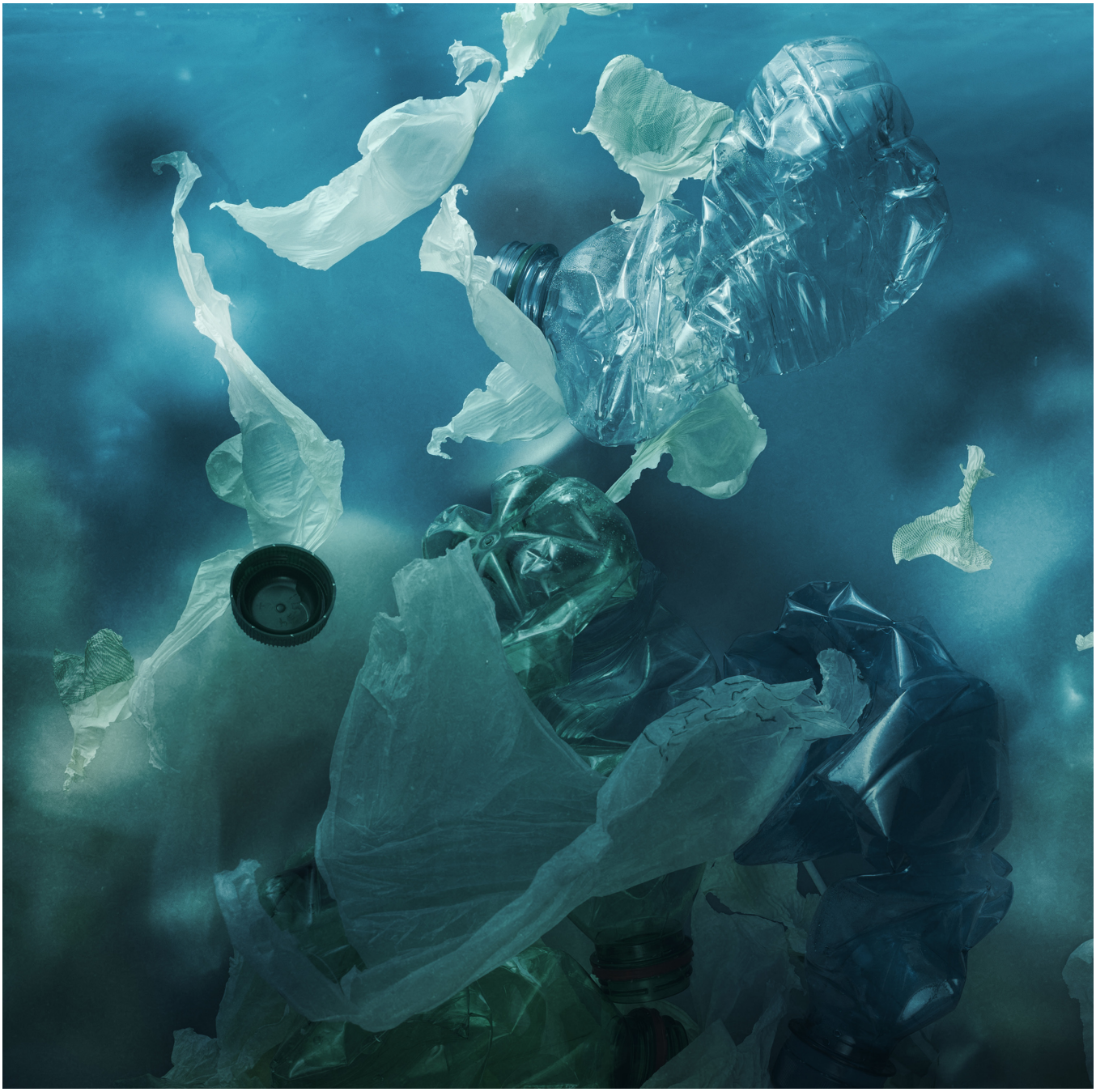
Table 2: Timetable for phasing out the most littered plastic items[16]

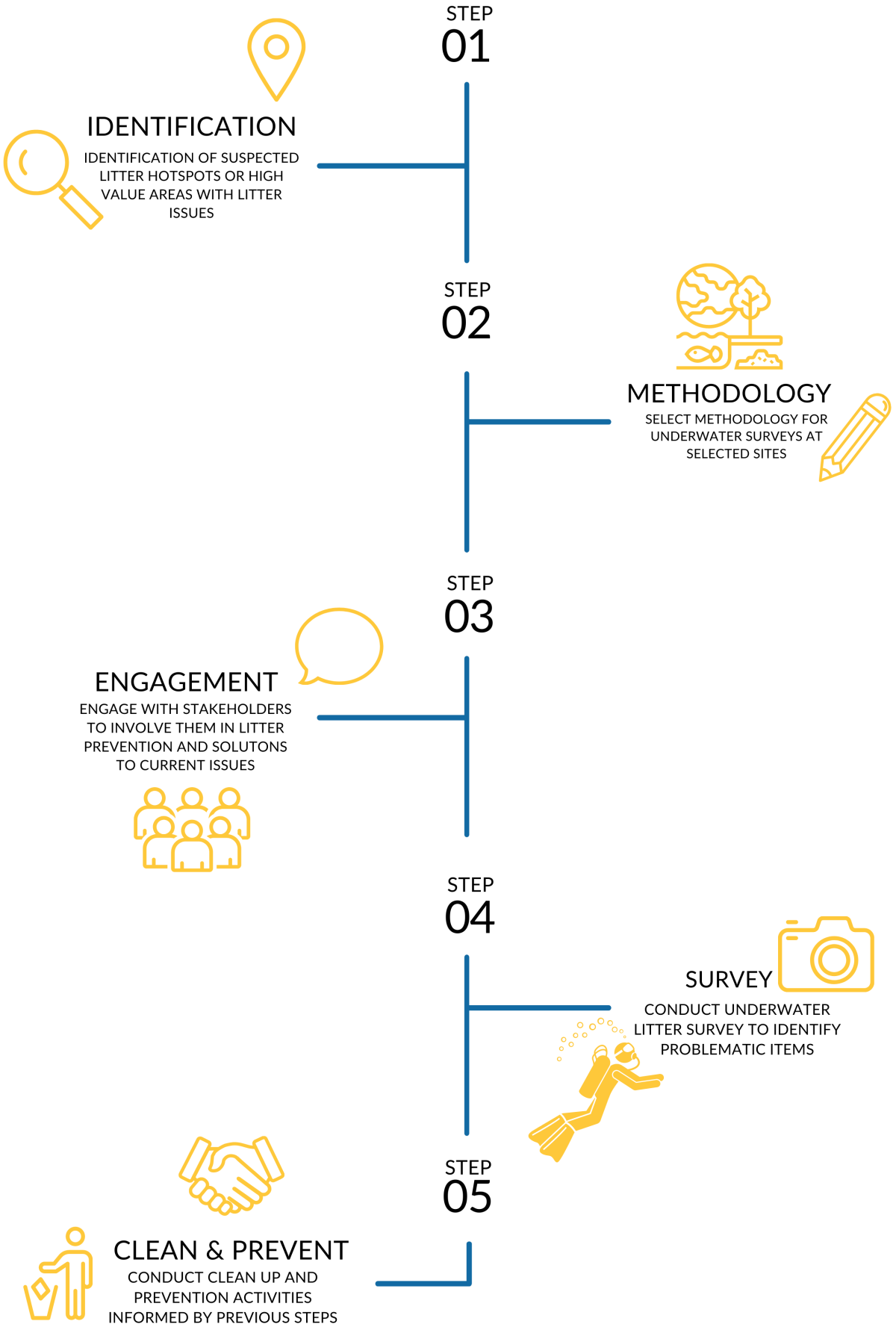
Phase out period (from passage of legislation)	Single-use and problematic plastic items
6 months	Lightweight shopping bags
12 months	Plastic straws
	Plastic stirrers
	Plastic cutlery
	Expanded polystyrene food service items
	Cotton buds with plastic sticks
	Microbeads in rinse-off personal care and cosmetic products
Review in 3 years	Plastic bowls (including lids) and plates
	Plastic cups (including lids)
	Oxo-degradable plastics
	Fruit stickers (non compostable)
	Heavyweight plastic shopping bags
	Barrier/produce bags

Benthic Litter Prevention Framework

This framework provides a guide for understanding and preventing litter in benthic habitats of estuaries. It has been developed to combat a poorly understood subset of litter, i.e., benthic litter. Benthic litter often goes unnoticed as it is not always visible, like shoreline or floating litter. However, this underwater litter can cause serious degradation to the biodiversity, recreational, social, or cultural value of an estuarine area.

All estuaries are unique as can be the litter issues that plague them, but the steps presented here are to be used as useful procedures to follow and as recommendations for what to do at each stage of the litter prevention journey.




STEP
01
IDENTIFICATION
IDENTIFICATION OF SUSPECTED LITTER HOTSPOTS OR HIGH VALUE AREAS WITH LITTER ISSUES
STEP
02
METHODOLOGY
SELECT METHODOLOGY FOR UNDERWATER SURVEYS AT SELECTED SITES
STEP
03
ENGAGEMENT
ENGAGE WITH STAKEHOLDERS TO INVOLVE THEM IN LITTER PREVENTION AND SOLUTONS TO CURRENT ISSUES
STEP
04
SURVEY
CONDUCT UNDERWATER LITTER SURVEY TO IDENTIFY PROBLEMATIC ITEMS
STEP
05
CLEAN & PREVENT
CONDUCT CLEAN UP AND PREVENTION ACTIVITIES INFORMED BY PREVIOUS STEPS

1. Identify Litter Hotspots & High Value Areas

This initial step of the framework involves identifying the areas within an estuary that require intervention to mitigate and manage litter. These areas may be litter hotspots or high value areas with litter issues. This phase involves reviewing and collating available information on the estuary and litter problems that exist there. It also includes reaching out to the local community and other local stakeholders to utilise their knowledge and perspectives on litter issues and to highlight areas of concern within the estuary.

Under this framework **high value areas** refer to locations that have high biodiversity, recreational, social, or cultural value, which also have litter issues. These may be popular locations for recreational fishing or diving, or important fish habitats and nursery grounds.

Litter hotspots refer to areas where large amounts of litter have accumulated compared to other sites. In these areas litter may be impacting the health and productivity of the ecosystem and/or harming the social and cultural values communities place on the area. High value areas and litter hotspots may occur in the same location.

1.1. Get to Know the Estuary

Understanding the dynamics of the estuary and how the estuary is used will assist in determining what the local issues are, and the locations of litter hotspots. Various features of an estuary will influence the location of litter hotspots; these include hydrodynamic forces such as currents, wind, and wave action, morphological features and habitats that may trap litter.

The importance of processes such as hydrodynamics will depend on the density and the size of litter particles as well as the drag force and buoyancy of these items[18]. However, strong currents are likely to push litter out of the estuary or away from an area, whilst little to no current will allow floating litter to sink and accumulate in benthic habitats. Furthermore, deep pools with limited exposure to wind/currents compared to surface waters are more likely to accumulate litter. Alternatively in shallow areas litter is more likely to be subject to hydrodynamic forces and it is likely to be in constant movement/circulation within the water body. Regarding the impact of habitat on litter accumulation, habitats such as mangroves, seagrass, and rocky substrate can easily trap and accumulate large amounts of litter (Figure 3), whilst sandy/silt substrate with minimal rugosity is less likely to trap litter.

Features such as river outfalls and storm water drains often act as the initial entrances of litter into the estuary ecosystems (Figure 5). As such, the locations of these features will also provide insight into locations of litter hotspots downstream. Furthermore, the adjacent land use and population density around the estuary strongly influences the occurrence of litter in a given area of the estuary. Areas with high population density commonly generate the bulk of rubbish entering the estuary nearby.

Figure 4: Mangroves can become traps for littered items.

Figure 5. Litter can be washed into drains and end up in our estuaries.

1.2. Reach Out to Local Stakeholders

Local stakeholders can be the biggest source of information on litter issues in the estuary. Moreover, engaging local stakeholders in litter prevention activities and gaining support and assistance will be critical in the success of any litter prevention measures. These stakeholders include groups like the local community, estuary users, recreational and commercial fishers, dive groups, and local government.

It is important to find out what the community knows about the litter in the estuary and where hotspots may occur. This engagement can also highlight the concerns of stakeholders and areas of high value that may have litter issues. Engagement may be through face-to-face discussions, community surveys, or forums.

1.3. Compile & Review Existing Data

Engagement with local stakeholders may highlight previous litter initiatives that have occurred in and around an estuary, which may have compiled data on litter in the estuary. Additionally, the local government may regularly record data from litter collected by gross pollutant traps and litter booms that can provide insight into what litter enters the estuary. Reviewing these available data can help to determine the locations of litter hotspots, potentially removing the need of conduct an on-ground assessment. Here we list several resources available that have extensive data on marine litter, and these readily available information sources can provide insight into litter in and around the estuary. Whilst they do not specifically detail underwater litter data, the shoreline or floating litter in an area may be indicative of litter in the benthos and may also be useful for locating hotspots. However, these resources and datasets may not have information available for every estuary.

The **Australian Marine Debris Initiative (AMDI)**, developed by the **Tangaroa Blue Foundation**, is an on-ground network of volunteers, communities and organisations that contribute data to the AMDI database, and then work on solutions to stop the flow of litter at the source. The database is available on the Tangaroa Blue Foundation website where users can actively upload clean-up data and search the database for previous clean-up data across Australia. For large datasets, Tangaroa Blue Foundation also provides custom datasets to download.

The **Australian Microplastic Assessment Project (AUSMAP)** is designed to document and analyse microplastic pollution in Australian aquatic environments. The **Total Environment Centre (TEC)** and **Macquarie University** are the project leaders, working with a consortium of research, environment, education, government, and sustainable business organisations. Their website provides a map of microplastic hotspots around Australia, with details on the types, size, colours, and shapes of fragments.

The **Key Littered Items Study (KLIS)** is a long-term program for monitoring marine debris along the NSW coast which shows what types and quantities of marine debris can be found in our coastal and marine waters. The study, which is run by the **NSW Department of Planning, Industry, and Environment,** began in 2017 and surveys are currently conducted quarterly. The KLIS monitoring sites are in mangroves in urban estuaries and on select remote beaches which span the full length of the NSW coast. The information is compiled on a database that is available on the NSW Government website.

Additionally, there are several other resources not specifically aquatic or marine that will be useful in understanding the wider litter issues in the catchment that may impact the estuary.

The **Keep Australia Beautiful National Litter Index (NLI)** is a national measure of litter across Australia. The NLI has now been replaced by the Australian Litter measure; however, since 2005, the NLI has been used to collect quantitative data on the type and volume of litter around Australia. In total, the NLI encompasses 983 sites which include beaches, car parks, industrial areas, shopping centres, residential areas, highways, recreational parks and retail precincts. The data collected have provided direct input into federal and state government policy on litter prevention.

The **Australian Litter Measure (ALM)** launched in November 2021 is a peer-reviewed methodology for measuring litter across Australia. The ALM is a national measure that provides more detailed data than that collected through the NLI will also provide open access data that can assist in future litter initiatives.

2. Select the Methodologies for Benthic Surveys

Selecting the appropriate methodology for surveying the chosen litter hotspot/high value area will relate to capacity, and the habitat of the chosen site. To assist in selecting the appropriate survey methodology, OceanWatch Australia has trialled and reviewed several survey methods in a variety of estuarine habitats and provided recommendations on the suitability of each. Additionally, OceanWatch Australia has provided comparisons of the survey methods based on a number of criteria including data quality, affordability, practicality, safety, and invasiveness. The survey methods that are considered in this framework include remotely operated vehicles (ROVs), scuba dive surveys, a benthic sled, and a trolling paravane.

2.1. Survey Methodologies

Remotely Operated Vehicles

Description

Remotely Operated Vehicles (ROVs) are submersible vehicles capable of exploring underwater environments whilst being controlled by a pilot at the surface. They have many applications in underwater environments, and vary greatly in size, price, and usability. Generally, ROVs are fitted with a camera, lights, and thrusters for moving around underwater, however they can also be fitted with other equipment including grabbing arms, and instruments for collecting samples, and measuring underwater environments. ROVs offer a useful method of exploring underwater environments due to the ability to control the device from the shoreline or a boat. They are becoming increasingly more accessible devices, and with their ease of use, they are likely to become a popular method for surveying litter in underwater habitats.

The ROV used for this study was the CHASING M2 (Figure 6), which can be purchased at a price that ranges from $3700 to $4500 depending on the supplier. This model is connected to a remote control with a 200 m tether and can reach depths of 100 m. Moreover, a grabbing arm can be fitted to the device, as well as additional cameras or torches. Our evaluation of the ROV as a survey methodology is based on this model. We acknowledge that other ROV models may have strengths and weaknesses that differ from those of the CHASING M2 (henceforth referred to as "the ROV").

Use

To conduct the surveys the ROV can be operated from the shoreline or a vessel. The device is deployed into the water with the tether attached to the remote control. The footage can be viewed real time by connecting a phone to the remote control. The ROV is fitted with a depth gauge and a compass so that it is easy to navigate and ensure you can stay on track. Transects are easy to complete using this device; however, it can also be used to cover larger spaces, going back and forth across an area following a grid pattern.

Comments: The ROV requires some training to gain proficiency in its use, however, this does not take long. Surveying the benthic environment with an ROV is a straightforward activity, particularly because surveys can be conducted from the shoreline without the operator entering the water. The device can also be operated by only one person, but it is useful to have a second person present to ensure the tether does not become snagged or tangled. The device is fitted with 8 thrusters that provide omni-movement, which allows easy manoeuvrability and allows the device to get better angles of the litter. This is particularly helpful for items hard to identify. The movement also ensures easy avoidance of obstacles on the seafloor. The battery life is 3-4 hours depending on the strength of the current, as such lengthy surveys can be undertaken. It is important to take note of the general direction on the compass when the survey begins to ensure that the device stays on track.

Figure 6: CHASING M2 ROV used in this study.

Benthic Sled

Description

The benthic sled is a device developed by OceanWatch Australia for the purpose of underwater litter surveys (Figure 7). The device is a steel frame sled fitted with a camera that records footage of the estuarine floor. The materials used for the construction of the sled were approximately $70. For the purposes of assessing the functionality of the benthic sled we fitted it with a GoPro Hero 8 camera. However, any underwater action camera can be fitted to the device. The sled could also be fitted with a live feed camera which would provide more effective monitoring as the footage could be viewed in real time. The device is towed behind a vessel (preferably motorised), and it works by sliding along the substrate.

Use

To conduct litter surveys, the benthic sled should be attached to a rope which is pulled by a motorised vessel. As the vessel moves forward the camera will record a transect of the substrate capturing imagery of the litter present on the estuary floor. The footage can then be viewed to collect the data.

Comments

When trialled, the device maintained a constant height from the seafloor, and the footage captured by the GoPro Hero 8 was very clear, making litter easily identifiable. However, the sled caused significant drag when towed by a kayak, so to counteract that a motorised vessel could be considered instead. Depending on the softness of the sediment, the sled can also sink in slightly, increasing drag. Unfortunately, this means the sled can also cause damage to the substrate and therefore should not be used in vulnerable habitats.

Scuba Diving

Description

Scuba diving is a common method for surveying underwater habitats. Divers can conduct transects or large area searches by noting down the litter encountered or collecting litter for later identification on land. There are a number of scuba diving organisations and volunteer groups that conduct underwater litter surveys. Some of these groups regularly assist in litter initiatives. The Underwater Research Group, a not-for-profit scuba diving club is one of these groups.

Use

To conduct underwater litter surveys scuba divers can follow a transect or grid pattern.

Comments

Scuba diving is a highly effective method of gathering quality data and collecting litter from underwater habitats. However, survey time can be more limited than the other methods, and there are significant safety concerns for divers operating in estuaries.

Figure 7: The Benthic Sled

Trolling Paravane

Description

This survey methodology utilises a trolling paravane fitted with a camera (Figure 8). This device works like an inverted wing, diving deeper as vessel speed increases and dragging the camera down to a greater depth. At a constant speed the device can be kept at a steady depth to capture imagery of the benthic environment and the litter that may be present there. The camera we fitted to the paravane to assess this survey methodology was a GoPro Hero 8; however, any underwater action camera can be fitted to the device. It can also be fitted with a live feed camera that would provide more effective monitoring as the footage could be viewed in real time. However, these devices can be costly. A trolling paravane is typically used for fishing, for which a hook is fitted in place of the camera. The device can be purchased from most fishing and tackle stores for approximately $10-$15.

Use

To conduct the surveys the paravane must be attached to a rope which is pulled behind a vessel (kayak or boat). The depth of the camera will be dependent on the speed, so it may take some practice to get the preferred depth. Once the depth is achieved the device can be towed behind the vessel recording a transect of the benthic substrate. The footage can then be viewed to collect the litter data.

Comments

This device is very simple, light and easy to deploy. It can be effortlessly towed behind a vessel with very minimal drag. The main issue with the device is ensuring it is being maintained at the correct depth for the entire transect. Some alterations may be required with sinkers or floats. Another downside is that when using this device, the surveyor cannot stop and capture different angles of littered items hard to identify, which instead is possible when using the ROV or diving. However, using the GoPro Hero 8 provided very clear imagery, and during our assessment of this technique, litter was quite easy to identify.

Figure 8: Trolling Paravane

2.2. Recommendations

The four survey techniques all offer unique methods of understanding underwater litter issues. The methods were each reviewed based on the effectiveness of the methodology in different habitat types at collecting litter information, as well as a number of other criteria which included data quality, affordability, safety, practicality, and invasiveness. Whilst each method offers advantages among the criteria, there are clear distinctions that make certain methodologies more effective in estuarine ecosystems.

Mangroves

Mangroves are a particularly difficult habitat to survey due to the presence of pneumatophores. Mangrove trees are out of the water at low tide, and therefore above water surveys will be more appropriate for most mangrove areas. For subtidal areas or at high tide, the ROV and paravane can be used, but no method is without issues. When operating the ROV in this habitat care must be taken to avoid entangling the tether and catching parts of the mangroves in the thrusters. Operating the paravane in mangrove habitats may also encounter some issues, as the device must be towed by a vessel there is a chance of snagging/entanglement. Care also must be taken with the vessel to ensure it does not damage the habitat.

Due to the shallow environment that surveys must be conducted in, scuba diving is not a viable method. There is also great potential for encountering snags and obstacles that would make diving difficult. Similarly, the benthic sled is not viable for use in mangroves, as the sled drags along the sea floor it would cause significant damage to the pneumatophores, and likely snag on the mangroves.

Seagrass

Scuba diving, the ROV and the paravane are all suitable methodologies for use in seagrass habitats. Due to the invasiveness of the benthic sled, it cannot be used, as it would likely cause damage to the seagrass bed.

Kelp

The benthic sled is not viable in kelp habitats as it would damage the substrate. If care is not taken, the ROV could catch kelp in its thrusters and damage the habitat. The paravane and diving are both appropriate for use as they are unlikely to encounter issues and will not damage the habitat.

Rocky Bottom or Oyster Reef

Conducting surveys in rocky or oyster habitats requires significant manoeuvrability. Because of this, the ROV is highly effective in these habitats as the omni-movement of the device allows easy avoidance of obstacles. The paravane is not manoeuvrable like the ROV, and as a result in rocky habitats it will be difficult to alter the depth to avoid hard or sharp obstacles. A paravane can still be used in these habitats, but it may encounter some issues with snagging. Scuba diving can be conducted in these habitats, however in shallower areas with oysters the sharp shells may damage scuba gear and injure the divers. The benthic sled is not viable as it will easily snag on the substrate.

Sand/Sediment

All methodologies are suitable for use on sand and sediment substrates. In areas with high sediment loads, turbidity can be an issue for all survey types. Litter can also become quickly buried in these habitats, particularly if there are high levels of sediment input, such as at the entrance of tributaries into the estuary, or due to storm water runoff. In these cases, there may be significant amounts of legacy litter buried under the sediment that will not be captured by any of the survey methods.

Shallow Habitats (<3m)

All methods are viable for use in shallow habitats.

Deep Habitats (>3m)

The ROV is viable in deep habitats, it can travel to depths of 100 meters, therefore it has a much greater capacity to cover these habitats. Scuba diving is also viable in deep habitats, though increasing depth with shorten the available survey time, and will require more experienced divers depending on the target depth. The paravane and benthic sled may encounter some issues in deep habitats. It may be difficult to determine the substrate in deeper areas of an estuary, as such the benthic sled could encounter unknown snags on the sea floor or damage habitats. Regarding the paravane it may be difficult to determine if the device is in the correct position above the sea floor in deep water, as such it may require additional time to achieve the correct depth.

Safety

This criteria details how safe the method is to conduct for the individual or group carrying out the survey. There are many hazards within estuarine environments that must be taken into account when conducting surveys, as well hazards encountered when operating some equipment.

Whilst scuba diving is an effective method for data collection in underwater environments, it's use in estuaries poses significant issues. This is mostly due to safety concerns for divers operating in estuarine environments. Issues such as pollutants, high turbidity, predators, and high vessel activity make dive surveys difficult in many areas of an estuary. Therefore, in areas with such hazards, diving is not recommended. Alternatively, survey methodologies which can be conducted from a vessel or the shoreline, such as the ROV, paravane, and sled, offer significant advantages in environments where diving is not suitable and are recommended for use where diving cannot be safely undertaken. However, in habitats nearer to the estuary mouth with high oceanic influence, diving offers a useful method for understanding the litter on the sea floor.

Practicality

Practicality refers to how easy it is to undertake the survey using a particular methodology. We considered survey time, the set up required, and hazards. The ROV here was a clear stand out, with a battery time of 3-4 hrs, virtually no set up time required, and easy to deploy. As such, using this survey method has many advantages. There are some disadvantages associated with the tether, as it can become easily entangled if care is not taken to avoid objects that are likely to ensnare it. It also takes a little time to get used to the remote controls and how to navigate underwater. Despite this, it is the most practical method of surveying in estuarine environments. In comparison, the benthic sled is the least practical of all survey methods, as the device has significant drag and can easily catch on items of the sea floor. Furthermore, the device must be pulled by a boat as a kayak encounters too much drag to pull the sled at a consistent speed.

Alternatively, the paravane is very easy to deploy and can be used from both a kayak and a boat with virtually no drag. For both devices survey time is based on camera battery, but it is likely to exceed dive surveys. These surveys can also be undertaken with fewer people than is required for dive surveys. One issue apparent with the paravane is achieving the desired height in the water column. Indeed, the device must not drag on the bottom, but also must not be too high in the water column, as otherwise it will be unable to capture clear footage. A height of approximately 0.5 meters above the substrate is ideal. This requires some adjusting of sinkers, floats and boat/kayak speed to maintain a consistent height in the water column.

Diving requires significant set up and dive time is limited, it's also reliant on weather conditions. When diving as well as when using the ROV, the data could be collected during the survey without the need to capture footage and score it afterwards, which could significantly decrease the time needed for data analysis.

Data Quality

The identification of litter in the underwater environment offers many challenges. The deterioration of littered items in the benthos can make usually identifiable features indistinguishable, making it difficult to categorise items. Similarly, high sediment loads in many areas of the estuary cause the rapid burial of littered items, consequently much of the litter is only partially visible. High quality litter data are crucial for understanding the underlying issues behind litter in the marine environment. Without effective identification of litter, it is difficult to understand the types/source of litter and thus difficult to implement effective prevention measures into the future. As such, methodologies that offer the greatest ability to identify litter in the benthos are more useful for the litter prevention effort.

The assessment of the litter methodologies highlighted some clear differences between the methodologies. The ability to collect litter during the survey for later identification on land offers the best method of identifying litter found in the benthos. Here, diving is the only method that can achieve this, as imagery-based methods are unable to collect litter. Despite this the other methodologies (paravane, ROV, and sled) have clear differences in the quality of data they collect. The ROV offers superior capabilities for data quality compared with the other two methods due to the ability to maneuver around the litter to capture footage at different angles to best identify items. Furthermore, the capability to view the footage in real time through the ROV remote controller also provides many benefits. Real time viewing also helps to ensure there are no issues encountered during data collection that would affect the data quality. The paravane and sled can both be fitted with a live stream camera which would solve this difference, but this would make both devices more expensive,

Invasiveness

Ideally the surveys should have no impact on the marine environment; therefore, it was important to look at how each method interacted with vegetation and substrate in underwater habitats. The sled interacts significantly with the underwater habitats, as it moves along the floor of the estuary it can damage substrate and vegetation on the benthos and can stir up the sediment. As such it cannot be used in most underwater habitats. Alternatively, scuba diving and the paravane are the least invasive methods as they have no interaction with underwater habitats. The ROV can damage pneumatophores and kelp strands in the thrusters, if care is not taken to avoid these, but interactions with habitats can mostly be avoided.

Affordability

It is important that these survey methodologies are able to be utilised by community groups and NGOs working on litter prevention, as such the affordability should be an important consideration. The ROV is the most expensive method. The ROV used in this study ranges in price from $3700-$4500 and therefore may not be accessible for many NGOs/community groups. However, as OceanWatch Australia now has ROV capabilities there is potential to collaborate with other community groups/ NGOs. Alternatively, the paravane and benthic sled are considerably more affordable than the drone. Most of the cost is in sourcing an underwater camera suitable for the survey. The devices themselves are relatively inexpensive to put together. Scuba diving is perhaps the most affordable survey method, if done by volunteers with their own equipment. There are a number of dive groups, and volunteers around NSW that are willing and able to conduct underwater litter surveys, which would make the activity very affordable.

OCEANWATCH AUSTRALIA

BENTHIC SURVEY METHODOLOGIES

RECOMMENDATIONS FOR THE USE OF FOUR SURVEY METHODOLOGIES IN A RANGE OF ESTUARINE HABITATS AND SUBSTRATES

	REMOTELY OPERATED VEHICLE	SCUBA DIVING	BENTHIC SLED	TROLLING PARAVANE
MANGROVES	★★★★	★	★	★★★
SEAGRASS BEDS	★★★★★	★★★★★	★	★★★★★
KELP	★★★★	★★★★★	★	★★★★★
ROCK/OYSTERS	★★★★★	★★★	★	★★★
SAND/SEDIMENT	★★★★★	★★★★★	★★★★★	★★★★★
SHALLOW <3M	★★★★★	★★★★★	★★★	★★★★
DEEP >3M	★★★★★	★★★★	★★	★★

EVALUATION CRITERIA

★ - METHOD IS NOT VIABLE IN THIS HABITAT/SUBSTRATE

★★ - METHOD WILL ENCOUNTER ISSUES IN THIS HABITAT/SUBSTRATE

★★★ - METHOD CAN BE USED IN THIS HABITAT/SUBSTRATE, ISSUES MAY BE ENCOUNTERED

★★★★ - METHOD IS EFFECTIVE IN THIS HABITAT/SUBSTRATE, MINOR ISSUES MAY BE ENCOUNTERED

★★★★★ - METHOD IS EFFECTIVE IN THIS HABITAT/SUBSTRATE

OCEANWATCH AUSTRALIA

BENTHIC SURVEY METHODOLOGIES

RECOMMENDATIONS FOR THE USE OF FOUR SURVEY METHODOLOGIES FOR SURVEYING LIYYER HOTSPOTS/HIGH VALUE AREAS IN ESTUARIES

	REMOTELY OPERATED VEHICLE	SCUBA DIVING	BENTHIC SLED	TROLLING PARAVANE
DATA QUALITY	★★★★	★★★★★	★★	★★
SAFETY	★★★★★	★	★★★	★★★★
PRACTICALITY	★★★★★	★★★	★★	★★★
INVASIVENESS	★★★★	★★★★★	★	★★★★★
AFFORDABILITY	★	★★	★★	★★

EVALUATION CRITERIA

1 DATA QUALITY

- ★ - DATA COLLECTED IS INACCURATE
- ★★ - DATA QUALITY IS POOR, MOST LITTERED ITEMS ARE MISSED OR DIFFICULT TO IDENTIFY
- ★★★ - DATA IS ACCEPTABLE, SOME LITTERED ITEMS ARE MISSED OR DIFFICULT TO IDENTIFY
- ★★★★ - DATA IS MOSTLY ACCURATE, NOT ALL LITTER CAN BE IDENTIFIED
- ★★★★★ - DATA IS ACCURATE, ALL LITTER CAN BE IDENTIFIED

2 SAFETY

- ★ - METHOD IS UNSAFE
- ★★ - SAFTEY ISSES ARE LIKELY IN MOST AREAS OF ESTUARIES
- ★★★ - METHOD MAY ENCOUNTER SOME SAFTEY ISSUES
- ★★★★ - SAFTEY ISSUES UNLIKELY IN MOST AREAS OF ESTUARIES
- ★★★★★ - METHOD IS SAFE IN ALL AREAS OF AN ESTUARY

3 PRACTICALITY

- ★ - METHOD IS TOO DIFFICULT TO UNDERTAKE AND NOT RECOMMENDED FOR USE
- ★★ - METHOD IS DIFFICULT TO UNDERTAKE BUT CAN BE USED IN SOME HABITATS
- ★★★ - METHOD HAS SOME ISSUES WITH PRACTICALITY
- ★★★★ - METHOD HAS MINOR ISSUES WITH PRACTICALITY
- ★★★★★ - METHOD IS SIMPLE AND EASY TO UNDERTAKE

4 INVASIVENESS

- ★ - METHOD WILL INTERFERE WITH/DAMAGE MOST HABITATS
- ★★ - METHOD IS LIKELY TO INTEREFE WITH/DAMAGE MOST HABITATS
- ★★★ - METHOD MAY INTERFERE WITH/DAMAGE SOME HABITAT IF CARE IS NOT TAKEN
- ★★★★ - METHOD IS UNLIKELY TO INTERFERE WITH/DAMAGE ANY HABITATS
- ★★★★★ - METHOD WILL NOT INTERFERE WITH/DAMAGE ANY HABITATS

5 AFFORDABILITY

- ★ - >$1000
- ★★ - $100- $1000
- ★★★ - <$100

3. Engage with Stakeholders

This step is perhaps the most crucial part of the litter prevention process as effectively engaging stakeholders in aspects of litter prevention ensures that the initiative has a long and lasting impact on the estuary. This is also the first step towards achieving effective behaviour change by raising awareness in the community and helping to educate participants on the impact of litter in estuarine environments[10]. Important stakeholders to target here are local government, NGOs and community groups, but could also include an array of diverse stakeholders depending on the estuary.

Firstly, it's important to understand the capacity of local government to support litter prevention initiatives in and around the estuary, and connect with NGOs to explore ideas and possible collaborations on litter prevention. Finally, engaging local communities in on-ground actions ensures the community takes ownership of litter prevention in the estuary, and can ensure the longevity of litter prevention long over funding stops. Having the support of the local community on ground also increases the capacity to survey and monitor areas.

3.1. Collaborate with NGOs

There are various NGOs that work on litter/ marine debris initiatives in NSW and more widely across Australia (Table 3). Engaging with these organisations, discussing litter prevention ideas, and utilising the available expertise is highly recommended. These organisations have worked on numerous projects to understand and reduce the impact of litter and marine debris in our environment.

Exploring the possibilities of collaborating on litter prevention initiatives would likely bolster the impact of the project.

Table 3: Organisations involved in Litter Prevention

ORGANISATION	ROLE
Tangaroa Blue Foundation	Tangaroa Blue Foundation works to successfully solve the problem of marine debris, creating the Australian Marine Debris Initiative (AMDI), an on-ground network of volunteers, communities, and organisations that contribute data to the AMDI database and then work on solutions to stop the flow of litter at the source. The AMDI helps communities look after their coastal environment by providing resources and support programs and collaborates with industry and government to create change on a large scale.
Take 3	Take 3 inspires participation in simple actions that reduce the impacts of plastic pollution and waste in the ocean and broader environment. The simple message to 'take 3 for the sea' has resonated across the globe with participation from 129 countries. Take 3 are involved in many great initiatives that work to educate people on plastic pollution and inspire participation in managing and preventing the problem.
Clean4Shore	Clea4Shore is a small not-for-profit community-based organisation located at MacMasters Beach on the Central Coast of NSW. The program utilises schools, youth, disability, community, and corporate groups to clean litter and general rubbish along the foreshores of the Hawkesbury River, Brisbane Water, Tuggerah Lakes System, and more recently Lower Lake Macquarie and Hunter River.
OceanWatch Australia	OceanWatch Australia is the national marine NRM that works to ensure Australia's marine environment is healthy, productive, and valued. OceanWatch works on a broad range of projects to improve environmental practices, protect marine species, reduce by-catch, introduce sustainable technologies, change behaviours, restore marine habitats, and combat marine debris.
Clean-up Australia	Clean-up Australia inspires and empowers communities to clean-up, fix-up and conserve our environment. They focus on preventing rubbish entering our environment as well as removing what has already accumulated.

3.2. Capacity of Local Government

It is important to engage with Local Government to discuss their capacity to support litter prevention initiatives as it helps to understand what is possible within the area. This particularly relates to the implementation of any infrastructure (e.g. bins) or signage (e.g. EPA's 'Don't be a Tosser' materials) that could help with litter prevention, as well as improved monitoring of areas surrounding the hotspot or high value area. This may involve talking with council staff that are involved in cleaning and waste services to understand how areas adjacent to the estuary are managed, what the cleaning schedules are, and if there is capacity to increase or change these in some areas. Some local councils may have staff specifically employed for work litter prevention that can help provide support to the initiative.

3.3. Involve the Community in On-ground Activities

It's important to find out which community groups operate in the area, particularly groups that already work on clean ups and litter prevention, or those that regularly use/visit the estuary. Connect with these groups to find out if there is interest in litter prevention and what the capacity of the group is to be involved in on-ground activities, you can then determine what is feasible to achieve under the project, i.e. how many sites you can focus on, how often can they be monitored.

Community education and awareness of the litter in the estuary is crucial for achieving effective behaviour change[10]. Engagement with the community raises awareness of issues surrounding littering, helping change perspectives amongst the wider community that littering is never okay[10]. Additionally, having community groups involved ensures that the community takes ownership of litter prevention and values the initiative, this can improve the impact and longevity of the project.

The community should be made to feel as if this is their project too, and should be allowed to have significant input on site selection, activities and the implementation of prevention measures, as this will improve how community support the project.

4. Conduct Benthic Litter Surveys

Following an exhaustive engagement with all stakeholders, the next step of the framework involves the conducting of benthic litter surveys to identify problematic items. This step is critical, because it allows for the identification of problematic items and for a detailed description of what is the local litter issue. The results from the underwater surveys ultimately inform the activities of clean up and prevention.

Firstly, it is the leading organisation's responsibility to coordinate and oversee stakeholder involvement and ensure that the methodology followed is the one determined at Step 2. For example, if the most effective methodology for the site chosen is a community survey scuba dive, it is important to make sure that all divers are aware of safety and data collection protocols, and of the logistical arrangements for the event. As part of the data collection protocol, it is important to communicate with clarity how the data need to be collected. This is vital to ensure interoperability between the new data and existing and national datasets. If the survey method chosen allows, it is possible to conduct a clean-up activity at the time of surveying.

Once the data are collected, they need to be analysed to extract the information such as what items were identified, where they accumulated, the abundance of litter and whether any item category was overrepresented. As a part of this step, it is important to integrate the data collected with any dataset existing for the area and identified in Step 1.

Any dataset merging is advised, provided that the survey methodologies followed are comparable, and that the data aren't too far apart spatially or temporally, as this could confound the effects of certain strategies in place since their collection. An additional action to undertake upon data collection, is their submission to the Australian Marine Debris Database (AMDI, Figure 9) which is managed by Tangaroa Blue Foundation. Because of this step, it is important that data collection and entry protocols are clear to the surveyors, as wrongfully categorising litter would result in the impossibility to merge the datasets.

Finally, from the analysis of the data, it will be possible to determine and report on what litter issues are present at the focus site. This could be a category of items (e.g., Glass & ceramic), or a specific item (e.g., Disposable face masks). This reporting is important because it will inform the activities of clean-up and prevention detailed in Step 6. For example, if disposable face masks are found to be a particularly problematic item, this will allow for a much more targeted behaviour change campaign.

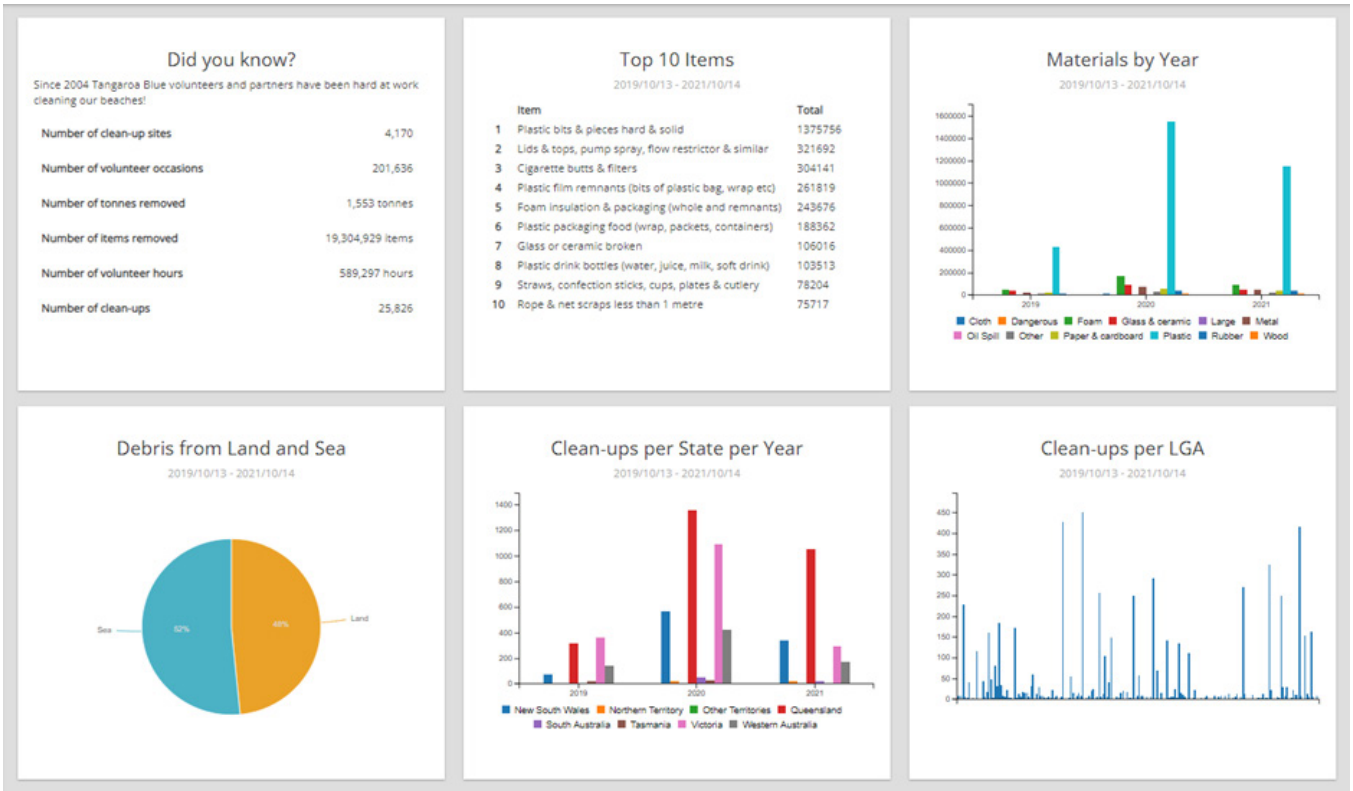


Figure 9: The Australian Marine Debris Initiative Database Portal[19].

5. Conduct Litter Prevention Activities

The clean-up of litter costs Australia more than a billion dollars every year, therefore it is important to target funds towards the most effective strategies to efficiently reduce pollution[20]. The initial steps 1-4 of the Benthic Litter Framework provide the data necessary to inform litter prevention measures. This step instead offers insight into the drivers behind benthic litter within estuaries, and helps to identify the most problematic areas and items, capturing information about litter at the end point of the litter journey. By identifying the issues that pose the greatest threat to our estuaries and marine ecosystems we can apply a risk-based framework to determine the most appropriate and effective actions to prevent litter entering estuaries and settling in benthic habitats. This allows us to effectively work back through the litter journey to implement effective actions at each stage.

The NSW Litter Prevention Strategy can help to inform preventative actions, the five approaches detailed in the strategy act to stop litter at each step of the litter journey from production, through to dispersal in the wider environment (Figure 10).

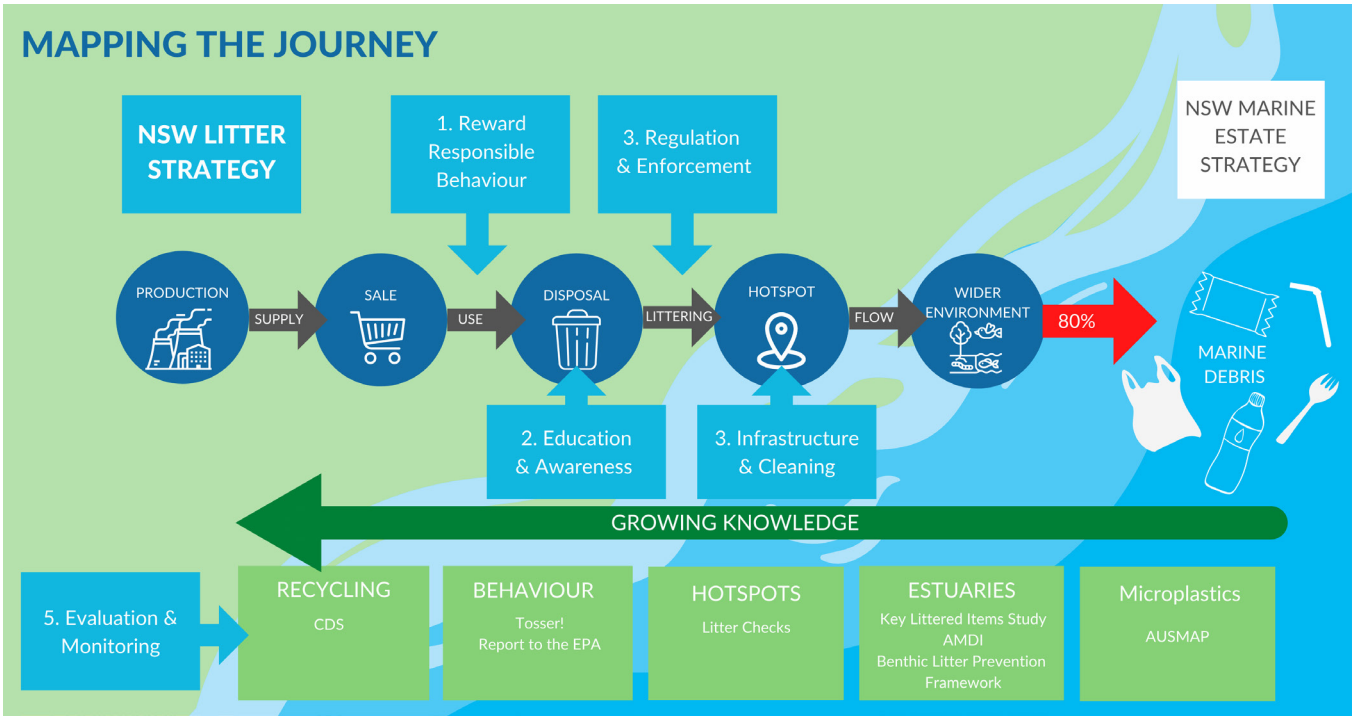


Figure 10: The litter journey (adapted from Lavarack 2021[12]) highlighting the process through which litter ends up in the environment and how the Benthic Litter Prevention Framework fits into the journey.

5.1. The NSW Litter Prevention Strategy

The five approaches of the NSW Litter Prevention Strategy include:

1. **Rewarding responsible behaviour:** This covers the NSW governments return and earn initiative which has made a significant contribution to reducing the prevalence of beverage containers in the environment. This approach works to influence littering behaviour through encouraging appropriate disposal and collection of littered items by providing a 10 cent reward or refund.
2. **Education and awareness:** This approach seeks to raise awareness about littering within the community and build the norm that littering is not okay. The NSW EPA have a number of resources to aid this approach, including 'Don't be a Tosser' materials, social research, and information about designing effective litter prevention initiatives.
3. **Infrastructure and cleanup:** This approach works to send the message that a place is cared for and well-maintained and therefore not a place to litter. This includes actions like ensuring bins are well designed, and appropriately placed and the site is well maintained.
4. **Regulation and enforcement:** This covers the need to enforce litter laws to change the social norm around litter. This underpins the 'Don't be a Tosser' message that every bit of litter gets noticed.
5. **Monitoring and evaluation:** This covers the need to monitor and evaluate litter prevention to determine the success of activities and ensure efforts are effective in achieving the desired result.

Figure 11: Examples of the NSW EPA Don't be a Tosser signage

Figure 12: Implementing effective infrastructure like bins near hotspots

5.2. Working through the Litter Journey

Production and Sale

Targeting this stage of the litter journey helps the litter prevention effort by stopping the issue at the source. Source reduction schemes include product modification, improvement, or substitution, and they are an important method to reduce the availability of items that can become litter[21]. Examples of these schemes include designing alternative packaging so that it is biodegradable, it is re-fillable or it is more durable and easier to repair[21].

Another type of source reduction scheme is through legal means, such as the ban or reduction of plastic bags and single-use plastic availability, which Australian states are progressively adopting (e.g., NSW Plastics Action Plan). Source reduction schemes are particularly effective if the items targeted are largely problematic in the estuaries of interest, therefore knowing what the problem items are is critical to inform these schemes. Other regulations, such as the prohibition of certain kinds of waste being dumped in landfills close to estuaries or coastlines, or the dumping of waste at sea (e.g., the Environment Protection (Sea Dumping) Act 1981), may also help mitigating litter issues in estuarine areas.

Disposal and Hotspots

Behaviour change in an important component of encouraging the correct disposal of items before they become littered, and ensuring that littering is reduced at hotpots. It is important to remember that people tend to choose the most desirable and easy path, therefore a critical way of thinking about this type of campaign is creating or modifying paths available to people, facilitating their choice[22]. People will follow pathways that feel familiar (they can see themselves doing it), visible (advertised by clear messaging), easy (convenient), normal (endorsed by the majority). There are several examples of anti-litter campaign strategies that have been used in Australia and overseas. Strategies may include signage on bins or streets (e.g., "Bin your butts" or 'Don't be a Tosser'), implementation of effective infrastructure (e.g. TAngler Bins), outreach and educational programs (e.g., "Clean Marine" by Keep Australia Beautiful WA), posters, social media and video campaigns (e.g. "Don't be a tosser").

Interrogation of benthic litter data as well as analysis of community behaviour in the catchment will help to inform the implementation of behaviour change strategies. Benthic litter is also less obvious to people than other types of litter which makes behaviour change more complex. Ensuring effective monitoring and evaluation of these strategies is crucial for their success.

Clean-up in the Environment

Whilst the other stages of the litter prevention journey work to stop litter reaching the environment, this section deals with cleaning up litter once it is deposited in benthic habitats. If the items are safe to handle, a freedive or scuba dive clean up can be organised, either run by professional staff or volunteer groups. Several volunteer diver groups get involved in underwater clean ups, for example the Friends of Chowder Bay in Sydney Harbour. A particularly good example is the initiative 'Dive Against Debris' by PADI's Project Aware, a citizen science programme helping individual divers or groups to conduct clean up dives anywhere in the world, following a standardised protocol. Also, many dive shops around Australia regularly organise clean up dives with their local members as a social gathering, and this type of event may be beneficial if there is coordination in place.

5.2. Enabling Involvement in Litter Prevention

The NSW EPA's Own it and Act Strategic Framework (OIAA) helps to enable long-term involvement in litter prevention[23]. The OIAA Framework can be utilised alongside other litter prevention initiatives to build capacity to focus on litter prevention long-term. The Framework highlights the importance of collaborations and building networks to sustain litter prevention. The OIAA framework identifies 4 key enablers for long-term involvement in litter prevention including leadership, commitment, permission, and process.

The NSW EPA also provides a self-assessment tool that allows organisations to understand their existing capacity to support long-term litter prevention and identify areas where capacity can be improved.

Table 4: Organisational best practice identified in the OIAA Framework to achieve long-term litter prevention[24].

OIAA ENABLER	BEST PRACTICE
Leadership	Emphasises long term vision for litter prevention
	Publicly promotes litter prevention
	Supports progressive litter prevention policies
	Discusses litter prevention agendas
	Demonstrates how to implement litter prevention activities
	Allocates resources towards litter prevention
	Has litter prevention as a key organizational outcome
Commitment	Understands the benefits to the organisation of a commitment to long term litter prevention
	Actively engages in future involvement in litter prevention
	Understands the benefits of litter prevention outcomes for our community and the environment
	Understands the benefits of collaboration as a key element to long term litter prevention
Permission	Has duties, roles and position descriptions that include litter prevention
	Employs a litter prevention officer
	Provides a clear career path for those involved in litter prevention
	Provides induction and training in litter prevention
	Allows staff to make decisions about litter prevention
	Has litter prevention included in a strategic or corporate plan
	Has established litter prevention target
	Has established litter prevention objectives and goals
	Allocates budget specifically for litter prevention programs
Process	Understands the key litter prevention strategies
	Delivers integrated litter prevention programs using multiple strategies
	Incorporates source reduction as part of our litter prevention programs
	Links and coordinates activities with relevant local government and state agency programs
	Links and coordinates activities with other NGO's involved with litter prevention
	acknowledges gaps within its delivery of litter prevention and seeks assistance from others
	Uses the Local Litter Check for litter prevention initiatives
	Monitors and evaluates it's litter prevention programs
	Tracks litter prevention performance using NSW EPA tools
	Recognises and celebrates successful litter prevention initiatives and shares lessons learnt

6. Strategic Directions

OceanWatch Australia has identified 3 key strategies required to achieve our objective to reduce the volume of benthic litter in NSW estuaries, encourage its inclusion in NSW litter prevention efforts, and seek collaborations to achieve the NSW litter prevention target of 60% reduction by 2030.

Strategy 1 seeks to fill the gap in our knowledge regarding litter in benthic habitats, helping to develop effective methods of surveying the benthos, and increasing knowledge of applicable litter prevention actions. This strategy seeks to bring attention to this subset of litter that is often unrecorded and unnoticed.

STRATEGY	ACTION	MEASURE
1. Develop methods to understand and monitor benthic litter in NSW estuaries	1.1. Investigate, trial, and validate techniques for monitoring litter in benthic habitats of estuaries.	By 2022 recommendations for monitoring benthic litter are finalised.
	1.2. Increase knowledge base around key litter prevention strategies applicable to benthic litter.	OceanWatch Australia discusses with stakeholders their litter prevention strategies in Brisbane Water and Sydney harbour.
	1.3. Publicly promote and discuss benthic litter monitoring techniques.	The awareness of monitoring techniques is amplified through publishing benthic data collection techniques.

Strategy 2 aims to initiate effective long-term monitoring of benthic litter, allowing a greater understanding of the dynamics of litter in benthic habitats and providing crucial information for NSW litter prevention targets. By integrating monitoring into existing and emerging initiatives this strategy seeks to gather the information required to inform the development and implementation of appropriate solutions to the issue.

STRATEGY	ACTION	MEASURE
2. Encourage long-term monitoring of benthic litter in NSW estuaries	2.1. Utilise partnerships and seek funds to identify benthic litter hotspots in NSW estuaries.	Benthic litter are hotspots identified and integrated into litter prevention strategies in three NSW estuaries by 2023.
	2.2. Integrate benthic litter data into a publicly available online portal for sharing and reporting information.	Benthic data are integrated with existing databases, and are publicly available by 2023.
	2.3. Develop a benthic litter monitoring plan for NSW estuaries with key partners	A plan that encourages monitoring benthic litter in NSW estuaries is established by 2023.
	2.4. Encourage the integration of long-term monitoring into existing and emerging litter prevention initiatives.	Ongoing monitoring of benthic litter is integrated into litter prevention initiatives by 2024 across NSW.

Strategy 3 seeks to deliver the actions required to reduce litter in benthic habitats. Through collaborations with both land-based stakeholders and water users (e.g. oyster farmers, recreational fisheries, community groups) OceanWatch will initiate and implement actions to reduce litter. This strategy employs the use of the EPA's Own it and Act Framework to embed litter prevention principles and targets both internally and among stakeholders.

STRATEGY	ACTION	MEASURE
3. Collaborate with land-based stakeholders and water users to reduce inputs	3.1. Seek funding for a benthic litter prevention officer to coordinate litter prevention initiatives originating on water. 3.2. Collaborate with key partners to identify priority actions and targets required for a reduction in benthic litter. 3.3. Consolidate commitment to litter prevention among stakeholders through the integration of targets into organisational plans and policies using the Own it and Act Framework. 3.4. Collaborate on source reduction plans with stakeholders to achieve targets.	OceanWatch Australia receives funding for a marine litter prevention officer. Priority actions are identified and targets established, by 2023. The number of stakeholders that have completed Own it and Act Framework and ratified targets has increased. Three major source reduction plans developed and implemented by 2025.

Own it and Act

To support the implementation of this strategy OceanWatch Australia is implementing the EPA's Own it and Act Framework, through the adoption of the following goals.

OIAA ENABLER	GOALS
Leadership	Amplify our focus on benthic litter prevention across NSW estuaries Actively promote the prevention of benthic litter Engage with stakeholders to implement litter prevention methods and establish targets
Commitment	Continually seek collaboration on litter prevention projects
Permission	Seek funding for a benthic litter prevention role Establish organisational litter prevention targets
Process	Carry out source reduction plans Collaborate with stakeholders to achieve positive litter prevention outcomes. Monitor and evaluate litter prevention outcomes

Case Studies

Through the development of the Benthic Litter Prevention Framework, OceanWatch Australia has completed several case studies to understand the dynamics of litter issues in benthic habitats. These studies have been crucial in determining appropriate methods for combating this subset of litter. OceanWatch Australia has also investigated potential new projects, which highlight how the framework will be utilised into the future. These case studies include:

- Brisbane Water litter hotspots
- Benthic litter in Sydney Harbour
- Methodology comparison assessment
- Hawkesbury River flood debris
- Source reduction of chemical light sticks

Brisbane Water Litter Hotspots

Introduction

Brisbane Water is a wave-dominated barrier estuary on the Central Coast of NSW. It is important for commercial, recreational, and shipping purposes. The catchment of Brisbane Water includes Erina Creek, Kincumber Creek, Woy Woy Creek, Ettalong Creek and the main tributaries of Narara Creek and Coorumbine Creek, with a total area of 152.5km^2. There is extensive development in the catchment for urban, industrial, and commercial use.

The estuary habitats consist of salt marsh, extensive mangrove forests, seagrass beds, oyster reefs, and areas of sand and sediment. However, the large population size and coastal development put significant pressure on the crucial marine habitats within the estuary. As a result, the estuarine ecosystem has long been plagued with litter and illegal dumping issues. To combat this, local NGO Clean4Shore has worked to collect significant amounts of debris from the shorelines and mangroves. These clean-ups have been crucial in managing litter in the estuary since 2013. The data collected from these clean-ups are stored in the AMDI database. Along with the work done by Clean4Shore, the local council has a history of running litter prevention initiatives around the catchment. There are also key community groups that play a role in cleaning up the shores of the estuary, including the Central Coast Kayak Group. These efforts have led to positive improvements for the estuary.

Whilst extensive work has been done to clean-up the shoreline and mangroves of the estuary, litter remains a concern. Moreover, there is no available information about the volume and type of litter found in benthic habitats. The absence of this information would suggest that the extent of litter in the estuary remains unknown. Furthermore, to correctly apply a risk-based framework for preventing litter in the estuary, it is crucial to understand the full extent of litter in all habitats. There may be areas of the benthos plagued with litter not found along the shorelines or in mangroves. To understand litter in the estuary and take the first step in the framework for litter prevention, OceanWatch Australia aimed to identify litter hotspots in Brisbane Water estuary and determine the problematic types of litter.

Methods

Utilising the Litter Prevention Framework as a guide, OceanWatch Australia focused on identifying litter hotspots in the estuary and high value areas. To achieve this OceanWatch Australia reached out to local stakeholders to discuss litter in the estuary and determine the locations of likely litter hotspots as well as the type of litter that plagues the estuary. The extensive data collected by Clean4Shore were also reviewed, providing insight into problematic areas within the estuary and wider catchment. The data from Clean4Shore only consist of floating and shoreline litter and not benthic litter, but the locations of hotspots of floating/shoreline litter may provide insight into the possible locations of benthic litter hotspots.

OWA mapped the extent of clean-ups in the estuary since 2013, to create a heat map of clean-up effort and identify possible hotspots. Additionally OWA identified the commonly littered items in the estuary since 2015.

Brisbane Water Litter Hotspots

Results & Discussion

The data highlighted several areas of concern within the estuary, particularly around the entrances of creeks. The problematic areas include the entrance of Narara Creek, Erina Creek and Kincumber Creek as well as the area surrounding Pelican Island (Figure 14). The hotspots corresponded with areas of concern raised by other stakeholder groups. These areas should be the focus of future benthic surveys to determine the extent of the litter issue here.

Plastic film remnants are responsible for the highest percentage of litter in the estuary (Figure 13). Plastic drink bottles, foam insulation and packaging, as well as plastic food packaging make up a significant portion of litter found in the estuary. The implementation of the NSW government Return & Earn scheme aligns with the disappearance of plastic drink bottles from clean-ups. However these items were found again in 2020.

The commonly littered items that are responsible for the higher percentage of litter, have high levels of buoyancy, suggesting that the makeup of benthic litter may differ significantly from the items found by Clean4Shore. As such, it will likely reveal a different dynamic of the overall litter issues in the estuary.

The next step is to select the appropriate survey methodology based on the various habitat types at each of these hotspots, which is the focus for future work in the estuary.

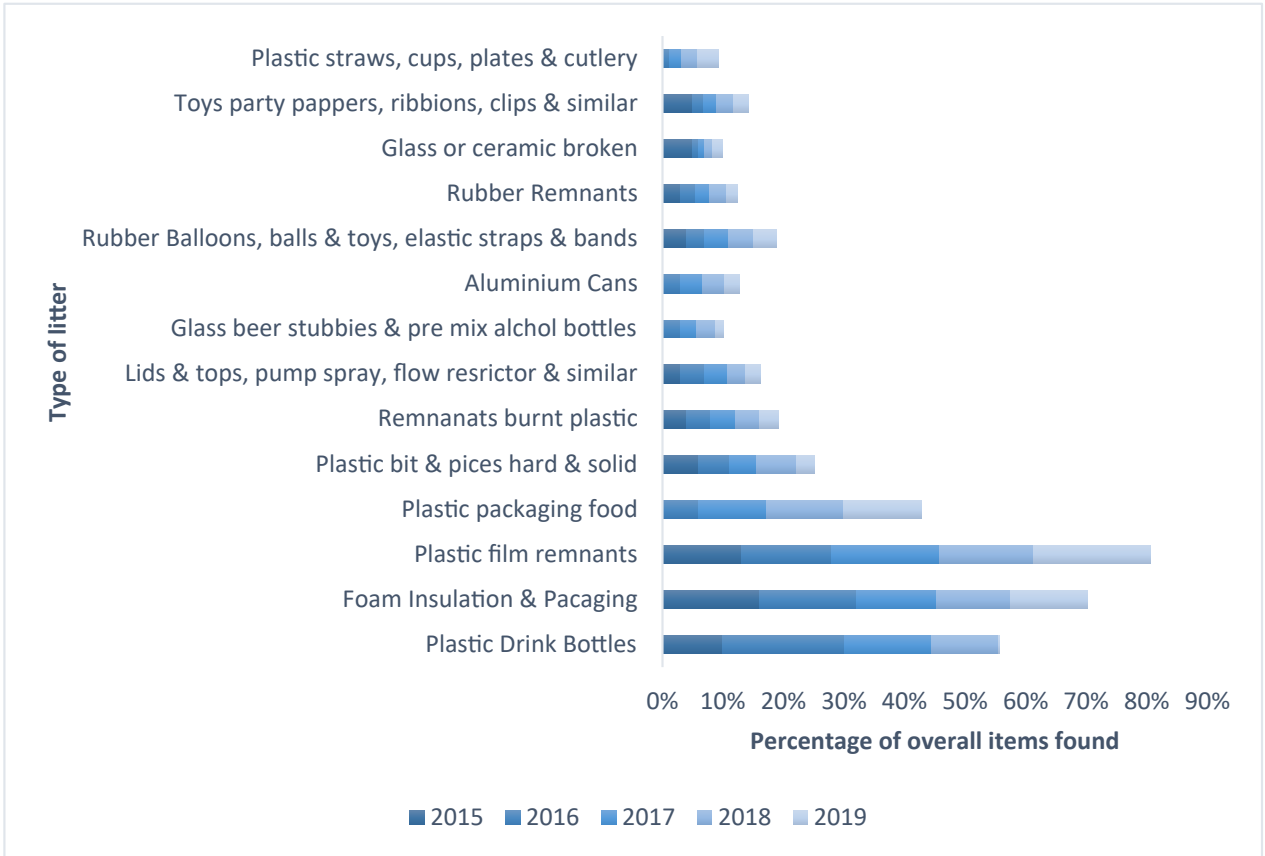


Figure 13: Commonly littered items found in clean-ups conducted by Clean4Shore between 2013-2021 in Brisbane Water estuary.

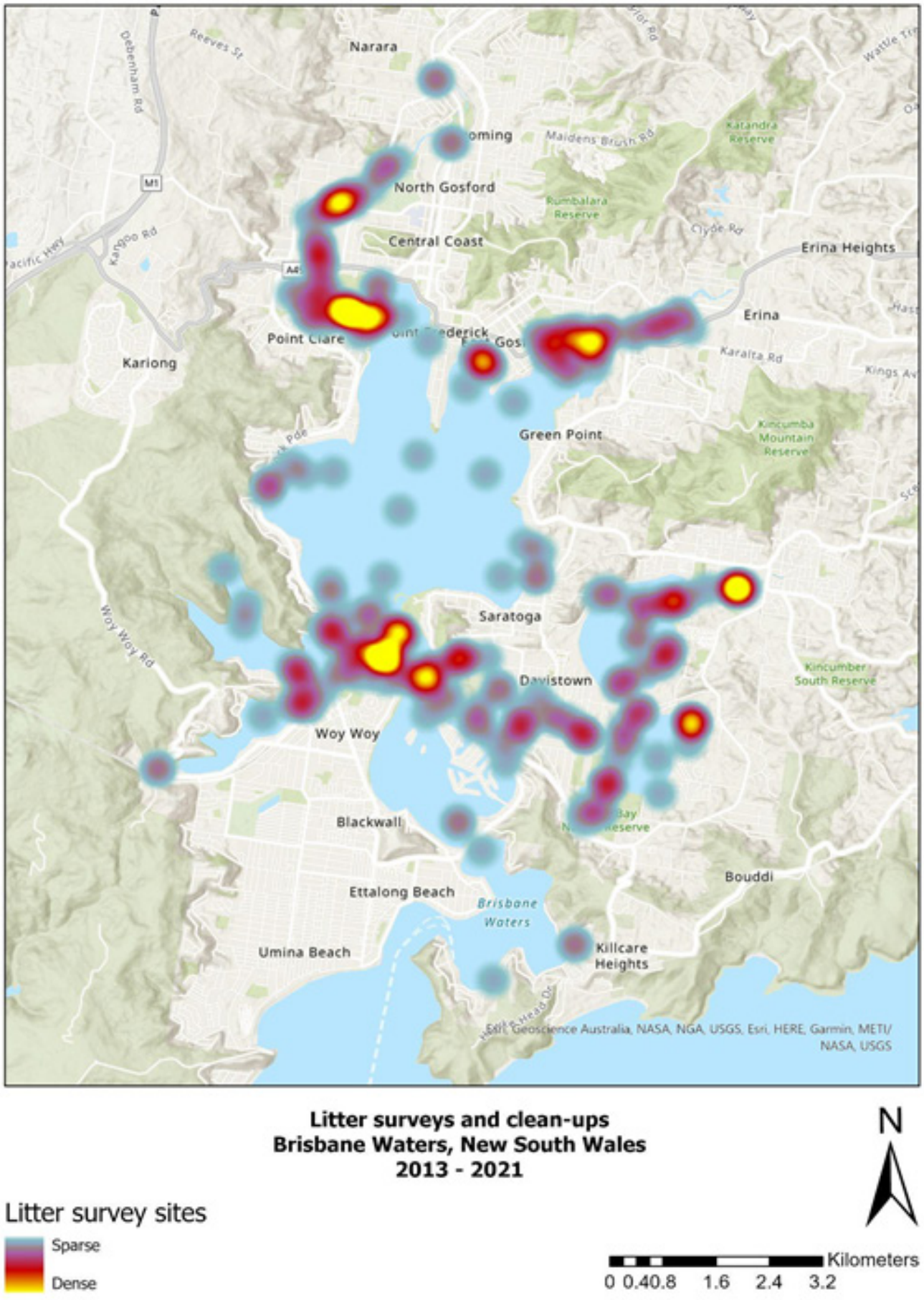


Figure 14: Heatmap of litter surveys in Brisbane Water conducted by Clean4Shore between 2013-2021

Benthic Surveys in Sydney Harbour

Introduction

Knowledge of litter in benthic estuarine habitats is relatively minimal as these areas are typically difficult to survey[4]. Due to this there is little information on the extent of the litter in these areas. Approximately 70% of all marine debris is eventually deposited in benthic habitats[6], suggesting that a large portion of litter goes unnoticed by the wider community. Understanding litter in these habitats requires effective methods for surveying benthic environments. As such OceanWatch Australia aimed to determine the suitability of four methodologies for surveying benthic habitats, including remotely operated vehicles (ROVs), scuba dive surveys, a benthic sled, and a trolling paravane.

Method

The four methodologies were tested across 17 locations in Sydney Harbour (Figure 15), within the Lane Cove River, Canada Bay, the Inner West, and Mosman. They were reviewed based on several criteria including data quality, affordability, practicality, safety, and invasiveness. The methods were tested in across various estuarine habitat types including mangrove forests, seagrass beds, kelp, rocky/oyster substrate, sand/sediment, shallow (<3m), and deep (>3m).

The results were compiled into a set of recommendations for the suitability of each method.

Results & Discussion

The four survey techniques all offer unique methods of understanding benthic litter issues. Whilst each method offers advantages among the criteria, there are clear distinctions that make certain methodologies more effective in estuarine ecosystems. The recommendations for each of the criteria can be found in section 2.2. of the Benthic Litter Framework.

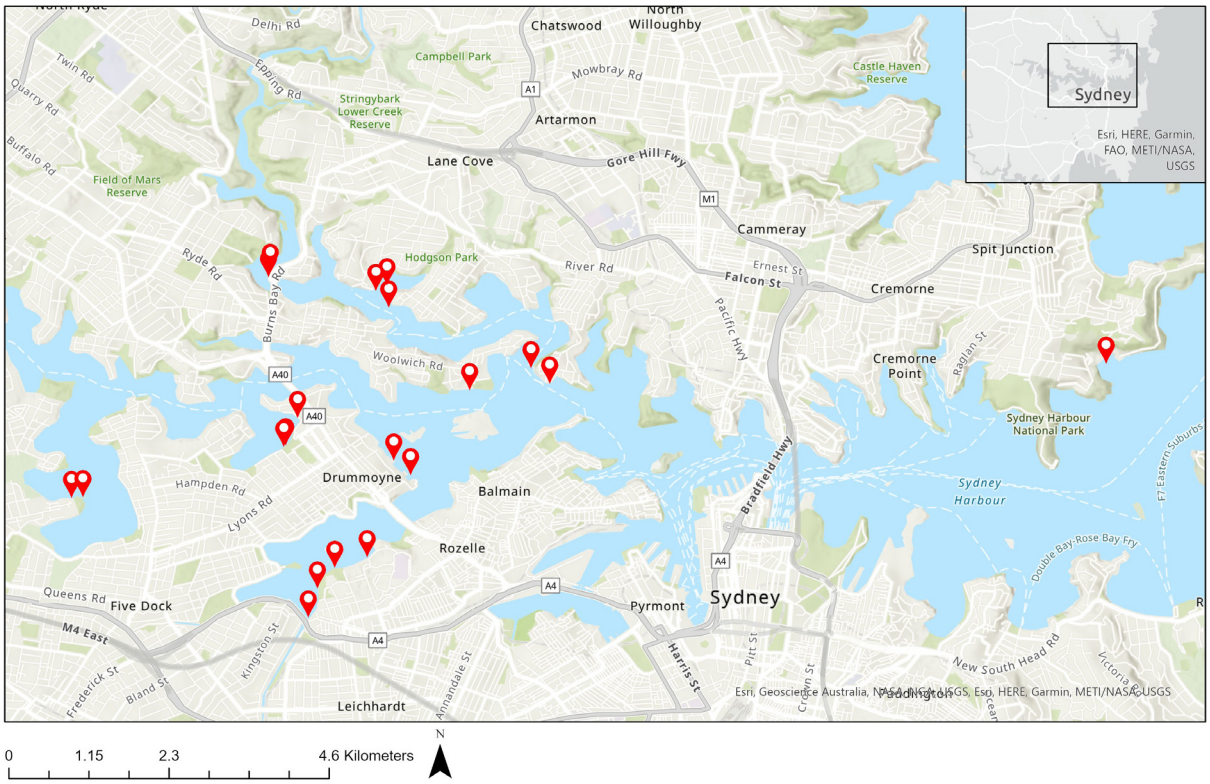


Figure 15: Survey locations in Sydney Harbour

Methodology Comparison Assessment

Introduction

The quality of imagery and data collected by the paravane, the sled, the ROV, and snorkelling were assessed in a near shore habitat of Sydney harbour to compare each method's performance when collecting footage for the purposes of assessing litter issues at an estuarine site. Scuba diving was substituted with snorkelling for this assessment as the depth was approximately 2m and more suitable for snorkelling.

Method

A number of common items were selected to represent typical litter found underwater in Sydney Harbour. These were selected in consultation with community divers often involved in underwater clean-up activities. The items selected were: a disposable coffee cup, a lure with fishing line and two hooks, a transparent glass bottle, a brown glass bottle, a t-shirt, an aluminium can, a plastic bag, a snack packet, a plastic take-away food container, a disposable mask tied to a zip-lock bag, a cardboard container of cereal bars, a ball of fishing line .

The items were placed along a 30 m transect that was delineated by a tape meter secured to the seafloor, within 50 cm on either side of the meter. The items were secured to the bottom, to ensure they would not move between surveys and that they would be easily retrievable upon completion of the assessment. The order and placement of the items along the transect was randomised.

Each survey technique was trialled twice. The person who conducted the surveys did not place the items along the underwater transect, to minimise bias when searching for the items. Each technique followed similar speeds and depths to allow for a fair footage comparison. The order of techniques was randomised apart from the sled that was kept last, for its potential to interfere and move the items. Because of the different limitations of each technique, we decided to perform the comparison over habitat that was suitable to all, i.e., bare sand.

Each survey technique captured footage that was then watched by a person not involved in the field survey, to validate the performance of each technique in an unbiased way. It is worth mentioning that a scuba or snorkeling survey would not necessarily need the capture and post-survey processing of footage, as the information could be collected during the survey by writing on a slate. However, we captured footage while snorkeling for ease of comparison of the different techniques. The performance of each technique assessed was judged in terms of how many items were noticeable in the footage, as well as the ease of set- up and running.

Results & Discussion

The controlled experiment highlighted the advantages of viewing the transect in real time using the snorkelling and ROV methods. All methodologies had clear footage; however, it was difficult to keep the benthic sled and paravane in line with the transect. Such issues are not apparent until the footage is reviewed, as such the paravane and benthic sled missed some items as they were unable to follow the transect. This highlighted clear issues with data quality and practicality. The findings from this assessment were included in the recommendations which can be found in section 2.2.

Other Applications

Source Reduction of Chemical Light Sticks

Introduction

A source reduction plan documents the process of investigation of the debris information, tracks it to a source and puts in place steps to mitigate the likelihood of that type of debris entering the system. The more information that such a plan can draw upon the better the quality of the intelligence to pinpoint the likely source location and demographic user group of the target item.

Method

OceanWatch Australia teamed up with the Tangaroa Blue Foundation to investigate the issue of chemical light sticks (CLS) being found in beach cleanups off Queensland. Existing data were compiled for items found on beaches. Likely because of currents, the items found didn't correlate with any obvious user group or activity in the immediate vicinity. For the CLS the Tuna longline industry was surveyed as they use light to attract baitfish which in turn attracts the targeted species of finfish. We looked at catch and effort data as well as grids of gear loss due to in most cases bite offs (from predators and bigger fish) and cut-offs (from vessels).

Discussion

From this project, we could surmise the number of CLS lost was greater than that found on Australian shores. We could link the type being lost to the type being found but any other types being found were assumed to be from other user groups or overseas origin. Had we had the means to incorporate benthic data we would have been in a better position to look at other user groups closer to shores such as raves, kids parties, divers or the military. The project went on to trial the use of two alternative multiple-use battery operated lights with the tuna longline industry. Full results can be found at www.oceanwatch.org.au/source-reduction

Hawkesbury River Flood Debris

Introduction

Extreme rainfall on the east coast of Australia beginning on 18 March 2021 led to widespread flooding in New South Wales, affecting regions from the North Coast to the Sydney metropolitan area in the south. The Hawkesbury River had an estimated 60 caravans float off from owners plus a myriad of other smaller litter items. Stakeholders such as Hornsby Council and the Hawkesbury professional fishermen have been vocal in wanting to know how the aftermath has affected the asset they use to make a living or take a part in managing.

Discussion

While we are yet to trial methods on the River at the time of writing due to Covid restrictions it was requested by River residents through the council that reports of vessels being intentionally sunk needed to be investigated after finding various boating related litter items onshore and not knowing the source. Secondly, professional fishermen were concerned by the litter being hauled up and especially worried by snags now in unknown locations of trawl grounds which had the potential to sink boats or damage nets. The flood was the known agent in transferring huge loads downstream however very little is known about the benthic load history. Both user groups have expressed interest in trialling methods when possible and provide some practical examples of applications of this type of survey.

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